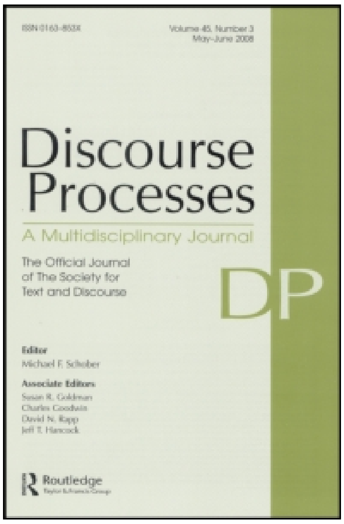

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Visual Signals Vertically Extend the Perceptual Span in Searching a Text: A Gaze-Contingent Window Study

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This study investigated the effect of visual signals on perceptual span in text search and the kinds of signal information that facilitate the search. Participants were asked to find answers to specific questions in chapter-length texts in either a normal or a window condition, where the text disappeared beyond a vertical 3° gaze-contingent region. The texts either contained no signals, paragraph marks, or headings that did or did not inform about the text content—that is, topic headings or fake headings. The information conveyed by paragraph marks and topic headings both proved to be very helpful to the search process. Moreover, the results revealed a larger perceptual span for the signaled texts than for the unsignaled ones. The results are taken as evidence for the existence of a *text layout span* in text search, which is larger than the span for letter and word processing, and includes the useful typographical information on the printed page.

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The perceptual span, also called the functional visual field or the visual span, refers to the region around a fixation point from which useful information can be extracted (Rayner & Liversedge, 2004). Exactly how far from a fixation point information can be obtained is a question that has prompted a great deal of research in various contexts, including reading (McConkie & Rayner, 1975; Pollatsek, Raney, Lagasse, & Rayner, 1993; Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981; Underwood & McConkie, 1985; for a review, see Rayner, 1998), scene perception (DeGraef, Christiaens, & d'Ydewalle, 1990; Nelson & Loftus, 1980; Saida & Ikeda, 1979; for a review, see Henderson & Ferreira, 2004), visual search (Bertera & Rayner, 2000; Pomplun, Reingold, & Shen, 2001; Rayner & Fisher, 1987), reading music (Gilman & Underwood, 2003), and playing chess (Reingold, Charness, Pomplun, & Stampe, 2001).

When we are reading a text, watching a movie, or searching for something in our visual environment, we generally move our eyes several times per second. The main reason for making saccadic eye movements is the rapid decline in visual acuity away from the fovea—the central 2° of the visual field. The purpose of most eye movements is to place objects inside the fovea, where they can most easily be processed. Letters and words are high-resolution objects that require particularly good acuity if they are to be identified. Indeed, previous studies investigating the perceptual span in reading have found that it encompasses a relatively small proportion of the visual field. For readers of alphabetic orthographies (e.g., English, French, or Dutch), it extends horizontally from 3 to 4 letter spaces to the left of fixation to about 14 to 15 letter spaces to the right, and is restricted vertically to the fixated line (Inhoff & Briihl, 1991; Inhoff & Topolski, 1992; Pollatsek et al., 1993).[1] Of particular relevance here, Pollatsek et al. (1993, Experiment 2) found that the perceptual span is also very limited when the text is searched for a specific target word. In their study, Pollatsek et al. (1993), like many of the aforementioned researchers, used the gaze-contingent window technique, also called the moving window technique (McConkie & Rayner, 1975), to determine the perceptual span. In a gaze-contingent window study, the visual input (e.g., text or scene) around the reader's fixation point is disturbed in some way, except within an experimenter-defined "window" region. Beyond

[1]The horizontal extent of the perceptual span in reading is not constant, but varies according to the difficulty of the words being read and the context within which the words appear (Balota, Pollatsek, & Rayner, 1985; Henderson & Ferreira, 1990; White, Rayner, & Liversedge, 2005). More generally, the characteristics of the span vary greatly according to the language studied and the direction of reading. For the vertical reading of Japanese, for instance, the span extends five to six character spaces in the vertical direction of the eye movement (Osaka & Oda, 1991). For Hebrew, which is printed from right to left, the span extends further to the left of fixation than to the right (Pollatsek, Bolozky, Well, & Rayner, 1981). The span is generally smaller for languages with non-alphabetic writing systems, such as Japanese (Ikeda & Saida, 1978; Osaka, 1992) and Chinese (Inhoff & Liu, 1998).

this window, all the letters of the text may be replaced by other letters or by Xs, or the scene may be blurred or masked. Each time the reader's gaze moves to another fixation location, the window moves along to this new location, too. The logic behind the use of this technique is that when the window is smaller than the perceptual span, it will hinder processing and deteriorate performance; whereas when it is as large or larger, it will not. In Pollatsek et al.'s (1993) study, the window region included the currently fixated line plus either zero, one, two, or three subsequent lines. The results showed that the target word could be occasionally detected one or two lines below the fixated line, although never three lines below. Thus, the perceptual span in visual searches of text seems to encompass two lines below the fixated line at the most.

It should be noted that none of the texts used in Pollatsek et al.'s (1993) study, or indeed in any of the studies dealing with perceptual span, contained any visual signals of the text structure, such as headings or paragraph marks. Hence, it is unknown whether visual signals can modify the characteristics of the perceptual span. This issue is relevant, given the fact that authentic texts encountered in the course of everyday human activity usually contain visual signals. Two conditions have to be met if visual signals are to extend the perceptual span beyond the traditionally defined region. First, visual signals have to be perceptible in extrafoveal vision beyond this traditional region, despite the rapid decline in visual acuity with eccentricity. One can argue that, unlike word and letter identities, the presence of visual signals may indeed be registered some distance away from the fovea. Everyone can experience the perception of a heading somewhere on the page while fixating on another more or less adjacent point. Second, the information provided by the visual signals, and obtained in extrafoveal vision, has to be useful for carrying out the task-relevant activity. Again, one can argue that this may indeed be the case. Let us imagine that one is searching a text about the world's endangered species to find out how many parrot species are under threat. If the text's author has flagged the different subsections of the text with informative headings, such as "Whales," "Bears," "Penguins," and so forth, searchers can skim the text and check the headings until their gaze aligns on the relevant one (i.e., "Parrots"). In this instance, they may benefit from perceiving the presence of headings away from fovea. Although visual acuity may be insufficient to identify the content words of headings far away from fovea, it may be sufficient to perceive their presence in order to guide long saccades toward them. This efficient eye guidance may allow the searcher to have prompt access to the content of headings, thereby speeding up the search.

The influence of visual signals on text processing has been extensively researched (for a review, see Lemarié, Lorch, Eyrolle, & Virbel, 2008). Most studies have examined how signals can help *remember* the text contents. It has been consistently found, for instance, that readers remember more of the topics discussed in a text when it contains headings than when it does not contain headings (Hyönä & Lorch, 2004; Lorch & Lorch, 1996; Lorch, Lorch, Ritchey, McGovern, & Coleman, 2001; Sanchez, Lorch, & Lorch, 2001). Typographical signals, such as boldface or underlining, have also consistently proved to enhance memory for the signaled information (Crouse & Idstein, 1972; Fowler & Barker, 1974; Glynn & Divesta, 1979; Lorch, Lorch, & Klusewitz, 1995; Nist & Hogrebe, 1987). Paragraph marks, in contrast, do not seem to have potent effects on memory for text (Goldman, Saul, & Coté, 1995). In comparison, much less research has examined how visual signals can help *search* through a text to find specific text information; and, to the best of our knowledge, no research has ever used the eye-tracking technique to address this issue.

Hartley and Trueman (1983, 1985) showed that the total time spent searching the text decreases substantially when the text contains headings compared with when it does not, suggesting that the headings are also of great help when searching through a text. More recently, Klusewitz and Lorch (2000) replicated and extended the Hartley and Trueman findings. Their research goal was to isolate different types of information provided by headings and related signals, and to determine their respective effects on the search activity. The researchers highlighted three types of information: the section information, the content information, and the organization information. Headings and related signals visually communicate the boundaries between successive *sections* of the text. At the same time, headings may provide a topic label that informs about the likely *content* of the following text sections. Finally, a hierarchical system of headings inform about the relations among topics in the text and their *organization*. To isolate the respective effects of the section, content, and organization information, four text versions were created. The first version provided signals for all the three aforementioned types of information. The second one contained signals for section and content information, but the organizational signals were excluded. The third version provided only section information, and the fourth one was a baseline condition that did not provide any of the three types of information (see also Lemarié et al., 2008). Finally, the researchers also investigated the effect of familiarity with the text—due to having previously searched or read the text.

Klusewitz and Lorch (2000) observed that signals of content information shortened the time spent searching through the text pages. This suggests that when headings inform about the text content (i.e., topic headings), they are of great help to the search process. Klusewitz and Lorch proposed that the searchers use the content information provided by topic headings to avoid reading the text sections that are unlikely to contain the target information. By contrast, they obtained no evidence for the view that the searchers use the organizational information; neither did the section information accelerate the search. When the searcher became more familiar with the text, the section information even *slowed down* the search. Finally, text familiarity strongly sped up the search. Among the reported results, the non-facilitative effect of the section information came as a surprise to the researchers. As they pointed out, this result might be specific to the texts used in their study, which had several section junctures on every page (often 3). They proposed that in a less frequently divided text, the section information may well speed up the search. The familiarity effect was interpreted to support the hypothesis that reading or searching a multiple-topic text results in a mental representation of the text's topics (Lorch, Lorch, & Matthews, 1985) that can be used to guide subsequent text search.

The goal of this study was twofold. The first goal was to further examine the kind of text layout information that searchers use. Following previous research (Klusewitz & Lorch, 2000), we investigated the respective effect of the content and section information provided by topic headings and paragraph marks. Participants were asked to find answers to specific questions in chapter-length texts; and, as illustrated in Figure 1 (normal condition), the texts either contained no signals (unsignaled condition), paragraph marks (paragraph condition), or both paragraph marks and headings (fake heading condition and topic heading condition). The topic heading condition and the fake heading condition were identical with the exception that in the fake one all the letters of the headings were replaced by Xs. Thus, possible differences observed between the topic heading and the fake heading condition should be attributed to the content information conveyed by the topic headings. Possible differences between the unsignaled and the paragraph condition, on the other hand, should be attributed to the section information conveyed by the paragraph marks. The texts were designed as having a small number of section junctures on every page (1 or 2).

In line with the Klusewitz and Lorch (2000) study, we expected the content information conveyed by topic headings to speed up the search. On the basis of the following rationale, we expected that the section information conveyed by paragraph marks would also speed up the search. Given that new topics are typically introduced in paragraph-initial sentences (Goldman et al., 1995; Hyönä, 1994), these sentences may be used in a similar manner than topic headings. The searchers may attend to those sentences to assess, given their topic content, whether an extensive search of the entire subsection is worthwhile. Of course, the topic information contained in the paragraph-initial sentences may be less clear-cut than in the topic headings, but it may still be helpful. Thus, in signaling by paragraph marks the sentences introducing new topics, such section information may also speed up the search. The effect of text familiarity was also investigated by manipulating the number of previous searches (0 vs. 2). Here we expected to replicate the facilitative effect of text familiarity reported by Klusewitz and Lorch.

The second goal of the study was to find out whether visual signals can have an effect on the perceptual span while searching a text. We hypothesized that visual signals would extend the perceptual span in text search because the presence of visual signals can be perceived at a greater distance from the

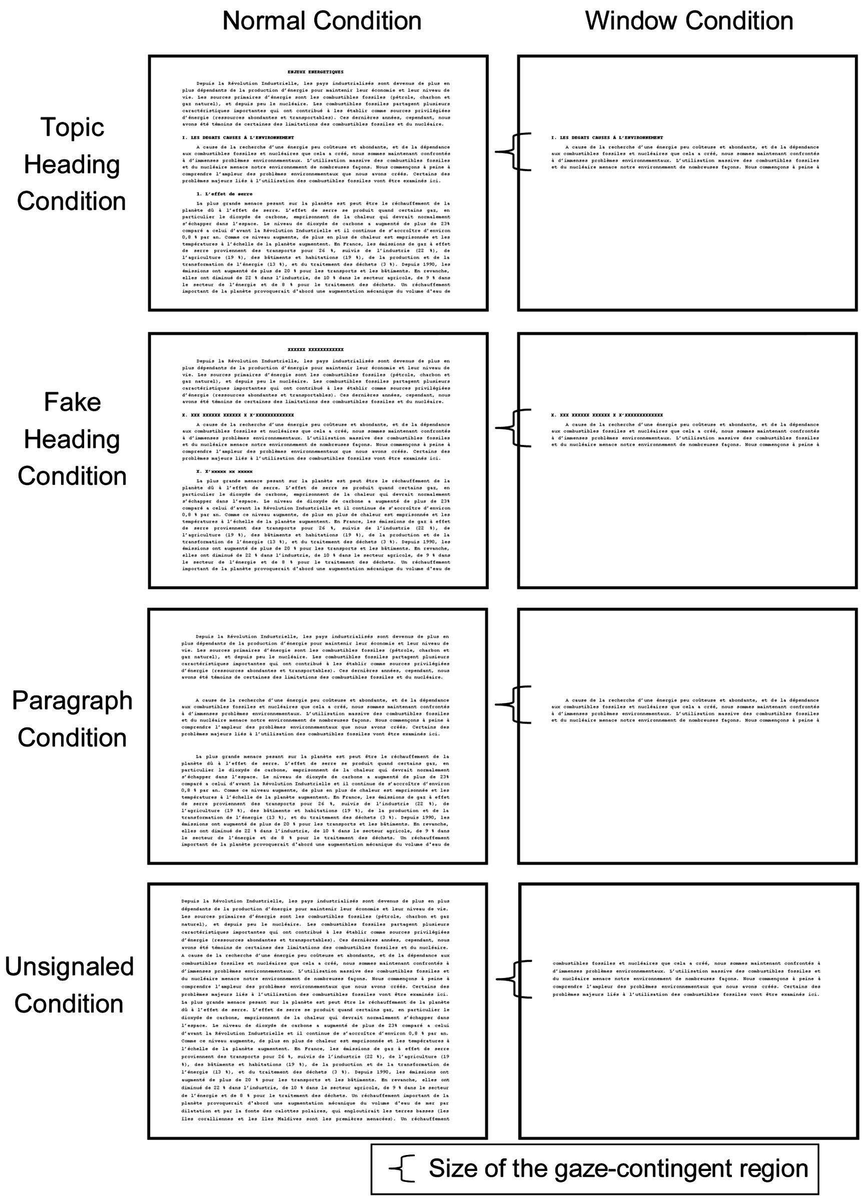

FIGURE 1 Illustration of the text types and the gaze-contingent window for a screen page (all the letters of the headings were replaced by Xs in the fake heading condition).

fixation point than letter and word information. Participants' eye movements were monitored during the experiment, and the texts were searched in either a normal or a window condition, where the text above and below a vertical 3° gaze-contingent region was not visible. The window was large enough to include the fixated line and two additional lines both above and below it. We expected to observe different effects of the window manipulation depending on text type. As the gaze-contingent region was vertically as large as the maximum perceptual span previously determined for searching unsignaled texts (Pollatsek et al., 1993), we did not expect the limited text window to deteriorate performance for searching through unsignaled texts. By contrast, we predicted that the window manipulation will impair the search activity for the signaled texts.

With respect to the texts with topic headings, in the normal condition the searchers may not read much of the texts, but rather check the headings to find the search-relevant topic. In doing so, they may benefit from perceiving the presence of headings extrafoveally. The perception of headings on a text page may allow the searchers to execute long saccades toward them fast and with little effort. By contrast, in the window condition, such efficient eye guidance is impossible. Instead, the searcher may resort to browsing the page by making smaller vertical jumps until a heading falls into the text window so that it can be fixated. Thus, in the window condition, long saccades toward headings may be replaced by shorter intermediary ones, resulting in more fixations and longer search times. Furthermore, consistent with previous gaze-contingent window studies (Bertera & Rayner, 2000; Gilman & Underwood, 2003; McConkie & Rayner, 1975; Pomplun et al., 2001; Rayner & Fisher, 1987; Rayner et al., 1981), a general impairment in eye guidance due to the limited window should lead to longer fixation durations as well.

With respect to the texts with fake headings and paragraph marks, in the absence of informative headings the searchers may, as argued earlier, visually attend to the paragraph-initial sentences. If so, in the normal condition, at least some saccades should be guided by the visual cues provided by paragraph marks in extrafoveal vision, and such eye guidance should be impaired in the window condition. In all, although the texts with topic headings may yield the most clear-cut results, we expected the limited text window to hamper with the processing of all three signaled texts.

METHOD

Participants

A total of 88 university students were given movie tickets in exchange for taking part in this study. Their ages ranged from 18 to 35 years. Forty-four of the participants were women. They were all native French speakers, with normal uncorrected vision and naïve to the purpose of the experiment.

Apparatus

The texts were presented on an LG Flatron L2010P 20-in. monitor interfaced with an HP Compaq Pentium IV computer, which, in turn, was interfaced with an Applied Science Laboratories Model 504 eye tracker. The monitor had a 60-Hz refresh rate. The eye tracker is a remote infrared video-based tracking system, placed below the monitor. The camera sampled pupil location and pupil size at the rate of 50 Hz.[2] Registration was monocular. Head movements were restricted by means of a chinrest, so that measurements were spatially accurate to approximately 0.5°. The distance between the participant's eyes and the screen was held constant at 80 cm. At this distance, characters subtended horizontal and vertical visual angles of 0.25° and no more than 0.29°, respectively, and the whole screen covered about 27° horizontally and 21° vertically. The gaze-contingent window, which subtended a vertical visual angle of exactly 3.2°, was continually centered on the participant's current gaze position with one restriction. The position of the window was only updated when the position of the gaze moved more than 0.5 cm (0.4°) up or down, to eliminate potential flicker caused by microsaccades, drift, or small inaccuracies in registration.

Materials

Two texts were translated into French and adapted from a previous study (Hyönä & Lorch, 2004). One text was about endangered species, and the other was about energy use. Both texts began with a short introduction, and then discussed eight distinct topics organized into two major sections. The first major section of the endangered species text was on threatened mammals and discussed bats, whales, apes, tigers, and bears. The second section of the endangered species text was on threatened birds and discussed parrots, penguins, and migratory birds. The two major sections of the energy text were on environmental damage and renewable energy sources. The first section discussed the greenhouse effect, acid rain, and radioactive waste, whereas the second one described solar energy, geothermal energy, tidal power, wind power, and ocean thermal energy.

Four versions were created for both texts (see Figure 1), which contained either no signals (unsignaled condition), paragraph marks (paragraph condition),

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[2] The temporal resolution of the eye trackers used in eye-contingent display change studies is usually more fine-grained. These devices usually sample the signal every millisecond (1,000 Hz) or every 4 ms (250 Hz), whereas ours only sampled it every 20 ms (50 Hz). A coarse sampling rate is obviously not ideal for carrying out eye-contingent display change studies, but the window used in this study was large enough to avert any major problems in this respect.

or both paragraph marks and headings (fake heading condition and topic heading condition). In the versions with topic headings, each subsection was preceded by a heading that labeled its topic (e.g., "Whales" and "Apes"). The headings were presented on separate lines in boldface. The versions with fake headings were identical to the versions with topic headings, with the exception that all the letters of the headings were replaced by Xs. The versions with paragraph marks were identical to the versions with topic and fake headings in every other respect, except that all the headings were deleted. The unsignaled versions were identical to the versions with paragraph marks, except that all the paragraph marks were deleted. Both texts occupied seven screen pages and were approximately 2,700 words in length.

Three questions were created for both texts (endangered species and energy). Each question was displayed in the middle of a separate screen. The questions were provided prior to the search, and there was only one question per search (see the Procedure and Design section). Only the first and third questions were analyzed; the middle ones were used simply to increase familiarity with the text between the two critical searches. The answers to the questions were always provided within a single sentence in the text. The questions contained keywords from the target sentence and the corresponding section heading. For example, the target sentence of the question, "How many parrot species are thought to be endangered?," was "Ninety-five parrot species are thought to be endangered, a proportion reached by no other bird family in the wild." In both texts, the target sentences of the two critical questions were located on the fifth and sixth text screens, regardless of the version. The target sentences of the filler questions were always located on the fourth text screen (the order of presentation of the 2 critical questions was counterbalanced).

After each target had been located, a "validation screen" appeared. This screen looked like a multiple-choice question, presenting the original question and three possible responses—that is, the correct response and two distracters. If the correct response was selected, the screen disappeared and the next question appeared. If a wrong one was selected, an error message was displayed inviting the participant to choose another response on the screen until the correct one was selected. The sole purpose of the validation screens was to ensure that the participants remained attentive; their responses were not recorded.

In addition to the two experimental texts, a practice text about fire fighting was prepared in four different versions (topic heading, fake heading, paragraph marks, and unsignaled), together with two corresponding questions (adapted from Klusewitz & Lorch, 2000). These were created in exactly the same way as for the experimental texts. Each version occupied five screen pages and was approximately 1,900 words in length.[3]

[3]An English translation of the texts and the questions are available on request from Fabrice Cauchard.

Procedure and Design

The experiment began with a calibration of the eye tracking system. During calibration, the participant was requested to successively fixate nine points covering the computer screen. The accuracy of the calibration was verified using the same calibration grid; a recalibration was carried out if necessary.

The participants were instructed to search the text for answers to questions, one at a time and as quickly as possible. Each question was displayed on a separate screen prior to the search. The participants were instructed to take as much time as they needed to fully memorize the question before searching for the answer. They were told that the relevant answer was always to be found in a single sentence. As soon as they had found it, they clicked with the mouse on the target sentence. If they clicked on the wrong sentence, they heard a beep and the search went on. If they clicked on the correct one, the text disappeared, and a validation screen asked them to select the correct answer from among two other possible, but slightly different, responses. The next question then appeared. Participants turned the text pages (returning to a previous page was also possible) by pressing the right and left arrows on the keyboard. After an arrow button was pressed, but before a new text page was displayed, a white page appeared with a fixation cross in the top left-hand corner. As soon as the participant's gaze moved to this cross, a new text page was displayed. This procedure allowed us to control the starting point of the scan path so that it was identical for all text pages, trials, and participants.

Each participant searched through the two experimental texts, one after another three times (i.e., 1, 1, 1, 2, 2, 2 or 2, 2, 2, 1, 1, 1). Before that, a practice text was searched twice to familiarize the participants with the technical aspects of the experiment and the gaze-contingent device. The participants were assigned, at random, to one of the four text type conditions. The text type remained constant throughout the practice and experimental texts. By contrast, the window factor was a within-subjects factor. Accordingly, one of the two experimental texts was always searched through the window, whereas the other one was searched normally. In sum, the experiment had a mixed, three-factor design. The between-subject factor was text type (topic heading, fake heading, paragraph mark, or unsignaled condition), and the within-subjects factors were window (normal vs. window condition) and familiarity (first vs. third search). The order of presentation of the energy and endangered species texts (first vs. second), the order of the window conditions and its assignment to the texts (first vs. second), and the order of presentation of the critical questions (first vs. third) were all counterbalanced across participants. There were an equal number of participants in each text type condition (i.e., 22).

RESULTS

Four search measures were used as the dependent variables. The total search time was recorded by the computer independently of the eye movement monitoring, and corresponded to the summed duration of page displays. It was terminated by the mouse click on the target sentence (see the Procedure and Design section). The other measures—number of fixations, saccade length, and fixation duration—were derived from the eye movement recordings. Each dependent variable was analyzed using a mixed $4 \times 2 \times 2$ (Text Type $\times$ Window $\times$ Familiarity) analysis of variance (ANOVA).

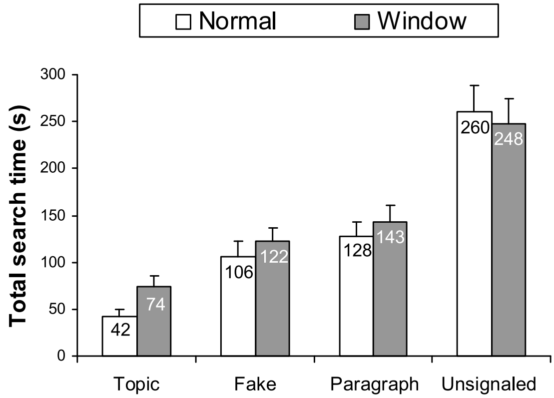
The first goal of this study was to examine whether participants use textual layout information when searching through a text. We predicted that both the content information conveyed by topic headings and the section information conveyed by paragraph marks speed up the search. The effects of text type on total search time relevant to this issue are presented in the first section.

The second goal was to examine whether visual signals can have an effect on the perceptual span while searching a text. We assumed the perceptual span to be larger for signaled than for unsignaled texts. More precisely, we predicted that the window would impair the search performance for signaled texts, which would show up as longer search times, more fixations, shorter saccades, and longer fixation durations. By contrast, we predicted the window device not to impair the search with unsignaled texts. All four dependent measures are relevant for testing these predictions.

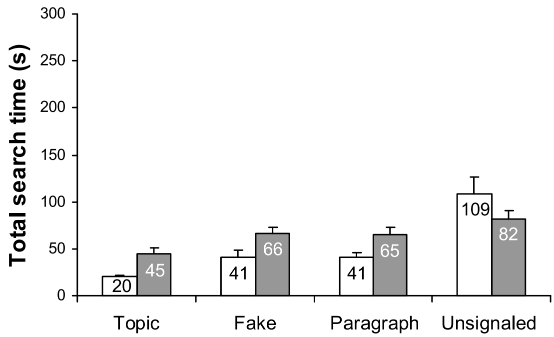
Finally, we intended to replicate the familiarity effect observed by Klusewitz and Lorch (2000) with regard to the total time spent searching the text. Obviously, the results on the total search time are of relevance to this issue.

Total Search Time

The first goal of this study was to examine whether texts' visual layout information are used in text search. Consistent with our expectations, and in line with the Klusewitz and Lorch (2000) study, the results showed that the content information provided by the topic headings sped up the search. The total search time data are presented in Figure 2. Specifically, the analysis of total search time revealed a main effect of text type, $F(3, 84) = 32.90$, $p < .001$ ($\eta_p^2 = .54$); Scheffe's tests revealed that participants were faster at searching a text containing topic headings ($M = 45$ s) than fake headings ($M = 84$ s), $p < .05$. These results demonstrate the facilitative effect of the content information provided by the topic headings. Also consistent with our predictions, the section information provided by the paragraph marks also sped up the search. Participants were faster at searching a text containing paragraph marks ($M = 94$ s) than a text not containing any signals ($M = 175$ s), $p < .01$. As expected, this last result



(a)



(b)

FIGURE 2 Total search time (in seconds) as a function of text type and presentation type for the first (panel A) and third search (panel B). Error bars indicate standard errors.

is at odds with the results of the Klusewitz and Lorch (2000) study. We return to this (expected) discrepancy in the Discussion section.

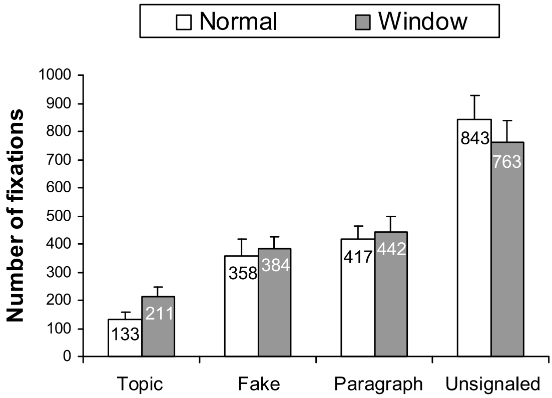
The second aim of this study was to examine the effect of visual signals on the perceptual span in text search. We assumed the perceptual span to be larger with texts containing visual signals than with texts not containing any visual signals. Accordingly, we predicted that participants would be slower at searching the texts in the window condition than in the normal condition, but only when the texts contained visual signals. As can be seen in Figure 2, the results were consistent with our predictions, supporting the hypothesis of a larger perceptual span for signaled than for unsignaled texts. More specifically, the Text Type × Window interaction proved significant, $F(3, 84) = 5.18$, $p < .01$ ($\eta_p^2 = .16$); and separate analyses indicated that participants were faster at searching the texts in the normal condition than in the window condition when the texts contained topic headings (31 s vs. 59 s), $F(1, 21) = 9.52$, $p < .01$ ($\eta_p^2 = .31$); fake headings (74 s vs. 94 s), $F(1, 21) = 4.48$, $p < .05$ ($\eta_p^2 = .18$); and paragraph marks (85 s vs. 104 s), $F(1, 21) = 4.84$, $p < .05$ ($\eta_p^2 = .19$). By contrast, there was no significant difference when the texts did not contain any visual signals; the total search time was even (nonsignificantly) slightly shorter in the window condition than in the normal condition (165 s vs. 184 s), $F(1, 21) = 3.79$, $p < .07$ ($\eta_p^2 = .15$).

Finally, we replicated the familiarity effect previously reported by Klusewitz and Lorch (2000). Participants were faster at searching the texts when they had already searched it twice (third search, $M = 59$ s) than when they had not perform any previous searches (first search, $M = 140$ s), $F(1, 84) = 83.18$, $p < .001$ ($\eta_p^2 = .50$). In accordance with the interpretation provided by Klusewitz and Lorch, this finding suggests that searching a text results in a mental representation of the text content that can be used to guide subsequent text search.

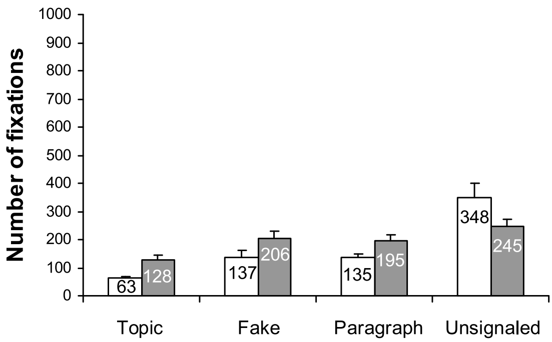
Number of Fixations

The eye movement measures are relevant to the second goal of this study, which was to examine the effect of visual signals on the perceptual span. We predicted more fixations in the window condition than in the normal condition when searching through the three signaled texts because the window would prevent participants from programming long saccades toward visual signaled headings and paragraph-initial sentences perceived in the periphery (long saccades would be broken down to several shorter ones). By contrast, we did not predict any adverse effect of window when searching the unsignaled texts.

As can be seen in Figure 3, the results were globally consistent with our predictions. More precisely, the Text Type × Window interaction proved significant, $F(3, 84) = 6.03$, $p < .001$ ($\eta_p^2 = .18$); and a separate analysis indicated that participants made more fixations in the window condition ($M = 170$) than in the normal condition ($M = 98$) when searching the texts with topic headings, $F(1, 21) = 6.85$, $p < .025$ ($\eta_p^2 = .25$). Although participants made more fixations in the window condition than in the normal condition when searching the texts with fake headings (295 s vs. 248 s) and paragraph marks (319 s vs. 276 s), the effects did not reach significance. Finally, the readers made *less* fixations in the window condition ($M = 504$) than in the normal condition ($M = 596$) when searching the unsignaled texts, $F(1, 21) = 8.71$, $p < .01$ ($\eta_p^2 = .29$).



(a)



(b)

FIGURE 3 Number of fixations as a function of text type and presentation type for the first (panel A) and third search (panel B). Error bars indicate standard errors.

Although not contradicting our predictions, the decrease in the number of fixations for the unsignaled texts in the window condition compared with the normal one was unexpected. It suggests that, instead of hampering the eye guidance, the window actually improved it. It may be the case that the searches of the unsignaled texts were more difficult in the normal condition because the fixated text was continually and densely surrounded by other, potentially distracting, text, thus possibly producing a crowding effect. In other words, unlike in the signaled text, the visual information available outside the window region may, if anything, have generated interference in processing. It should be noted that this possibility was also raised by Pollatsek et al. (1993) in the context of a reading task (as stated earlier, the researchers used unsignaled texts). Pollatsek et al. (1993) argued that, although the perceptual span in reading was restricted to the fixated line, some interfering visual information may occasionally have been obtained from the adjacent lines (see also Van Overschelde & Healy, 2005).

Saccade Length

We assumed that the saccade length data would provide further evidence for our hypothesis of a larger perceptual span when searching signaled than unsignaled texts. More precisely, we predicted that the saccades would be shorter in the window condition than in the normal condition for the signaled texts because the window would prevent the readers from programming long saccades toward signaled text regions. By contrast, we predicted that the text window would not shorten the saccades made when searching the unsignaled texts because no visual signals were perceptible in the periphery regardless of the presence or absence of the window.

As can be seen in Figure 4, the saccade length data were generally consistent with our predictions, supporting the hypothesis of a larger perceptual span for signaled texts. The Text Type × Window interaction was significant, $F(3, 84) = 16.96$, $p < .001$ ($\eta_p^2 = .38$); and separate analysis indicated that participants made shorter saccades in the window condition than in the normal condition when searching the texts with topic headings (4.21° vs. 5.13°), $F(1, 21) = 80.09$, $p < .001$ ($\eta_p^2 = .79$); fake headings (4.19° vs. 4.53°), $F(1, 21) = 23.66$, $p < .001$ ($\eta_p^2 = .53$); and paragraph marks (4.49° vs. 4.94°), $F(1, 21) = 20.83$, $p < .001$ ($\eta_p^2 = .50$). However, surprisingly, participants also made shorter saccades in the window than in the normal condition when searching the unsignaled texts (4.55° vs. 4.65°), $F(1, 21) = 4.72$, $p < .05$ ($\eta_p^2 = .18$). Although this result is at odds with our predictions, it should be noted that the effect was very small (see Figure 4).

Finally, given that signaled texts yielded much shorter search times than unsignaled texts, one might have expected saccades to be longer for the former than the later condition, due to searchers reading less and skipping over larger chunks of text. However, as can be seen in Figure 4, this was not the case (the main effect of text type did not prove significant). It may be the case that the lack of a significant text type effect may be due to long return sweeps (taking the eyes from the end of one line to the beginning of next line) obscuring the effect of text type on saccade length. The more searchers spent reading the text, the more return sweeps were entailed in their eye movement record. Thus, frequent return sweeps made in the unsignaled texts might have obscured the effect of text type on saccade length because most of them were probably very long saccades (the distance between the left and right margins of the page corresponded approximately to 21° of visual angle).[4]

Fixation Duration

Previous research (e.g., Bertera & Rayner, 2000) has shown that when a gaze-contingent text window encroached on the perceptual span of the participants, the general impairment of eye guidance leads to more fixations, shorter saccades, *and* longer fixation durations as well (and as a result of these effects, to longer total reading and search times). Accordingly, we predicted that participants would make longer fixations in the window than in the normal condition when searching the signaled texts, but not when searching the unsignaled texts. As illustrated in Figure 5, the fixation duration data were only partially consistent with our predictions because the window inflated the fixation durations for both the signaled and unsignaled texts. More precisely, although the Text Type × Window interaction proved significant, $F(3, 84) = 4.63$, $p < .01$ ($\eta_p^2 = .14$), participants made longer fixations in the window condition than in the normal condition when searching the texts with topic headings (309 ms vs. 270 ms), $F(1, 21) = 66.23$, $p < .001$ ($\eta_p^2 = .76$); fake headings (279 ms vs. 256 ms), $F(1, 21) = 51.29$, $p < .001$ ($\eta_p^2 = .71$); paragraph marks (284 ms vs. 259 ms), $F(1, 21) = 45.39$, $p < .001$ ($\eta_p^2 = .68$); *and* no signals (284 ms vs. 263 ms), $F(1, 21) = 61.93$, $p < .001$ ($\eta_p^2 = .75$). As may be noted from the means, the effect of the mode of text presentation was largest for the topic heading condition (39 ms) and smallest for the no-signal condition (21 ms).

The fact that the readers made longer fixations in the window condition than in the normal condition when searching the unsignaled texts clearly contradicted our prediction. However, it should be noted that this effect cannot be interpreted

[4]We tried to compute an algorithm to remove the return sweeps from the data before reanalyzing them. The principle of the algorithm was as follows: Typically, return sweeps are launched five to seven letter spaces from the end of a line, and they land five to seven letter spaces from the beginning of the next line (Rayner, Juhasz, & Pollatsek, 2005). Thus, to be categorized as return sweeps, the saccades were to meet three criteria. First, they should be launched close from the right margin. Second, they should land close to the left margin. Third, the vertical distance between the two fixations separated by a saccade should not significantly exceed the vertical distance between two text lines. However, these criteria did not reliably detect return sweeps. The distance between the right and left margins, on the one hand, and the launch and landing sites of the return sweeps, on the other hand, proved to be very variable in our data. Hardly any saccades were categorized as return sweep when the acceptable launch and landing sites in the algorithm were reasonable (5–7 letter spaces). Moreover, even when we increased the critical regions (to 10–15 letter spaces), the algorithm still did not prove satisfactory because most return sweeps were composed of two saccades separated by a very short fixation more or less halfway between the right and left margins.

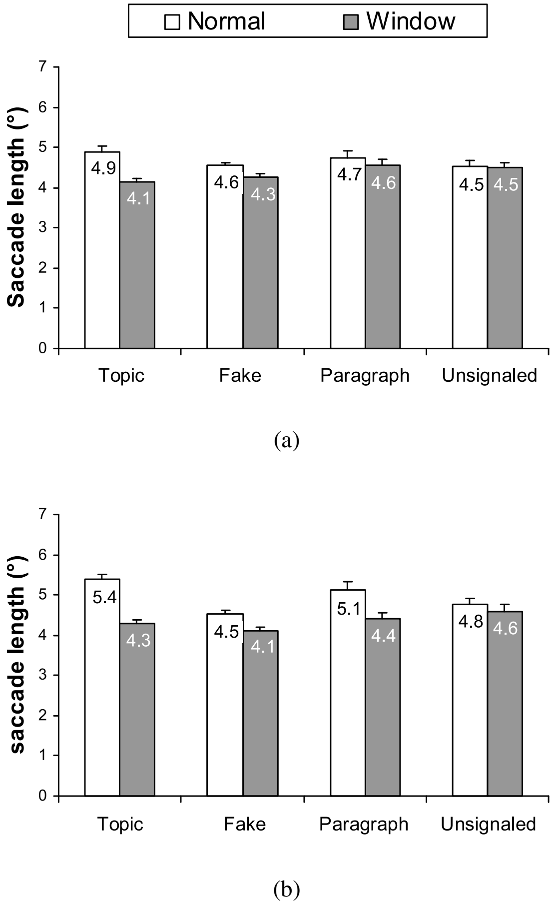


FIGURE 4 Saccade length as a function of text type and presentation type for the first (panel A) and third search (panel B). Error bars indicate standard errors.

as revealing a general impairment in eye guidance, when considered in the context of the other dependent measures. Although participants made longer fixations in the window condition than in the normal condition when searching the unsignaled texts, it did not lead to longer total search times because the readers made longer but *fewer* fixations in the window condition compared to the normal condition. As a result, the window tended to decrease the total time spent searching the unsignaled texts (see Figure 2), suggesting no general impairment in eye guidance. By contrast, in the case of the signaled texts, when considered together, the dependent measures indicated a clear impairment in eye guidance

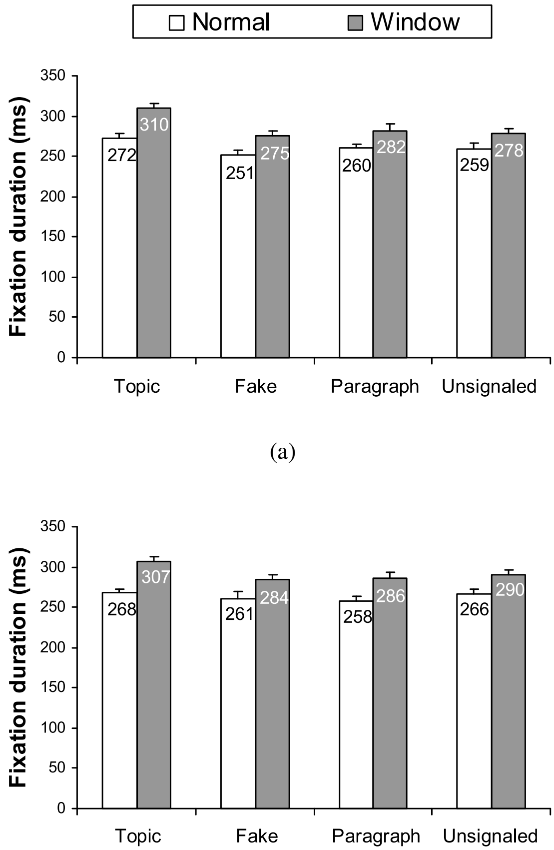


FIGURE 5 Fixation duration as a function of text type and presentation type for the first (panel A) and third search (panel B). Error bars indicate standard errors.

in the window condition compared to the normal condition (i.e., longer search times, more fixations, shorter saccades, and longer fixation durations; see Figures 2–5). This overall pattern of result provides strong support for the hypothesis that visual signals are capable of extending the perceptual span during text search.

Subsidiary Analyses

We hypothesized that the perceptual span would be larger for signaled than for unsignaled texts because participants can perceive visual signals in extrafoveal vision and utilize them in programming long saccades toward signaled text regions. The results reported earlier provide strong evidence for a larger perceptual span for texts containing visual signals, such as headings and paragraph marks. However, they provide only indirect evidence for the hypothesis that readers can program long saccades toward visual signals perceived in extrafoveal vision. The only evidence for the existence of such "signal-guided" saccades was that participants searching the signaled texts made longer saccades in the normal than in the window condition, where eye guidance via textual signals perceived in extrafoveal vision was impossible.

To draw more definitive conclusions about the existence of long-range saccades programmed on the basis of visual signals, we computed a subsidiary analysis where we directly examined the length of the saccades that landed on the topic headings (in the texts with topic headings) or on the paragraph-initial sentences (in the texts with fake headings and paragraph marks). The mean lengths of these saccades are reported in Table 1. These data were analyzed using a mixed 3 × 2 × 2 (Text Type × Window × Familiarity) ANOVA. The analysis yielded a main effect of window, $F(1, 63) = 50.87, p < .001$ ($\eta_p^2 = .45$). This indicates that the saccades landing on the topic headings and paragraph-initial sentences were longer in the normal condition than in the window one (6.01° vs. 4.44°). Separate analyses showed that these saccades were longer in the normal than in the window condition for the texts with topic headings (5.83° vs. 3.97°), $F(1, 21) = 17.67$, $p < .001$ ($\eta_p^2 = .46$); fake headings (6.11° vs. 4.63°), $F(1, 21) = 16.41, p < .001$ ($\eta_p^2 = .44$); and paragraph marks (6.15° vs. 4.77°), $F(1, 21) = 18.21$, $p < .001$ ($\eta_p^2 = .48$). These findings provide strong evidence for the existence of signal-guided saccades; or, to put it in another

TABLE 1
Saccade Length (in Degrees) Immediately Before Fixating a Heading (Topic Heading Condition) or a Paragraph-Initial Sentence (Fake Heading and Paragraph Conditions)

	Normal Condition		Window Condition	
Variable	*M*	*SE*	*M*	*SE*
First search				
Topic heading	6.1	0.4	4.2	0.5
Fake heading	6.2	0.4	5.1	0.4
Paragraph	6.1	0.3	5.0	0.4
Third search				
Topic heading	5.5	0.4	3.7	0.3
Fake heading	6.0	0.3	4.2	0.3
Paragraph	6.2	0.4	4.5	0.3

way, these results lend strong support for the hypothesis that searchers can perceive visual signals in extrafoveal vision and program long saccades toward them.

DISCUSSION

The first goal of this study was to examine whether and what kind of text layout information is used when searching an answer to a specific question in long expository texts. Following previous research (Klusewitz & Lorch, 2000), we investigated the respective effects of content and section information provided by topic headings and paragraph marks. The effect of content information was assessed by comparing the topic heading condition to the fake heading (the heading comprised a row of Xs) condition (see Figure 1). Total search times were much shorter in the topic heading condition than in the fake heading one, replicating the facilitative effect of content information previously observed by Klusewitz and Lorch. The effect of section information was assessed by comparing the paragraph mark condition and the unsignaled (i.e., no paragraphs were present) condition. Total search times were much shorter in the former than in the latter condition, demonstrating that section information is also of great help in the search process. Finally, we replicated the effect of text familiarity previously reported by Klusewitz and Lorch. This finding suggests that searching a text results in a mental representation of the text content that can then be used to guide subsequent text search (see also Rouet, Vidal-Abarca, Erboul, & Millogo, 2001).

In their study, Klusewitz and Lorch (2000) failed to find any benefit of the section information. When the searcher had obtained some familiarity with the text, section information even slowed down the search. By contrast, in this study, the section information accelerated the search to a large extent, regardless of text familiarity. The discrepancy between our results and those of Klusewitz and Lorch may come from their experimental texts containing more sections than ours (about 3 section junctures per page vs. 1 or 2 in our study). Consider, for instance, a searcher who reads the beginning of a new text section and finds out, given its initial content, that it is unlikely that the section contains the target information, and then jumps to the beginning of next section. If the text page contains several section junctures, the search will be slowed down. By contrast, if the text page does not contain any other section juncture, the searcher may promptly jump to the next text page, thereby speeding up the search process. Finally, the discrepancy between our results and those of Klusewitz and Lorch echoes previous signal studies showing that "over-signaling"—that is, putting too many signals in a text—can reduce the effectiveness of those signals (Crouse & Idstein, 1972; Lorch et al., 1995).

The second goal of the study was to find out for the first time, to our knowledge, whether visual signals can have an effect on the perceptual span during text search. We hypothesized that the perceptual span would be larger for signaled than unsignaled texts because searchers can perceive visual signals in extrafoveal vision and utilize them in programming long saccades toward them, leading to a more efficient search. Two pieces of data lent strong support for this hypothesis. First, the presence of the text window (only about 2 lines of text above and below the fixated line was available) slowed down the search of the texts with topic headings and paragraph marks. By contrast, it did not slow down the search when the texts did not contain any such signals. Second, a more detailed analysis of the saccades landing on headings and paragraph-initial sentences showed that when the signals were not fully visible in extrafoveal vision (in the window condition), these saccades were shorter (i.e., they were launched from a closer distance). Altogether, these results reveal that visual signals can extend the perceptual span in text search. In addition, they confirm the existence of what we call signal-guided saccades (i.e., saccades guided by textual signals perceived in parafoveal or even peripheral vision; the mean size of these signal-guided saccades was 6° in our experiment). These observations have important theoretical implications that are considered next.

Our results suggest that visual signals are perceived at a greater distance from the fixation point than word and letter information. Actually, the fact that different types of information are acquired at different distances from the fixation point has already been firmly established. A comparative analysis of reading and scene perception studies leads to the conclusion that coarse-grained information is acquired at a greater distance from the fixation point than fine-grained information (Henderson & Ferreira, 2004). In scene perception, coarse-grained characteristics of the scene, such as its overall *layout*, are perceived at a greater distance from the fovea than the identities of individual objects (Henderson, 2005; Loschky, McConkie, Yang, & Miller, 2005; Sanocki, 2003; Sanocki & Epstein, 1997). In reading, the length of a word can be registered at a greater distance than its identity, which requires foveal inspection (McConkie & Rayner, 1975). Hence, the *word identification span*—the region within which a word can be fully identified—is smaller (not exceeding more than 8 letter spaces to the right of fixation) than the perceptual span within which word length information is obtained (Rayner, Well, Pollatsek, & Bertera, 1982). This study suggests that there is also a *text layout span* in text search. This span, which is larger than the "traditional" perceptual span (i.e., the span for word and letter processing in reading), includes useful typographical information available on the printed page.

The previous discussion prompts an important question for future studies. Does the text layout span generalize to other tasks, particularly to reading? In other words, do visual signals extend the perceptual span also in reading where the attentional span may be considered generally narrower than in text search? This issue deserves further investigation, especially since the authentic expository texts encountered in everyday life very often contain visual signals, typically in the form of headings and paragraph marks.

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