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# Effects of topic headings on text processing: evidence from adult readers' eye fixation patterns

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**Abstract**

Effects of topic headings on the processing of multiple-topic expository texts were examined with the help of readers' eye fixation patterns. Adult participants read two texts, one in which topic shifts were signaled by topic headings and one in which topic headings were excluded. The presence of topic headings facilitated the processing of topic sentences and increased the number of topics mentioned in the text summaries written after reading the texts. The facilitatory effect of headings was reflected both in the fixations made during the first-pass reading as well as in the later look-backs directed to the topic sentences. A framework is outlined to depict the process of reading and comprehending multiple-topic expository texts.


## 1. Introduction

Cognitive scientists model text comprehension as the construction of a multilevel mental representation by the reader (Graesser, Millis, & Zwaan, 1997; Kintsch, 1988, 1998; Lorch & van den Broek, 1997). The representation includes three levels corresponding to successively deeper levels of processing of information communicated in the text (Kintsch, 1998). Initially, the reader must keep temporarily active the exact wording of phrases (i.e., surface representation) while a propositional representation of the text is constructed. By attending to linguistic devices (e.g., anaphoric reference) that cue the types of relationships between concepts and

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propositions expressed in the text, the reader gradually builds a network of propositions that captures both the local and global coherence relations expressed by the author. With the support of background knowledge relevant to the topics of the text, the reader may construct a representation not just of the relations among the text propositions, but of the situation described in the text. For example, in an expository text describing various attributes of a country, a reader may come to understand how the geography of the country shaped aspects of the economic, social and political development of the country. Thus, comprehension of a text involves the construction of a complex memory representation under the constraints of limited working memory capacity (Kintsch, 1998).

According to this view of text comprehension, the processing of the main topics of a text plays a critical role in the construction of a mental representation of the text. Topics serve as a context for the integration of subordinate information and thus contribute to the local coherence of a text. In addition, the relationships among a text's topics must be recognized and represented if the reader's representation is to be globally coherent. Finally, the identification of a text topic serves to activate relevant prior knowledge in support of the reader's attempts to construct a valid model of the situation communicated by the author. Presumably because they recognize the demands of topic processing, authors often use signaling devices to help readers identify topics and their relationships (Lorch, 1989). In this study, we examine the influence of a particular signaling device, headings, on the processing of sentences that are relevant to the text's topic structure. We first review evidence concerning the nature of on-line processing associated with the processing of text topics during reading. Next, we review what is known about the effects of topic-signaling devices on text processing and memory. Finally, we present an experiment that uses eyetracking methods to test our hypotheses about how headings influence the processing of topic relevant information.

### 1.1. The demands of processing a text's topic structure

In descriptive expository texts, the topics of the text are hierarchically organized (Meyer, 1984). For example, in one of the texts used in this investigation, the first half of the text discussed a variety of problems associated with conventional energy usage and the second half discussed alternatives to fossil fuels and nuclear energy. Each of these two main topics was developed in six subtopics that were relatively independent in the sense that the order of the subtopics could be changed without violating the global coherence of the text. Adequate comprehension of such a multiple-topic text must include representation of what we term the "topic structure" of the text (Lorch & Lorch, 1985). That is, readers must represent each of the major text topics and their relationships to one another.

According to the prevailing view of text comprehension as the on-line construction of a memory representation, points of transition between subsections of a text place relatively heavy processing demands on readers (Lorch & van den Broek, 1997). Although most sentences *within* a subsection can be understood in the context of the immediately preceding sentence (Britton, 1994; Haviland & Clark, 1974;

Kintsch, 1998), the initial sentence of a new subsection cannot usually be understood in the context of the final sentence of the preceding subsection. Further, readers must recognize that transitions between subsections correspond to important junctures in the topic structure of the text. Several theorists have proposed related analyses of the processing that is incumbent on readers at such transition points.

Within Gernsbacher's (1990) structure building framework and Britton's (1994) elaboration of that framework, points of transition between major topics require several mental operations on the part of readers. First, the realization that a subsection has been completed may trigger an attempt to "unitize" the information in the subsection (Britton, 1994), where unitization may be thought of in terms of the construction of macropropositions that capture the gist of the subsection (Kintsch, 1998). In addition, Gernsbacher has suggested that the topic of the terminating subsection must be suppressed when it is no longer relevant. Second, introduction of a new text topic requires identification of the new topic, opening a new memory "slot" for that topic (Gernsbacher, 1990) and computation of the place of the new topic in the text structure (Britton, 1994; Lorch, Lorch, & Matthews, 1985). Computing the place of the new topic in the text's topic structure is hypothesized to be a relatively demanding cognitive operation because it involves accessing a representation of the topic structure and inferring the relationship of the new topic to previously established topics.

To illustrate, consider the processing demands associated with the first sentence of the third paragraph of the text presented in Appendix A. Paragraph formatting suggests the possibility of a major topic shift at the start of the new paragraph, although paragraph formatting alone is ambiguous as to the magnitude of the shift. Thus, readers will need to process the entire first sentence in order to determine that a new topic (i.e., increasing cost of fossil fuels) has, indeed, been introduced. When the new topic is identified, readers will need to wrap up processing of the preceding topic and clearly distinguish it from the new topic so that subsequent information in the new paragraph is not mistakenly connected to a topic that is no longer relevant (i.e., hazards of conventional fuels). According to Britton (1994), readers will also need to determine how the new topic of "fuel costs" relates to the preceding topic of "production hazards" (i.e., both examples of consequences of decreasing availability of fossil fuels, or what Britton calls a "move across") and to the more general topic of "energy problems" (i.e., subordinate relationship, or what Britton calls a "move down").

There is substantial experimental evidence supporting Britton's (1994) and Gernsbacher's (1990) analyses of topic-processing demands. Studies examining sentence reading times have shown that sentences that introduce a new discourse topic or a new narrative episode are allocated more processing time than sentences that are continuations of the same topic or episode (Haberlandt, 1980; Haberlandt, Berian, & Sandson, 1980; Kieras, 1981; Lorch et al., 1985; Lorch, Lorch, & Morgan, 1987; Mandler & Goodman, 1982). Importantly, the slow down on topic-introducing sentences is smaller if the new topic can be directly related to the immediately preceding text topic than if it cannot be (Lorch, Lorch, Gretter, &

Horn, 1987; Lorch et al., 1985; Vauras, Hyönä, & Niemi, 1992). Further, this "topic-shift effect" is not restricted to skilled reading as it is also observed among elementary school-aged readers (Hyönä, 1994; Lorch et al., 1987). These findings support the hypothesis that readers determine the location of the new topic in their representations of the text's topic structure. Finally, two investigations produced findings suggesting that the processing of topic shifts involves a strategic component. Hyönä (1994) showed that adults manifest a proportionately greater topic-shift effect than fifth grade children when reading difficult expository text, but not when reading easier narrative texts. Similarly, Lorch et al. (1987) observed a more pronounced topic-shift effect for better than for poorer adult recallers.

In sum, theoretical analyses and empirical findings indicate that the on-line processing of topic-introducing sentences is relatively demanding because it entails the updating of a representation of the topic structure of the text.

### 1.2. Signaling devices as facilitators of text recall

In natural exposition, the text's topic structure is often cued by signaling devices such a headings and topical overviews (Lorch, 1989, 2001). Many studies have shown that signaling a text's topic structure affects memory for the text. These studies typically compare free recall for texts that include signals to topic structure (i.e., topical overviews, topical summaries, headings and subheadings) with recall of the same texts with the signals omitted. The findings from memory studies are quite consistent. First, signaling topic structure results in a greater number of text topics being discussed in recall (Dee-Lucas & DiVesta, 1980; Loman & Mayer, 1983; Lorch & Lorch, 1985, 1995, 1996a, 1996b; Lorch, Lorch, & Inman, 1993; Meyer, Brandt, & Bluth, 1980; Meyer & Rice, 1982). Second, signaling main ideas or topics generally improves memory for the organization of topics within the text (Brooks, Dansereau, Spurlin, & Holley, 1983; Krug, George, Hannon, & Glover, 1989; Lorch & Lorch, 1985; Lorch et al., 1993; Mayer, Dyck, & Cook, 1984). Finally, there is evidence that the influence of signals on memory is mediated by their influence on readers' processing strategies during reading and/or recall (Lorch & Lorch, 1995; Sanchez, Lorch, & Lorch, 2001). What is not clear from the memory studies, however, is whether signals directly influence readers' processing of topic structure information during reading.

How might signaling devices exert their influence on text recall? Perhaps the most plausible hypothesis is that signals—headings in particular—facilitate processing of a text's topic structure *during* reading (i.e., at encoding). Readers who receive headings and readers who do not receive headings both attempt to represent the topic structure of the text and both groups use their topic structure representations to guide their recalls of the text. However, the presence of headings may help readers to construct a more accurate and complete representation of the topic structure with the consequence that text recall is better.

An alternative hypothesis, however, is that signals exert their influence only on readers' recall strategies (Lorch & Lorch, 1995; Rawson & Kintsch, 2002; Sanchez et al., 2001). According to this hypothesis, readers do not need the help of headings

to construct a complete and accurate topic structure representation during reading. However, headings have the effect of making the text's topic structure more salient which, in turn, increases the likelihood that readers will adopt a recall strategy of using their topic structure representations to guide text recall.

These two hypotheses differ in their claims about the locus of the effects of signaling (i.e., encoding or retrieval). Unfortunately, memory measures cannot determine the locus of signal effects because they do not directly assess on-line processing. The goal of this study was to directly examine the effects of headings on on-line text processing.

### 1.3. Design and rationale of the experiment

The current investigation used eyetracking methods (Rayner & McConkie, 1976) to study the effects of headings on the processing of topic relevant sentences during reading. The methodology has been exploited to learn a great deal about "early" processes in reading, including basic questions about word processing (e.g., lexical access and perceptual span), sentence processing (e.g., syntactic parsing), and simple intersentential processing (e.g., processing of anaphora and lexical ambiguity). As successful as the method has been, researchers have not fully exploited the potential of eyetracking methodologies. In particular, the method has been used only infrequently to investigate global text processing strategies (Blanchard & Iran-Nejad, 1987; Hyönä, 1995; Hyönä, Lorch, & Kaakinen, 2002; Shebilske & Fisher, 1983; Vauras et al., 1992).

Eyetracking is particularly attractive as a method for studying global text processing strategies for several reasons. First, it permits investigation of on-line processing. Second, among on-line methods, it permits several indices of processing to be collected simultaneously with high temporal and spatial resolution. In contrast, for instance, the sentence-by-sentence presentation procedure allows only measurement of the time to read an entire sentence, with no possibility of examining systematic variation in processing across sentences (i.e., looking back to previously read sentences). Third, eyetracking does not disrupt normal reading the way many on-line methods do (e.g., probe procedures). Within a display screen, the reader is free to examine any part of the text in any order and is never interrupted with a secondary task.

In the experiment, adult participants read two multiple-topic texts in preparation to write a summary of the main contents of the texts. One of the texts included topic headings every two paragraphs; the other text omitted headings. Two stages of processing were delineated in the eye fixation records, first-pass reading and backtracking (see Fig. 1). First-pass reading consists of all fixations landing on the target segment during its initial reading and before exiting the text segment to another segment. In the first-pass reading we further distinguished forward fixations, which land on previously unread regions of the target segment, and reinspective fixations, which are fixations going back to already read parts of the sentence. Backtracking, on the other hand, consists of look-back fixations done after the first-pass reading. Look-back fixations were analyzed by taking into consideration

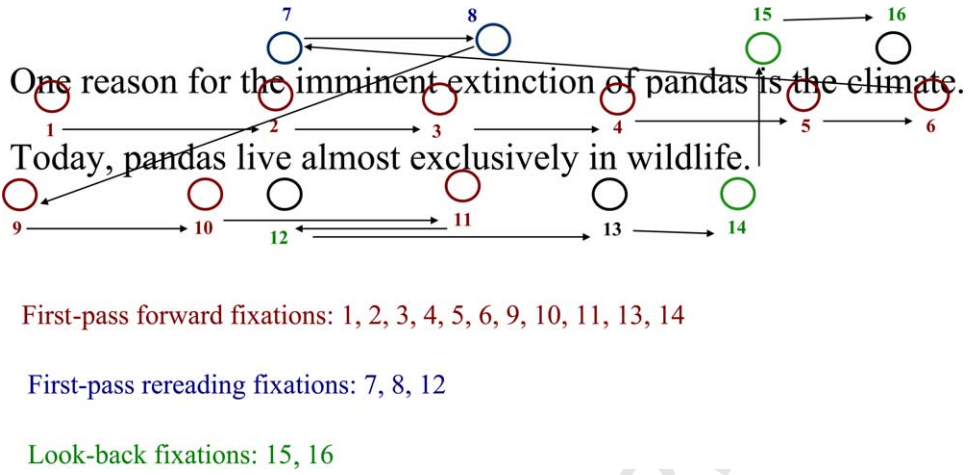


Fig. 1. A visual illustration of the fixation time measures employed in the present study. Open circles denote fixations; the order of fixations is given by the number next to the circle and further depicted by the arrows.

both the origin and the destination of the look-back sequence (for further details and motivation of the measures, see Hyönä et al., 2002; Hyönä, Lorch, & Rinck, 2003). In general, the first-pass measures allowed examination of relatively immediate effects, whereas the backtracking measures allowed examination of relatively delayed effects on processing.

To examine on-line topic processing, we compared eye movement records for three types of sentences: the initial, topic-introducing sentence of each paragraph (“topic sentences”), the last sentence of each paragraph (“end sentences”), and all of the intervening sentences (“medial sentences”). The rationale for this breakdown is that the topic and end sentences are both relevant to the topic structure of a text. As discussed earlier, substantial evidence exists that readers update their topic structure representations as a component of processing topic sentences. The processing of paragraph-ending sentences has not been studied, but there are theoretical reasons for distinguishing end sentences. Namely, end sentences are likely locations of wrap-up or “unitization” processing (Britton, 1994). Finally, the medial sentences of a paragraph are not generally directly relevant to the topic structure so they serve as a baseline for comparison with topic and end sentences.

Consider how topic processing might be revealed in eye movements for texts *without headings*. We have already established that the processing of a topic sentence entails the representation of the new topic, and the computation and representation of its relationship to previous text topics. In sentence-by-sentence presentation procedures, these processes result in slow reading of topic sentences relative to medial sentences (e.g., Lorch et al., 1985). In the case of eye movement records, the extra processing associated with topic sentences could be revealed in various ways. First-pass processing should be longer for topic sentences than for

medial sentences, primarily because reinspective fixations should be relatively frequent for topic sentences. In addition, there may be more backtracking from topic sentences to earlier parts of the texts compared to medial sentences. Looks back from topic sentences to preceding parts of the text would be expected to the extent that readers need to be reminded of the previous text topic.

Paragraph-ending sentences are also potentially relevant locations for topic structure processing. If readers engage in unitizing activities at the ends of paragraphs (Britton, 1994; Kintsch, 1998), processing of end sentences may differ from processing of medial sentences in a couple of ways. Again, first-pass processing of end sentences should be slow, particularly because of more reinspective fixations. Also, readers may look back from end sentences to earlier parts of the text to check information that may be relevant to the construction of a macroproposition to summarize the paragraph or section content. Of particular interest is the possibility that readers will look back from end sentences to topic sentences.

Finally, consider how topic processing may be altered for texts *with headings*. Headings serve several functions with respect to communicating the topic structure of a text (Lorch, 1989). They unambiguously demarcate subsections of a text. They explicitly label the upcoming topic of the text. And they often provide information about the hierarchical location of the new topic within the topic structure of the text, thus aiding readers in the determination of the relationship of the new text topic to preceding text topics. In short, headings provide topic structure information that would otherwise need to be inferred in the course of processing a topic sentence. Thus, including headings in a text should reduce the differences between topic and medial sentences compared to a text without headings. It is less clear, however, how the presence of headings should influence the processing of paragraph-ending sentences. Assuming that we find evidence of extra processing of end sentences compared to medial sentences in the texts without headings, the presence of headings may either reduce or increase the difference. One possibility is that unitization processing might shift from end sentences to headings, which would result in a smaller difference between end and medial sentences in the text with headings. Alternatively, the presence of a clear demarcation point between subsections (i.e., headings) may increase the likelihood that readers will engage in unitizing processes at the end of a section. If that happens, it would result in a larger difference between end and medial sentences in the text with headings.

## 2. Method

### 2.1. Subjects

A total of 66 students of the University of Turku participated in the experiment. All were native speakers of Finnish. Seven participants had to be excluded due to poor calibration or equipment failure.

### 2.2. Apparatus

Eye movements were collected by the EYELINK eyetracker manufactured by SR Research Ltd. (Canada). The eyetracker is an infra-red video-based tracking system combined with hyperacuity image processing. There are two cameras mounted on a headband (one for each eye) including two infra-red LEDs for illuminating each eye. The headband weighs 450 g in total. The cameras sample pupil location and pupil size at the rate of 250 Hz. Registration is monocular and is performed for the selected eye by placing the camera and the two infra-red light sources 4–6 cm away from the eye. The resolution of eye position is 15″ of arc and the spatial accuracy is better than 0.5°. Head position with respect to the computer screen is tracked with the help of a head-tracking camera mounted on the center of the headband at the level of the forehead. Four LEDs are attached to the corners of the computer screen, which are viewed by the head-tracking camera, once the subject sits directly facing the screen. Possible head motion is detected as movements of the four LEDs and is compensated for on-line from the eye position records. The system allows free head motion within a 100 cm cube.

### 2.3. Materials

Two multiple-topic expository texts were used as stimuli, the Energy and Endangered Species text. The Energy text on environmental damage and alternative energy sources was adopted from Lorch and Lorch (1996) and translated into Finnish. The text was approximately 1200 words long. The text began with a short introduction, then discussed 12 distinct topics organized into two major sections. The first section was on major problems associated with our current patterns of energy use. It discussed six types of problems, including dwindling fuel sources, pollution, acid rain, storage of radioactive waste, the greenhouse effect, and health problems. The second major section of the text was on alternative energy sources. It discussed six types of energy sources, including: geothermal energy, ocean thermal power, solar energy, tidal power, wind power, and waste as an energy source. Each topic contained two paragraphs, each of which discussed a different aspect of the topic. The text ended with a short conclusion section.

The Endangered Species text was written with the help of wildlife encyclopaedias. The text described 10 species whose existence is threatened for different reasons. The text began with a short introduction, then discussed the 10 topics organized into two major sections. The first major section was on endangered birds, and it discussed five birds (lesser white-fronted goose, peregrine falcon, sea-eagle, parrot, and penguin) each in its own section. The second major section was on endangered mammals, and it consisted of a discussion of five endangered mammals (Russian flying squirrel, panda, whales, bats, spotted cats). The text ended with a short conclusion section.

Two versions were created for both texts, one with headings and one without headings. In the version with headings, each text topic was preceded by a heading that labeled the topic (e.g., ''wind power'', ''pandas'', etc.). The headings were

presented on a separate line in bold-face. The other version was identical in every other respect except that all topic headings were deleted. The text was presented double-spaced on the computer screen, with a maximum of 12 lines of text at a time. Half of the topic breaks coincided with screen breaks (i.e., both topic paragraphs appeared on the same screen); for the other half, the screen break occurred between the two topic paragraphs. The screen breaks were identical for the two heading conditions. The Energy text contained 19 screens and the Endangered Species text 17 screens of text. Each participant read a text with headings and another without headings. The two text versions and their presentation order were counterbalanced across participants. Fifteen participants were included in three of the four counterbalancing groups; one group included 14 participants.

### 2.4. Procedure

Before the actual experiment, the eyetracker was calibrated for each participant. Participants were instructed to read the text to be able to summarize afterwards the main contents. Reading was self-paced with the restriction that returning to a previous page was prevented. A short practice trial preceded the first text to adjust the participants to the eyetracking equipment and to present the instructions. After the participants had read both texts, they wrote a summary of the main contents of the texts. It was decided not to have participants write a summary immediately after reading each text for two reasons. First, if participants had written a summary after reading the first text, it would have been necessary to recalibrate before continuing on to the next text. Second, it was feared that the act of writing the first summary might change participants' reading strategies for the second text (cf., Lorch et al., 1985). The participants were allowed to leave whenever they had finished the second summary; the total time of the experimental session was about 1 h 15 min.

## 3. Results

### 3.1. Text summary measures

Although we were primarily interested in the effects of headings on on-line comprehension processes, an analysis was also conducted on the text summaries to see whether topic headings had an impact on the mental representations that readers constructed of the texts. As the final step of the experimental session, participants were asked to write a summary of the two texts they read. Two judges scored which text topics were represented in each participant's summary. A topic was considered to be represented in a summary if at least one idea unit (corresponding roughly to the core meaning of a sentence in the text) subordinate to the topic was identified in the summary protocol. We analyzed both the number of topics represented in the summary ("topic access") and the correlation between the order of topics in the summary with the order of the same topics in the text ("topic order"),

Table 1
Means and standard deviations (in parentheses) of text summary measures for the two text versions (headings vs. no headings)

| | Headings | No headings |
|---|---|---|
| Topic access[a] | 70.9 (21.6) | 65.1 (21.8) |
| Topic order[b] | 0.646 (0.425) | 0.619 (0.483) |

[a] percentage.
[b] Spearman correlation.

(Lorch et al., 1993). The means and standard deviations for the two summary measures are given in Table 1. A pairwise $t$ test was performed on the two summary measures. For the topic access measure, a reliable difference emerged between the two text types, $t(58) = 2.49$, $p < 0.05$. More topics were included in the summaries of the text with headings. There was no effect of headings on the topic order measure, $t < 1$.

In sum, the effect of headings on topic access is consistent with findings from previous studies of text recall and text summarization (Lorch et al., 1993; Lorch, Lorch, Ritchey, McGovern, & Coleman, 2001). This suggests that participants' processing strategies in the current eyetracking experiment were similar to the processing strategies of readers presented similar texts in a less constrained, more naturalistic situation.

### 3.2. Dependent measures

Detailed records of eye fixation patterns were recorded for the different sentences of each topic section. In Fig. 2, an example of a topic section with heading is depicted. Eye fixation measures were computed for the topic and final sentences of the two topic paragraphs, as well as for the paragraph-medial sentences (i.e., excluding the initial and final sentence of the paragraph). Thus, sentence was the analysis unit for the different topic sections except for paragraph-medial segments, which consisted of several sentences. The medial sentences served as a baseline for comparison to topic and end sentences because the medial sentences did not serve any function with respect to the topic structure of the text. When a target segment consisted of a single sentence (i.e., topic and end sentences), it subtended 1–2 lines of text, depending on the sentence length.

Five measures were computed for each of the target text segments (see Fig. 1; see also Hyönä et al., 2002, 2003): (1) first-pass fixation time (the summed duration of fixations landing on a sentence when it is read through for the first time), (2) first-pass forward fixation time (the summed duration of fixations that land on unread regions of the sentence during its initial reading), (3) first-pass rereading time (the summed duration of fixations that land on already processed portions of the sentence during its initial reading), (4) look-back fixation time (the summed duration of look-back fixations to a sentence from an another sentence, and (5) look-from fixation time (the summed duration of look-backs launched from a sentence to another sentence). The first three measures index more immediate effects in proces-

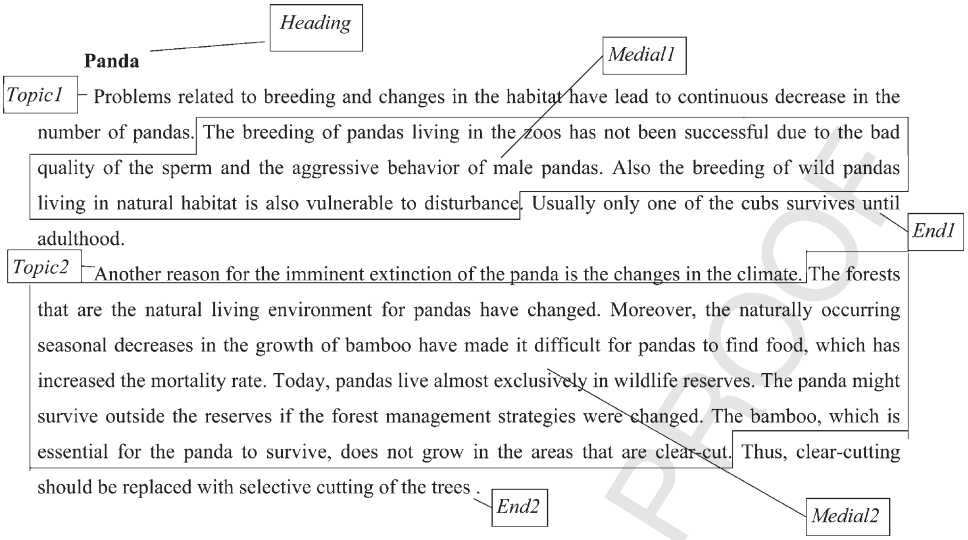


Fig. 2. An example of a topic section with heading of the Endangered Species text showing the different text segments used in the analyses.

sing, whereas the latter two reflect more delayed effects. First-pass fixation time is a composite score of first-pass forward fixation time and first-pass rereading time. Look-back fixation time indexes the destination of look-backs, whereas look-from fixation time reveals the origin of look-backs. The former look-back measure reflects the time taken to reprocess a text segment, whereas the latter measure provides an index of the extent to which a text segment is used as an "anchor point" for processing other text segments. To control for the differences in sentence length, all fixation time measures were converted to time-per-character measures.

### 3.3. Fixation times on topic headings

To demonstrate that topic headings were indeed properly attended to when they were present, we first report average fixation times on topic headings. The average first-pass fixation time was 53.1 ms (sd = 28.1), the average look-back fixation time was 16.9 ms (sd = 18.9), and the average look-from fixation time was 16.3 ms (sd = 27.3). These values are notably larger than those for the other text regions (see Figs. 3–7), which clearly demonstrates that topic headings received special attention from the readers.[1]

[1] The fact that the fixation time measures were adjusted for length may have exaggerated differences between headings and the other sentence types, because for short text segments, such as headings, the relationship between reading time and segment length in characters is not perfectly linear (see Trueswell, Tanenhaus, & Garnsey, 1994). Nevertheless, it is clear that topic headings were properly attended during reading.

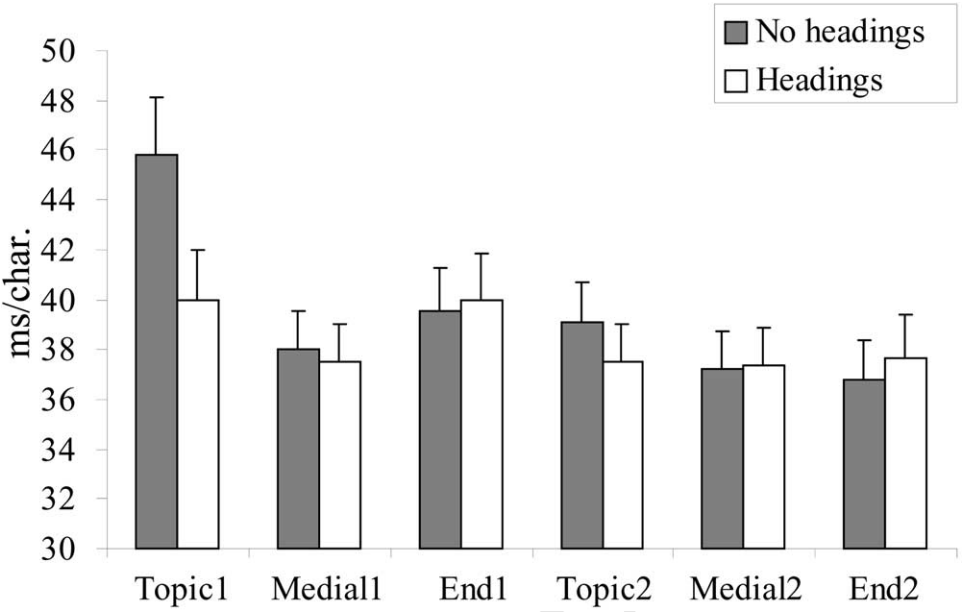


Fig. 3. Mean first-pass fixation time (+SE) in milliseconds (ms) per character (char.) for the different sentences of the text with and without topic headings. Topic1, topic sentence of first paragraph of each topic; Medial1, medial sentences of first paragraph; End1, final sentence of first paragraph of each topic; Topic2, topic sentence of second paragraph of each topic; Medial2, medial sentences of second paragraph; End2, final sentence of second paragraph of each topic.

### 3.4. Statistical analyses of the target sentences

Univariate analyses of variance were computed on the eye fixation measures using text type, sentence type and paragraph all as within-subject variables. Text type has two levels, a text with headings and a text with no headings; there were three sentence types, topic sentences, paragraph-medial sentences, and paragraph-final sentences; each topic section consisted of two paragraphs. In the following, the results are reported separately for the different fixation time measures mentioned above. Type III sums of squares were used to evaluate all effects because the number of participants per counterbalancing condition was not equal (although nearly so). Whenever necessary, a Greenhouse–Geisser correction was applied to the $p$ values.

In all the analyses to be reported, recall that our basic interest is in the interaction of Text type with Sentence type. More specifically, we predict that topic sentences will be processed more extensively than medial sentences in texts without headings, but that the difference will be reduced in texts with headings. In addition, if readers unitize their representations of a section at end sentences, end sentences should be processed more extensively than medial sentences in texts without headings, but the difference should be reduced in texts with headings. However, we also

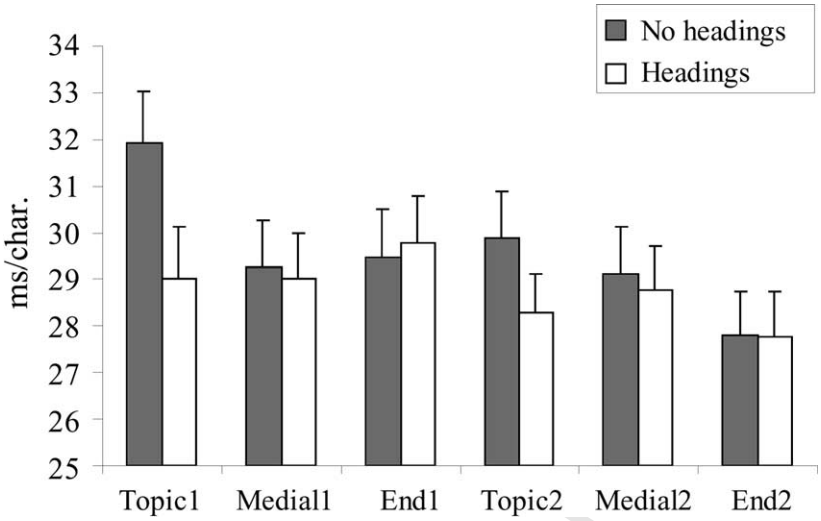


Fig. 4. Mean first-pass forward fixation time (+SE) in milliseconds (ms) per character (char.) for the different sentences of the text with and without topic headings. Topic1, topic sentence of first paragraph of each topic; Medial1, medial sentences of first paragraph; End1, final sentence of first paragraph of each topic; Topic2, topic sentence of second paragraph of each topic; Medial2, medial sentences of second paragraph; End2, final sentence of second paragraph of each topic.

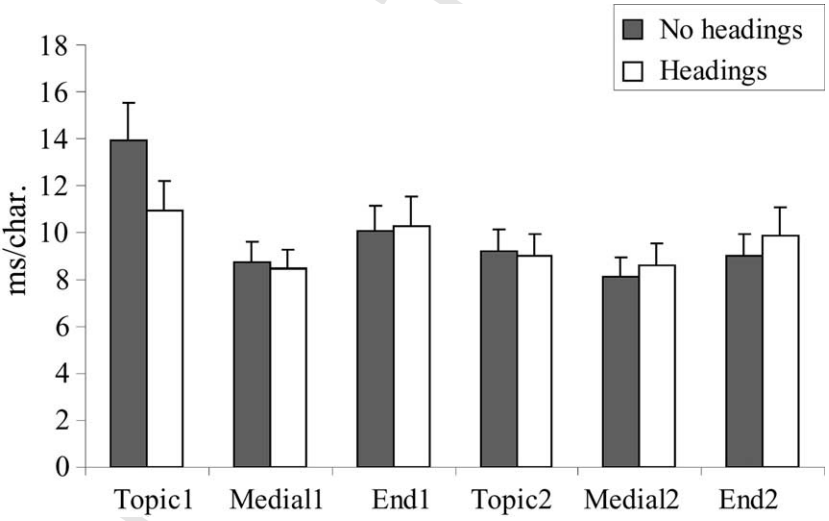


Fig. 5. Mean first-pass rereading time (+SE) in milliseconds (ms) per character (char.) for the different sentences of the text with and without topic headings. Topic1, topic sentence of first paragraph of each topic; Medial1, medial sentences of first paragraph; End1, final sentence of first paragraph of each topic; Topic2, topic sentence of second paragraph of each topic; Medial2, medial sentences of second paragraph; End2, final sentence of second paragraph of each topic.

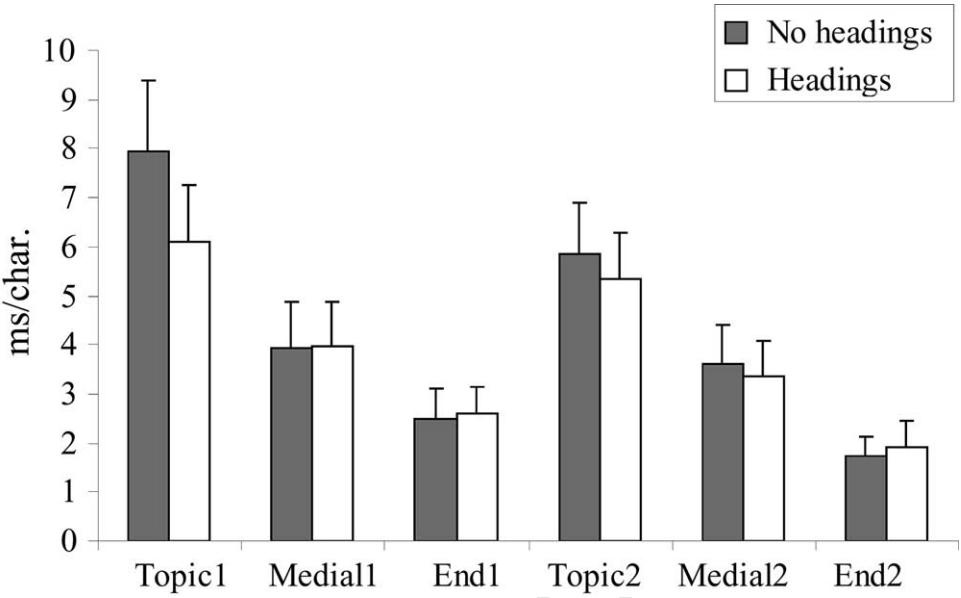


Fig. 6. Mean look-back fixation time (+SE) in milliseconds (ms) per character (char.) for the different sentences of the text with and without topic headings. Topic1, topic sentence of first paragraph of each topic; Medial1, medial sentences of first paragraph; End1, final sentence of first paragraph of each topic; Topic2, topic sentence of second paragraph of each topic; Medial2, medial sentences of second paragraph; End2, final sentence of second paragraph of each topic.

suggested that the opposite pattern might be observed for end sentences. That is, if readers do not systematically unitize in texts without headings, they may be more likely to do so when headings are present and, thus, the difference between end and medial sentences would be larger for texts with headings than for texts without headings.

### 3.5. First-pass fixation time

The means for first-pass fixation time are plotted in Fig. 3. The main effect of sentence type, $F(2,116) = 8.59$, $p = 0.001$, and the main effect of paragraph, $F(1,58) = 32.89$, $p < 0.001$, both proved significant. Topic sentences were read with longer first-pass fixations times than other sentence types, and first paragraphs were read with longer first-pass fixation times than second paragraphs. All two-way interactions reached significance: Sentence type × Paragraph, $F(2,116) = 9.57$, $p < 0.001$, Text type × Sentence type, $F(2,116) = 14.11$, $p < 0.001$, Text type× Paragraph, $F(1,58) = 6.74$, $p = 0.01$. These interactions were further qualified by a three-way interaction, Text type × Sentence type × Paragraph, $F(2,116) = 4.68$, $p = 0.01$. As it appears from Fig. 3, the effect of topic headings is restricted to topic sentences (i.e., the source of the Text type × Sentence type interaction), with the effect being more robust for the first than second topic sentence. Pairwise $t$ tests

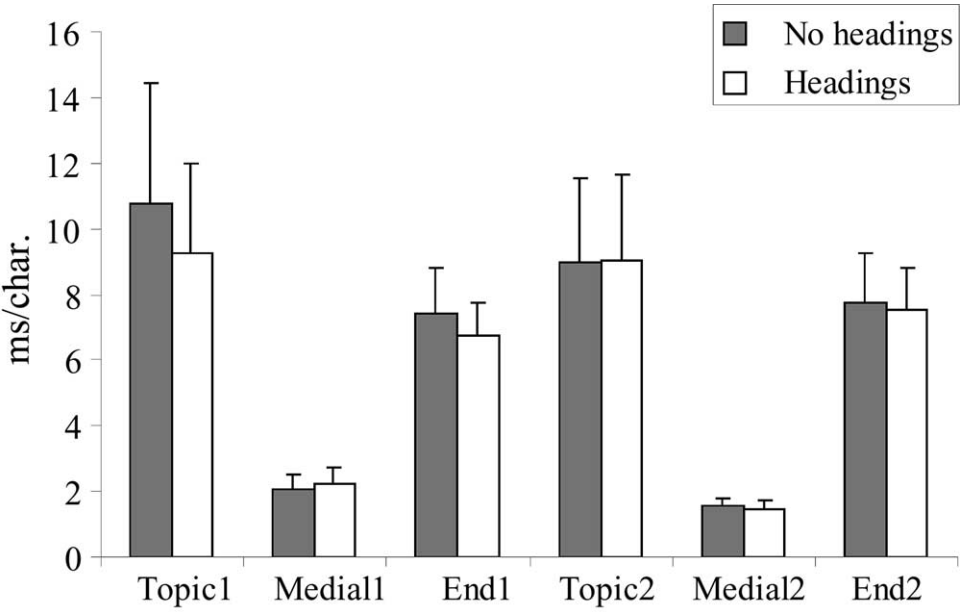


Fig. 7. Mean look-from fixation time (+SE) in milliseconds (ms) per character (char.) for the different sentences of the text with and without topic headings. Topic1, topic sentence of first paragraph of each topic; Medial1, medial sentences of first paragraph; End1, final sentence of first paragraph of each topic; Topic2, topic sentence of second paragraph of each topic; Medial2, medial sentences of second paragraph; End2, final sentence of second paragraph of each topic.

yielded a reliable effect of heading for the first topic sentence, $t(58) = 3.70$, $p < 0.001$, and a nearly significant effect for the second topic sentence, $t(58) = 1.84$, $p = 0.07$. Thus, headings facilitated the processing of topic sentences, particularly the first topic sentence.

First-pass fixations were further divided into forward and reinspective fixations to yield forward fixation and reinspection times.

### 3.6. First-pass forward fixation time

The means for the first-pass forward fixation time are presented in Fig. 4. For the forward fixation time, all main effects proved significant: text type, $F(1, 58) = 4.20$, $p < 0.05$, sentence type, $F(2, 116) = 4.84$, $p < 0.05$, and paragraph, $F(1, 58) = 40.71$, $p < 0.001$. The main effects were qualified by two interactions. First, there was an interaction of Text type with Sentence type, $F(2, 116) = 14.19$, $p < 0.001$, reflecting the fact that the effect of headings was restricted to topic sentences. Pairwise $t$ tests confirmed that the heading effect was separately reliable both for the first, $t(58) = 3.31$, $p < 0.01$, and the second topic sentence, $t(58) = 2.84$, $p < 0.01$. Second, there was a Sentence type × Paragraph interaction, $F(2, 116) = 9.38$, $p < 0.001$, reflecting that fact that topic and end sentences were processed faster in

the second paragraph than in the first paragraph, whereas the processing of medial sentences did not change over paragraphs.

### 3.7. First-pass rereading time

The means for the first-pass rereading time are presented in Fig. 5. For the rereading time, there was a significant main effect of sentence type, $F(2,116) = 7.72$, $p = 0.001$, and of paragraph, $F(1,58) = 17.57$, $p = 0.001$. These main effects were qualified by interactions of Text type × Sentence type, $F(2,116) = 6.34$, $p < 0.01$, a Text type × Paragraph, $F(1,58) = 6.58$, $p = 0.01$, and a Sentence type × Paragraph, $F(2,116) = 8.02$, $p = 0.001$. The Text type × Sentence type interaction reflects the fact that the heading effect is restricted to the topic sentences. As may be seen from Fig. 5, the effect of heading seems evident only for the first topic sentence. However, the three-way interaction that is implicated did not quite reach significance, $F(2,116) = 2.36$, $p < 0.1$. A pairwise $t$ test showed that the heading effect was only significant for the first topic sentence, $t(58) = 2.75$, $p < 0.01$. The Text type × Paragraph interaction reflects the fact that the effect of headings is restricted to the first paragraph. Finally, the Sentence type ×Paragraph interaction implies that the processing speeded up from first to second paragraph primarily for the topic sentences.

### 3.8. Look-back fixation time

The means for the look-back fixation time are presented in Fig. 6. For look-back fixation time, the main effect of sentence type, $F(2,116) = 31.43$, $p < 0.001$, and the main effect of paragraph, $F(1,58) = 14.20$, $p < 0.001$, proved significant. There was also a nearly significant Text type × Sentence type interaction, $F(2,116) = 3.04$, $p = 0.07$. The interaction is due to the heading effect being restricted to topic sentences. A follow-up $t$ test yielded a reliable heading effect for the first topic sentence, $t(58) = 2.08$, $p < 0.05$, but not for the second topic sentence, $t < 1$.

### 3.9. Look-from fixation time

The means for the look-from fixation time are presented in Fig. 7. These data revealed only one significant effect, a main effect of sentence type, $F(2,116) = 7.98$, $p < 0.01$. The effect is due to the fact that look-back fixations were initiated more often from topic and end sentences than from paragraph-medial sentences.

## 4. Discussion

In the Introduction, we made two predictions with regard to the effects of headings on on-line text processing. First, we expected topic headings to speed up the processing of topic sentences (i.e., the sentences that introduce a new topic in the text). Second, we expected topic headings to modulate the degree of integrative wrap-up processing at topic or paragraph boundaries. The data lent strong support

for the first prediction but no support for the second prediction. Headings speeded up the initial processing of topic sentences, particularly the first topic sentences that introduced a new text topic. This was seen both in the forward and reinspective fixations made during the first-pass reading. Also, the need to look back to topic sentences was less with headings. However, topic headings did not influence the degree of wrap-up processing at section boundaries, as was evident in the first-pass rereading time and in the look-from fixation time for the paragraph-final sentences. Although there were clearly more look-back fixations initiated from the final than the medial sentences (the same pattern was apparent for the first-pass rereading time), the presence of headings did not seem to influence this aspect of the reading behavior.[2] To sum up, we found headings to facilitate the processing of topic sentences, but we did not observe any effects of headings on wrap-up activity at paragraph or topic boundaries.

Based on the evidence summarized above, we would like to outline a sketch of how competent, adult readers read and comprehend multiple-topic expository texts. Adopting the structure building framework of Gernsbacher (1990) and Britton's (1994) elaboration, topic structure processing can be described as follows:

1. Readers actively look for (or infer, if needed) the currently relevant text topic. When a new text topic is identified, a new memory slot is opened for it. Headings are salient and unambiguous signals of new topics so they facilitate topic identification. When headings are not provided, topic sentences play a more important role in identifying a new topic so that is why they are processed more extensively than other sentences.
2. Once a topic is identified, it is used as a mental frame or substructure around which subsequent text information is integrated. That is why readers look back to and from headings (when they are provided) and topic sentences.
3. The processing goes smoothly until something in the text signals a potential shift in topic. Paragraph breaks are an indication of a likely shift of topic, but headings unambiguously signal a shift. When a (potential) topic shift is identified, information concerning the current topic is integrated and the currently active mental frame is terminated. These topic wrap-up processes are reflected in additional look-backs launched from topic-final sentences and in look-backs from paragraph-final sentences of the first topic paragraphs. The finding that the presence of headings did not increase topic wrap-up processing at these structural boundaries appears to be at odds with the above reasoning. We believe that the lack of a reliable effect of headings has to do with the way text was presented on the computer screen. The eyetracking technique allowed us to present a maximum of two paragraphs per page. Thus, a page break always coincided with a paragraph break. Readers are likely to have engaged in wrap-

[2] The finding that look-from fixation time is also inflated for topic sentences primarily reflects the increased number of look-backs directed to them. This is because the look backs to topic sentences were often accompanied by subsequent look backs to other text segments initiated from topic sentences.

up processing at page breaks because they could not return to a page once they had left it. If such an effect occurred, it would have tended to obscure effects of headings on wrap-up processing.

4. The processing cycle described above is then repeated for the new text topic. The outcome of such processing is an internal representation of the text in which text information is organized around the text topics. One implication of this would be that more topics are represented when the text's topic structure is signaled by topic headings. This prediction was supported by our findings. It would also imply that with headings provided, the order of topics in the internal representation should more closely mimic that of the actual text. Although the results were in the predicted direction, the effect was not significant. In fact, signaling effects on topic order have not always been statistically reliable in previous studies (Sanchez et al., 2001), although they are consistently in the predicted direction. In fact, even when texts lack organizational signals, readers are generally quite good at reproducing the order of topics at recall. Thus, perhaps it is not surprising that signals often have relatively weak effects on memory for topic order.

To what extent does the processing strategy outlined above characterize all competent readers? We have reason to believe that a good proportion of adult readers may not be genuine "topic-structure processors". Hyönä et al., (2002) examined individual reading strategies of university students who read texts analogous in structure to the one used in the present study while their eye movement patterns were registered. Only about 20% of the their participants displayed a strategy indicative of systematic and extensive use of the text's topic structure, such as paying particular attention to topic headings and looking frequently back to topic sentences or topic headings when reaching a topic boundary. The majority of readers was characterized as linear readers, who showed in their reading pattern relatively few signs of sensitivity to the text's topic structure. Clearly, adult readers differ in the extent to which they systematically adhere to a topic structure strategy (see also Lorch & Lorch, 1986). Yet, adults are found to demonstrate greater sensitivity to the topic structure than children (Hyönä, 1994).

There is also evidence to suggest that topic structure processing may be at least to some extent strategic in nature. Sanchez et al., (2001) demonstrated that training in the structure strategy led to its increased use, as indexed by the recall performance (i.e., the number and order of topics mentioned in the recall protocols). It is also possible that the reading goal may influence the degree of topic structure processing. When readers comprehend a text in preparation for writing an outline, they may be more likely to adhere to a structure strategy than when they read in preparation for a multiple choice test. Thus, even though the above outlined reading strategy may give a good approximation of the kind of processing done, it is quite clear that task demands and individual differences may significantly influence the extent to which it is applied during text comprehension.

Finally, the influences of signaling devices seem likely to depend on a variety of text factors and reader characteristics. Signals have greater benefits for text recall if

the text's topic structure is relatively complex (i.e., discusses more topics and involves more hierarchical levels) than if the text's topic structure is relatively simple (Lorch et al., 1993). In addition, signals have greater effects on text memory when other influences on memory for topics are lacking (i.e., prior familiarity with topic and extent of elaboration of topic; Lorch & Lorch, 1996a; Lorch et al., 1993). We may speculate that signals may have greater benefits for comprehension and memory when the topics of a text are not easily identified in a text (e.g., not explicitly stated or not introduced in paragraph-initial position) than when they are easily identified (Kieras, 1981). With respect to reader characteristics, sophisticated readers who regularly use systematic topic-processing strategies are less likely than relatively unsophisticated readers to benefit from the presence of signals like headings because they do not need the "crutch" provided by the signals (Meyer et al., 1980; Sanchez et al., 2001). In short, we can expect that a variety of text and reader variables will be found to moderate the effects of signaling devices on reading and memory. Nevertheless, signals had clear effects on text-processing in the current investigation—even with its relatively simple texts and relatively sophisticated readers.

To conclude, topic headings were observed to be powerful signaling devices that facilitate on-line comprehension processes and improve memory for text topics. The extent of their influence may come as a surprise, as topic headings are single noun phrases ("pandas", "wind power", etc.) that simply mention the upcoming new topic. Thus, they notably differ from more elaborate signaling devices (e.g., advanced organizers). As we have argued above, their effectiveness lies in the fact they provide a mental frame into which upcoming text information may be integrated.

## 5. Uncited references

Murray and McGlone (1997), Goldman and Saul (1990) and Lorch, Lorch, and Klusewitz (1995).

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## Appendix A. Excerpt from an expository text

Energy problems and solutions

Since the Industrial Revolution, developed countries have relied increasingly on the production of energy to maintain their economies. The fossil fuels of coal, oil

and gas share several important characteristics that helped establish them as favored energy sources. They are all relatively abundant and accessible natural resources. In addition, they are transportable and the technology to convert them to energy is relatively inexpensive. Since its development beginning in the 1950's, nuclear power has become an important energy source for the same reasons that the fossil fuels are so prominent. In recent years, however, we have witnessed some of the limitations of fossil fuels and nuclear power. Because of our society's addiction to cheap energy, we are now confronted by immense problems. In this article, we will first consider some of the major problems associated with our current patterns of energy use, then we will discuss some possible approaches to solving those problems.

Fossil fuels are increasingly hazardous and expensive to produce. Coal, oil, and gas are not as accessible as they once were. Miners must dig ever deeper to recover coal reserves and that means greater danger to the miners. For similar reasons, drilling for oil and gas has become more dangerous. The development of nuclear power received a boost from the realization that fossil fuel supplies are limited. However, the safety of nuclear technology is a major concern. The most striking example is the Chernobyl disaster, which will have environmental and health consequences for years to come.

The decreasing availability of conventional fuels has made them more expensive. This is because it is more costly to produce them and because it puts the seller in a powerful position. Ironically, it is increasing costs that are the strongest motivation to seek alternative energy sources.

Our energy habits result in extensive pollution of air and water. The burning of fossil fuels is a major source of air pollution. Fossil fuels contribute various particulates to our atmosphere, including sulfur dioxide, carbon monoxide, ozone and lead. In the US, nearly half of the population lives in areas with unhealthy air. In the case of smog ozone alone, approximately one-third of the population live in areas where ozone regularly exceeds acceptable levels.

Oil spills by supertankers have caused much damage to ocean ecologies. As one example, consider the spill in Alaska by the Exxon Valdez. To put the accident in perspective, an equivalent spill along the eastern coast...

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