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Individual Differences in Reading to Summarize Expository Text: Evidence From Eye Fixation Patterns

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Eye fixation patterns were used to identify reading strategies of adults as they read multiple-topic expository texts. A clustering technique distinguished 4 strategies that differed with respect to the ways in which readers reprocessed text. The processing of fast linear readers was characterized by the absence of fixations returning to previous text. Slow linear readers made lots of forward fixations and reinspected each sentence before moving to the next. The reading of nonselective reviewers was characterized by look backs to previous sentences. The distinctive feature of topic structure processors was that they paid close attention to headings. They also had the largest working-memory capacity and wrote the most accurate text summaries. Thus, qualitatively distinct reading strategies are observable among competent, adult readers.

Since Kintsch and van Dijk's (1978) seminal theory, a considerable amount of cognitive research on reading has focused on the moment-to-moment processes responsible for relating the entities and ideas expressed in a sentence to the entities and ideas previously established in the reader's text representation. For example, there has been a great deal of work on how readers process anaphora (e.g., Garrod & Sanford, 1994), as well as a substantial body of research on the processing of causal relations in narrative (for a review, see Graesser, Bertus, & Magliano, 1995). A compelling motivation for the theoretical and empirical focus on the microprocesses of reading is that they are assumed to be the core processes underlying processing in all reading tasks entailing meaningful comprehension (McKoon & Ratcliff, 1992).

Despite their preoccupation with the microprocesses of reading, theorists have from the beginning (Kintsch & van Dijk, 1978) acknowledged that the particular global processing strategy adopted by a reader will surely have pervasive effects on microprocessing and on the nature of the mental representation constructed by the reader. Nevertheless, this likelihood has generally been treated as a nuisance with respect to the goal of modeling the microprocesses of reading. Thus, researchers have generally attempted to minimize the influence of global processing strategies by investigating reading under circumstances that do not require such strategies (e.g., brief, simple texts read for very simple purposes). Given the focus on microprocesses, this research strategy is an intelligent one; our goals, however, are different. The goal of the current investigation is to provide an initial characterization of the global processing strategies used by different readers under the same reading conditions.

There has been some research on adult readers' global processing strategies for both expository (Fletcher, 1986) and narrative text (Fletcher & Bloom, 1988). This work has modeled alternative processing strategies and fit them to average recall and average reading time data of adult readers. The implicit assumption of this approach is that a model based on averaged data will describe the modal processing strategy of typical readers. Rather than subscribing to this assumption, we wish to allow for the possibility of systematic individual differences in global processing strategies. Thus, we decided to use an inductive approach to identifying alternative processing strategies (Klusewitz & Lorch, 2000). We chose for investigation a reading situation that is likely to evoke systematic individual differences in processing strategies. Specifically, we examined adult readers' processing of sentences relevant to the topic structure of an expository text.

Processing the Topic Structure of a Text

Consider some of the demands faced by a reader who is attempting to understand an expository text. A typical expository text is constructed around a global topic (e.g., energy issues) that is developed in a hierarchically related set of topics (e.g., environmental threats, alternative energy sources) and subtopics (e.g., oil

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spills and air pollution, geothermal energy and wind power). Comprehension of an expository text requires not only that readers represent what is communicated about each subtopic, but that they also aim to identify the text's topics and subtopics and their relationships. An important challenge to representing a text's topic structure is that the topics may often be developed relatively independently of one another. That is, although several subtopics may be directly linked to a common superordinate, the choice of subtopics for inclusion in the text may be rather arbitrary (e.g., not all alternative energy sources need be discussed). In addition, the sequencing of subtopics may also be arbitrary (i.e., do not possess an inherent order). To compound matters, the transitions between topics are often abrupt in the sense that most of the text is devoted to elaborating the subtopics rather than to elaborating the relations among topics. Therefore, to adequately represent the topic structure of a text, a reader must be alert to the introduction of new topics and to the need to represent their place in the text's topic structure.

Studies of readers' on-line processing of topic structure information have shown that sentences introducing a new discourse topic or episode are allocated more processing time than sentences that are continuations of the same topic or episode (Haberlandt, 1980; Haberlandt, Berian, & Sandson, 1980; Hyönä, 1995; Kieras, 1981; R. F. Lorch, Lorch, & Matthews, 1985; R. F. Lorch, Lorch, & Morgan, 1987; Mandler & Goodman, 1982). Furthermore, the effect on sentence reading times of a shift of topic is larger when the shift is relatively major (i.e., both the subtopic and relevant superordinate topic change) than when the shift is relatively minor (i.e., the subtopic changes but the superordinate remains the same; R. F. Lorch et al., 1985, 1987; Vauras, Hyönä, & Niemi, 1992). Sensitivity to topic shifts while reading has been observed for elementary-school-aged readers (Hyönä, 1994; E. P. Lorch, Lorch, Gretter, & Horn, 1987) and for adult readers at various skill levels (R. F. Lorch et al., 1985, 1987). In short, readers generally pay close attention to newly introduced topics and their relations to preceding text topics.

There are many possible reasons why topic sentences command extra attention from readers. Some of those reasons are irrelevant to global processing strategies. For example, topic sentences typically introduce a good deal of new information, requiring readers to spend additional resources to represent the new information (Haberlandt & Graesser, 1989). However, there is also good evidence that topic processing involves an optional, strategic component. First, the magnitude of the topic shift effect depends on the degree to which the readers' task makes topic information relevant (R. F. Lorch et al., 1985, 1987). Second, when topic boundaries are signaled (e.g., with number signals or topic headings), more processing time is devoted to topic sentences and the probability of including a topic in a summary is increased (R. F. Lorch & Chen, 1986; R. F. Lorch & Lorch, 1996). Finally, and most important in this context, there are systematic individual differences in the degree to which readers demonstrate on-line sensitivity to a text's topic structure. Hyönä (1994) demonstrated that with difficult expository texts, adults manifest a proportionately greater topic-shift effect than do 5th-grade children. Similarly, R. F. Lorch et al. (1987) observed a more pronounced topic-shift effect for better than for poorer adult recallers.

Individual Differences in Global Processing Strategies

Although it is well established that readers differ in their sensitivity to topic relevant information while reading, there are only suggestive findings concerning the range of global processing strategies used by different readers. The preceding portrayal of the average topic processing strategy is a plausible hypothesis about how competent readers are likely to process topic information. To elaborate, a smart topic processing strategy would be to use paratextual cues (e.g., paragraph structure), signaling devices (e.g., headings), syntactic cues (e.g., sentence structures that indicate topic transitions), and coherence breaks to help identify new topics. Once a new topic is identified, the reader constructs a representation of the new topic and its relationship to prior text topics. The literature reviewed above provides some support for such a strategy. In addition, Pressley and Afflerbach (1995) reviewed 38 studies in which reading strategies were investigated using a think-aloud method. According to their review, some readers explicitly mention that they look for topic sentences when trying to find important information in a text. Skilled readers also take notice of the ends of text sections. Furthermore, they frequently report going back in a text to look for particular information and to search for intersentential connections.

One of the few studies to have examined on-line strategies for reading expository texts provides support for these introspections. Goldman and Saul (1990) used a sentence reading time task with a backtracking option (i.e., readers were able to go back in text while these backtracks were recorded). One of the strategies they observed readers using involved systematically backtracking within the text to a single sentence; typically, the target of such regressions stated one of the main points in text or was a sentence elaborating a main point. Related to this finding, Vauras et al. (1992) demonstrated that when reading incoherently structured episodes, readers looked back from the episode-final sentence to the initial sentence, presumably to resolve the incoherent episode structure. Integrating these observations, we can speculate that many competent readers use a *selective processing strategy* in which they devote additional processing resources at junctures in a text that are likely to represent transitions between topics (e.g., headings, topic sentences, and paragraph- and section-ending sentences).

Not all readers are expected to use a selective processing strategy. At the opposite extreme, some readers may pay no special attention to topic relevant information. This possibility may be realized in either of two ways. One such *nonselective processing strategy* would be to read a text straight through with (a) no additional attention to headings or topic-introducing sentences, (b) no additional attention to paragraph- or section-ending sentences, and (c) no rereading of previous sentences (see R. F. Lorch et al., 1987). The other nonselective processing strategy would involve rereading information, but with no particular attention to topic structure relevant sentences. Rereadings could take at least two forms: (a) rereading each sentence (or part of it) before moving on, or (b) reading each paragraph or topic section once through followed by rereading of the whole paragraph (or most of it). Goldman and Saul (1990) found evidence of both general types of nonselective reading. Some of their readers adopted a once-through style of reading in which they did no backtracking as they read. Other readers used a review style of reading in which they read the text straight through until the end, then backtracked and skimmed or reread previously read text segments with no special attention to topic relevant statements.

Inducing Processing Strategies From Eye Fixation Data

We have hypothesized three different global processing strategies for expository text. First, some readers may use a selective processing strategy in which topic structure relevant statements receive extra processing both on initial reading and in rereading. Second, some readers may use a nonselective processing strategy in which topic structure relevant statements receive no additional processing on initial reading and there is no rereading. Third, other readers may use a nonselective processing strategy in which rereading is common, but topic structure relevant statements are not singled out for special attention at any point during reading. Although these three strategies seem plausible, there is no conclusive empirical support for any of them. Support for the selective processing strategy is based on studies that examined reading times on a few target sentences within a long text (e.g., Hyönä, 1994; R. F. Lorch et al., 1985, 1987). These studies looked at only one component of readers' general processing strategies (i.e., how they processed topic-introducing sentences) and the methodology did not permit readers to backtrack. The Goldman and Saul (1990) study that provides the basis for hypothesizing the two nonselective processing strategies indicates the importance of considering backtracking during reading. However, strategies found using the sentence reading time technique may differ from normal reading strategies under conditions where several lines of text are visible at the same time and where backtracking is done more naturally by the eyes. The need to make a conscious decision to go back to a sentence without being able to see it might significantly change the process of regressing and reviewing previous text sections.

Our study differs from most previous investigations in several important ways. First, an eye-tracking methodology was used to gather information about readers' global processing strategies. Although eye movement data have been used to investigate a number of issues related to reading (Rayner, 1998), this method has been used only infrequently to investigate global text processing strategies (Blanchard & Iran-Nejad, 1987; Hyönä, 1995; Rothkopf, 1978; Shebilske & Fisher, 1983; Vauras et al., 1992; for individual differences in local reading strategies, see Olson, Kliegl, Davidson, & Foltz 1985), but it has some important advantages for this purpose. 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 within the sentence. In addition, eye tracking 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.

Second, like Goldman and Saul (1990) but unlike most other investigations, on-line processing measures were recorded and analyzed for every sentence in a long, multiple-topic text. Given our interest in global processing strategies, it is important to have a comprehensive picture of reading behavior for each reader.

Finally, we took an inductive approach to identifying reading strategies. The battery of reading measures collected from each reader was analyzed using a clustering technique. Cluster analyses group together cases with similar profiles on a set of dependent variables and distinguish groups that differ in their mean profiles. Thus, they provide an approach to identifying distinct processing strategies. An advantage of the approach is that it does not require a priori specification of models and so allows the possibility that unforeseen processing strategies might be detected. On the other hand, compared with conventional inferential statistical methods, clustering techniques are more susceptible to chance patterns in a dataset. To guard against this potential pitfall, participants read two texts so that the reliability of the clustering solution could be checked.

Overview of the Experiment

The eye movements of college students were recorded as they read two multiple topic, expository texts for the purpose of summarizing each text from memory. The frequency and duration of fixations were classified into four categories for each sentence in each text. Forward fixations are those that land on an unread region of the sentence; thus, they reflect the initial encounter with the text contents. Immediate reinspections are regressions directed back to an already read region of the sentence before moving on to a subsequent sentence. They are typically made when reaching the end of a sentence and are thus thought to reflect the process of integrating and wrapping up the meaning of the sentence as a whole (see Blanchard & Iran-Nejad, 1987; Hyönä, 1995). After the initial processing of a sentence, readers often reprocess a sentence. Look backs are fixations that go back across sentence boundaries and thus reflect more global integrative processes (e.g., checking of topic information, reviewing of text sections). Look backs can be further categorized on the basis of their destination and their origin. With respect to the processing of a text's topic structure, the processing measures were computed for the following six types of sentences: (a) the headings that began each subsection of a text, (b) the initial, topic-introducing sentence of each section of the text, (c) the initial, subtopic-introducing sentence of the second paragraph of each text section, (d) the last sentence of the first paragraph of each section, (e) the last sentence of each section of the text, and (f) all other sentences. The first five sentence types all have potentially unique relevance to processing of the topic structure of an expository text; the sixth sentence type has no particular relevance to topic structure and thus serves as a type of baseline against which to compare the first five sentence types.

In addition to the measures of on-line reading, we recorded each participant's performance in a Finnish course and on a reading span test in order to correlate these individual difference measures with the cluster assignments (cf. Kennison & Clifton, 1995). The purpose of this information was simply to determine whether the cluster assignments related to measures of verbal achievement and ability. Moreover, we analyzed the participants' text summaries to get an estimate of how adequately they had represented the text topics in memory.

Method

Participants

Participants were 48 students (29 women; age range: 20–36 years) enrolled at the University of Turku, Finland. The data file for one participant was damaged because of technical problems; thus, data for 47 participants were included in the analyses.

Apparatus

Eye movements were collected by the EYELINK eye tracker manufactured by SR Research Ltd. (Toronto, Ontario, Canada). The eye tracker is an infrared video-based tracking system combined with hyperacuity image processing. There are two cameras mounted on a headband (one for each eye) including two infrared light-emitting diodes (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 infrared light sources 4–6 cm away from the eye. The resolution of eye position is 15 s 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 participant 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. The compensation is better than 1° over the acceptable range of head motion.

Materials

Two multiple-topic expository texts were used as stimuli, the Energy and Endangered Species texts. The Energy text on environmental damage and alternative energy sources was adopted from R. F. Lorch and Lorch (1996) and translated into Finnish. The text was approximately 1,200 words long. The text began with a short introduction, then discussed 12 distinct topics organized into two major sections. The first section was on environmental damage resulting from use of conventional fuels. It discussed six types of damage, including air pollution, disruption of environmentally sensitive areas, oil spills, storage of radioactive waste, acid rain, and the greenhouse effect. The second 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 conversion. Each text topic was preceded by a heading that labeled the topic. The headings were presented on the first line of the screen in boldface. Each topic was developed in two paragraphs, each of which discussed a different aspect of the topic. The initial sentence of the first paragraph of each section introduced both the general topic of the section (e.g., wind power) and the specific topic of the first paragraph (e.g., wind power is an ancient form of energy used by humans). The initial sentence of the second paragraph of each section introduced the specific topic of that paragraph (e.g., wind power is an economical form of energy). The initial sentence of a paragraph was topical in that most of the following sentences in the paragraph elaborated the initial sentence and were therefore subordinate to it. Each text topic was presented as a separate page on the computer screen. The text ended with a short conclusion section.

The Endangered Species text was written with the help of wildlife encyclopedias. The text described 10 species whose existence has recently become 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, falcon, white-tailed 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 (flying squirrels, pandas, whales, bats, spotted cats). As with the Energy text, each text topic was preceded by a heading that labeled the topic, and each topic was developed in two paragraphs, each of which discussed a different aspect of the topic. Analogous to the Energy text, the sentences of each topic paragraph were categorized into topical, paragraph-final, and other sentences. The text ended with a short conclusion section.

Texts were presented double-spaced on the computer screen, with a maximum of 12 lines of text at a time. The Energy text consisted of 15 pages and the Endangered Species text of 12 pages. The presentation order of the two texts was counterbalanced across participants.

Procedure

Before the actual experiment, the eye tracker was calibrated for each participant. Participants were instructed to read the texts to be able to summarize the main contents. Reading was self-paced with the restriction that returning to a previous page was prevented. Participants advanced to the next screen by pressing a button on a gamepad. A short practice trial preceded the first text to adjust the participants to the eye-tracking equipment and to present the instructions.

After the participants had read both texts, a reading-span test (Daneman & Carpenter, 1980) was administered. Participants read aloud sets of unrelated sentences. The sentences were presented on white index cards one at a time by the experimenter. After reading the sentences of a particular set, the participant was to recall the last word of each sentence in the set. The test began with sets of two sentences, and the set size increased as long as the participant successfully recalled the sentence-final words. Each set size was repeated three times. Testing terminated when the participant failed to recall the sentence-final words of all three repetitions of a particular set size. The test score of the participant was the maximum number of final words recalled correctly, with a half point credited for successful recall of only one of the three repetitions of a particular set size.

The reading-span test took approximately 15 min. After that, participants wrote a summary of the main contents of the first text they read (one half of the participants summarized the Energy text and the other half the Endangered Species text). The experimental session lasted about 1 hr 15 min.

Results

Data Reduction

Eight measures of eye movements were computed for each sentence in both texts: the frequency and duration of forward fixations during the first reading of a sentence (*forward fixations*), the frequency and duration of reinspective fixations during the first reading of a sentence (*reinspections*), the frequency and duration of looks back to a sentence that had already been read (*look backs*), and the frequency and duration of looks from a sentence back to an already read sentence (*look froms*).[1] Forward fixations and reinspections are presumed to reflect the relative difficulty of initially processing a sentence; looks to and from sentences are presumed to reflect how readers attempt to integrate information and resolve comprehension difficulties. All measures were computed as a ratio per character to provide some adjustment for differences in length across sentence types (see below).

[1] Traditionally, readers' eye fixations have been grouped into progressive (i.e., left to right) and regressive (i.e., right to left) fixations (see Rayner, 1998). Our reinspective and look-back fixations differ from regressions in that the saccadic direction is not decisive; rather, fixations that land on a previously fixated text region are defined either as reinspections (when rereading parts of the currently fixated sentence) or look backs (when rereading parts of a previously read sentence). A reinspective and look-back sequence is always initiated with a regression; subsequent reinspective or look-back fixations can either be regressive or progressive. In studies of word recognition and syntactic parsing, look-back fixations are often called second-pass fixations (Rayner & Sereno, 1994).

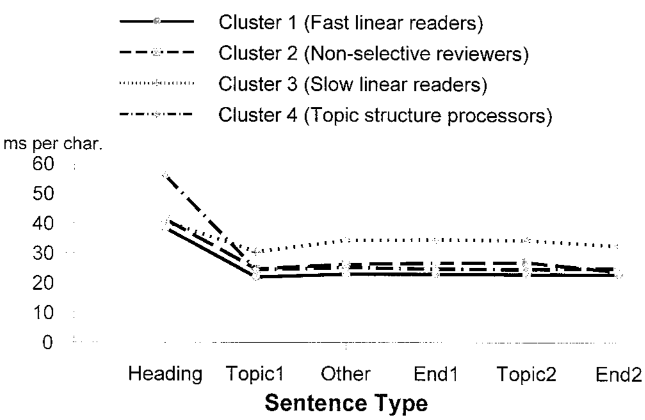

Figure 1. Duration of forward fixations in milliseconds (ms) per character (char.) for the four reader clusters, as a function of sentence type. Heading = topic heading; Topic1 = topic sentence of first paragraph of each topic; Other = all paragraph-medial sentences; End1 = final sentence of first paragraph of each topic; Topic2 = topic sentence of second paragraph of each topic; End2 = final sentence of second paragraph of each topic.

Once measures were computed for each sentence, they were averaged across sentences that had common functions with respect to the text's structure. Six sentence types were distinguished. Means were computed across (a) all headings in a text, (b) the initial, topic-introducing sentence of the first paragraph of each page (*topic1*), (c) the sentence that ended the first paragraph on each page (*end1*), (d) the initial, subtopic-introducing sentence of the second paragraph on each page (*topic2*), (e) the sentences that ended the second paragraph on each page (*end2*), and (f) all remaining sentences (*other*). We distinguished the two topic sentences on a page because the first topic sentence was also the initial sentence on each page and therefore might serve a special function with respect to the text processing strategies of readers. Similarly, we distinguished the two paragraph-ending sentences on a page because the second ending sentence was also the last sentence on the page. In sum, 48 measures were computed on each of two texts for each participant. There were two types of dependent variables (frequency and duration) for each of four distinct measures (forward fixations, reinspections, look backs, and look froms) on each of six types of sentences (headings, topic1, end1, topic2, end2, and other).

Cluster Analysis

We used cluster analysis to uncover different profiles of responses on the 48 measures of processing. The two sets of measures per participant (corresponding to the two texts) were treated as distinct cases in the cluster analysis. Thus, the final data set consisted of 94 cases (measures on two texts from each of 47 participants). As is typical of eye movement data for longer text regions, corresponding frequency and duration measures were very highly correlated (cf. Hyönä, 1995). Despite this, we included both dependent variables in the cluster analysis because the redundancy should result in a more stable solution.

Before conducting the cluster analysis, all measures were converted to standard scores across participants (i.e., *z* scores) to equate variability on the measures so that they would be weighted equally in the analysis. The transformed scores were analyzed using Ward's method, which is a hierarchical, agglomerative clustering procedure. The method attempts to minimize the sum of squares of observations within any two clusters that are formed at each step. Among the clustering techniques, Ward's method has been demonstrated to be particularly powerful (Morey, Blashfield, & Harvey, 1983). Five different clustering solutions were considered (i.e., from a two- to a six-cluster solution). The four-cluster solution was adopted as the best description of the data set; the five-cluster solution did not account for much additional variability in the data, and the fifth cluster to emerge did not seem very distinct from earlier emerging clusters.

We interpret the clusters as reflecting systematic individual differences in global text-processing strategies. If that is true, then the two cases (i.e., texts) contributed by each reader should generally be assigned to the same cluster. To evaluate whether individual readers were consistent in how they processed the two texts they read, we computed the proportion of individuals for whom both texts received the same cluster assignment. The raw proportion was .85; when corrected for chance (i.e., kappa), agreement was still .77. The main source of inconsistency in cluster assignments involved the two clusters with very similar profiles (i.e., one and three). Thus, individual readers were very consistent in how they read the two texts.

Cluster Profiles

The cluster profiles are summarized in Figures 1–4 for the fixation duration data; the corresponding fixation frequency data are given in Tables 1–4. Each figure presents the duration data for a separate category of eye fixations (i.e., forward fixations, reinspections, look backs, look froms) and shows how processing varied across the six sentence types for each cluster. Because of the high correlation between the frequency and duration measures, we concentrate primarily on the duration data.

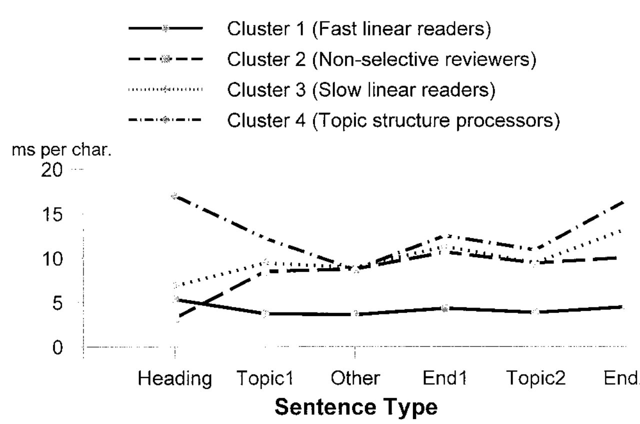

Figure 2. Duration of reinspective fixations in milliseconds (ms) per character (char.) for the four reader clusters, as a function of sentence type. Heading = topic heading; Topic1 = topic sentence of first paragraph of each topic; Other = all paragraph-medial sentences; End1 = final sentence of first paragraph of each topic; Topic2 = topic sentence of second paragraph of each topic; End2 = final sentence of second paragraph of each topic.

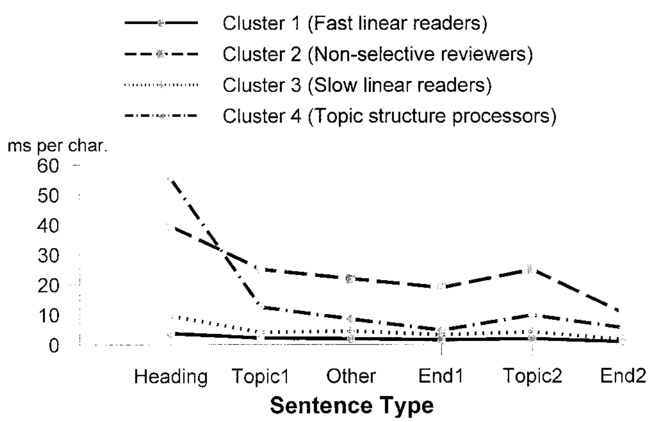

Figure 3. Duration of look backs in milliseconds (ms) per character (char.) for the four reader clusters, as a function of sentence type. Heading = topic heading; Topic1 = topic sentence of first paragraph of each topic; Other = all paragraph-medial sentences; End1 = final sentence of first paragraph of each topic; Topic2 = topic sentence of second paragraph of each topic; End2 = final sentence of second paragraph of each topic.

We describe each cluster profile separately in the same order they appeared in the cluster analysis. The profile descriptions are backed up by a set of statistical tests. For the forward fixations, the relevant comparisons were tested using *t* tests. First, independent groups tests were performed to compare the clusters at each level of sentence type. Second, repeated measures tests were performed to compare each sentence type with "other" sentences separately for each cluster. For the tests of reinspections and look-back fixations, we applied nonparametric statistics (Mann-Whitney U test and Friedman test), because some clusters showed floor effects for these data. All analyses were based on means across the two texts for the 40 participants who received identical cluster assignments for both texts. All reported effects are significant beyond the .05 level unless noted otherwise.

The four clusters that emerged are termed, in the order of their appearance in the cluster analysis, fast linear readers, nonselective reviewers, slow linear readers, and topic structure processors. In the next section, we will describe the reading behavior of each reader cluster.

Fast linear readers (Cluster 1). The first cluster to emerge included 19 readers who were assigned to Cluster 1 for both texts. Examining Figures 2–4, it is clear that the functions for Cluster 1 are all lower (shorter processing duration and lower frequency) and flatter than those of the other clusters. For forward fixation duration (see Figure 1), on the other hand, the profile for Cluster 1 is highly similar to that of at least two other clusters. Thus, the most distinctive feature of the fast linear readers is that they did very little reprocessing of any sort. As is evident from Figure 2, they demonstrate shorter reinspection times than all other readers. Pairwise group comparisons for each of the six sentence types yielded significant differences between Cluster 1 and the other clusters for all other sentence types except for headings. Fast linear readers also made very few look backs (see Figures 3 and 4). Pairwise comparisons showed that they reliably differed in look backs from nonselective reviewers (Cluster 2) and topic structure processors (Cluster 4) for all sentence types.

Apart from doing little reprocessing in general, the other distinctive feature of the fast linear readers is that they did not notably distinguish among sentence types on the rare occasions in which they did reprocess. Using the "other" sentences as a baseline to evaluate possible effects of sentence type within Cluster 1, it is apparent that there were only small effects of sentence type. For reinspections, there is a reliable tendency for end2 sentences to receive more and longer fixations than other sentences. Also, fast linear readers made more and longer look backs to headings than to other sentences. It should be emphasized, however, that fast linear readers generally did very little looking back.

Nonselective reviewers (Cluster 2). The next cluster to emerge included only three readers, so the stability of the cluster cannot be considered secure at this point. For this reason, the comparisons involving Cluster 2 should be considered with caution.

The distinctive feature of nonselective reviewers appears to be their general tendency to make more and longer look backs to previously read sentences than readers assigned to other clusters (see Figures 3 and 4). Moreover, the frequent look backs appear quite nonselective with respect to the text's topic structure. Nonselective reviewers differed from fast and slow linear readers in the number and duration of look backs on all sentence types. In addition, they differed from topic structure processors on all sentence types except headings and end2 sentences.

Analyzing the effects of sentence type within Cluster 2, there are some suggestive trends in the figures but very little statistical power to make comparisons (i.e., $n = 3$). Thus, no statistically reliable comparisons emerged when other sentences were used as the baseline.

Slow linear readers (Cluster 3). The overall profile of slow linear readers ($n = 11$) is very similar to fast linear readers in that they do very little looking back and they do not show very sharp distinctions among sentence types on any of the processing measures. Slow and fast linear readers differ primarily in overall speed of processing during the first pass. Slow linear readers produced the longest forward fixation times (see Figure 1). Compared with fast linear readers, they made more and longer forward fixations on

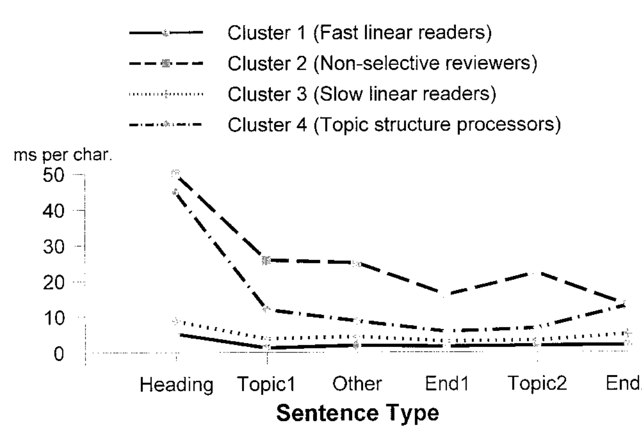

Figure 4. Duration of look froms in milliseconds (ms) per character (char.) for the four reader clusters, as a function of sentence type. Heading = topic heading; Topic1 = topic sentence of first paragraph of each topic; Other = all paragraph-medial sentences; End1 = final sentence of first paragraph of each topic; Topic2 = topic sentence of second paragraph of each topic; End2 = final sentence of second paragraph of each topic.

Table 1
Mean Frequency of Forward Fixations (Fixations/Character) as a Function of Sentence Type and Cluster Assignment

	Sentence type					
Cluster	Heading	Topic1	Other	End1	Topic2	End2
1. Fast linear readers	.171	.105	.109	.110	.108	.105
2. Nonselective reviewers	.186	.121	.126	.128	.126	.116
3. Slow linear readers	.199	.138	.147	.148	.145	.138
4. Topic structure processors	.227	.118	.121	.120	.116	.119

Note. Heading = topic heading; Topic1 = topic sentence of first paragraph of each topic; Other = all paragraph-medial sentences; End1 = final sentence of first paragraph of each topic; Topic2 = topic sentence of second paragraph of each topic; End2 = final sentence of second paragraph of each topic.

all sentence types except headings. Compared with topic structure processors, they made more and longer forward fixations on all sentence types except headings and topic1 sentences. Because of the small sample size of nonselective reviewers, most group comparisons between slow linear readers and nonselective reviewers were not significant.

Comparisons of the sentence types within the cluster demonstrated that slow linear readers made more and longer reinspections on paragraph-final (end1 and end2) sentences than on other sentences (Figure 2). They made marginally longer and more look backs to headings than to other sentences (Figure 3), but their overall look-back rate was very low.

Topic structure processors (Cluster 4). The reading behavior of Cluster 4 readers ($n = 7$) is characterized by their sensitivity to the text's topic structure. One distinctive feature of topic structure processors is that they devoted a lot of fixation time to headings; this was particularly the case for the look backs (Figure 3). They differed reliably from fast and slow linear readers in the number and duration of look backs directed to headings (the comparisons failed to reach significance against nonselective reviewers because of lack of statistical power). Comparing sentence types within the cluster, topic structure processors spent reliably more forward fixation time in reading headings than other sentences. The same difference also appeared for the number and duration of look-back fixations.

The second distinctive feature of topic structure processors is their tendency to devote additional visual attention to the topic-final (end2) sentences. They made more and longer reinspective fixations (Figure 2) in reading topic-final sentences than did the other readers (the difference remained marginal against nonselective reviewers). Moreover, the origin of their look backs was typically the section-final sentences (Figure 4). Topic structure processors initiated reliably more and longer look-back fixations from end2 sentences than did fast and slow linear readers. Comparisons within the cluster showed that topic structure processors made reliably more and longer look-back fixations from end2 than other sentences, as well as reliably more and longer reinspections on end1 and end2 than other sentences.

Overall Reading Rate

On the basis of all eye fixations made during reading, we computed the average individual fixation duration and the overall reading rate for the four reader clusters (see Table 5). The four clusters did not differ on average fixation duration, $F(3, 36) = 1.25$, $MSE = 497$, $p > .1$; however, they did differ on overall reading rate, $F(3, 36) = 12.37$, $MSE = 2{,}711$. Post hoc tests demonstrated that fast linear readers read faster than each of the other three groups, which did not differ from each other. The reading rates of the other three groups are noticeably slow, which reflects their greater incidence of reinspective and look-back fixations (see above).

Sentence Wrap-Up Effects

Prior eye movement research (Just & Carpenter, 1980; Rayner, Kambe, & Duffy, 2000; Wiley & Rayner, 2000) has established that additional fixation time is devoted to sentence-final words. This wrap-up effect is taken to reflect integrative processing at sentence boundaries. To determine whether the magnitude of wrap-up effects was modulated by reading strategy, we analyzed both first-pass fixation time and look-from time in a mixed-factors analysis of variance (ANOVA) with sentence type (topic vs. end), paragraph (1st vs. 2nd), and text (energy vs. endangered species)

Table 2
Mean Frequency of Reinspective Fixations (Fixations/Character) as a Function of Sentence Type and Cluster Assignment

	Sentence type					
Cluster	Heading	Topic1	Other	End1	Topic2	End2
1. Fast linear readers	.021	.019	.018	.020	.019	.022
2. Nonselective reviewers	.017	.044	.041	.050	.044	.049
3. Slow linear readers	.032	.045	.039	.049	.041	.058
4. Topic structure processors	.066	.058	.042	.062	.053	.079

Note. Heading = topic heading; Topic1 = topic sentence of first paragraph of each topic; Other = all paragraph-medial sentences; End1 = final sentence of first paragraph of each topic; Topic2 = topic sentence of second paragraph of each topic; End2 = final sentence of second paragraph of each topic.

Table 3
Mean Frequency of Look-Back Fixations (Fixations/Character) as a Function of Sentence Type and Cluster Assignment

	Sentence type					
Cluster	Heading	Topic1	Other	End1	Topic2	End2
1. Fast linear readers	.019	.011	.010	.007	.010	.004
2. Nonselective reviewers	.164	.126	.110	.096	.127	.051
3. Slow linear readers	.044	.020	.020	.016	.019	.008
4. Topic structure processors	.215	.064	.044	.024	.048	.027

Note. Heading = topic heading; Topic1 = topic sentence of first paragraph of each topic; Other = all paragraph-medial sentences; End1 = final sentence of first paragraph of each topic; Topic2 = topic sentence of second paragraph of each topic; End2 = final sentence of second paragraph of each topic.

as within-participants variables and cluster (excluding Cluster 2) as a between-participants variable. First-pass fixation time yields the time readers spent fixating on the wrap-up region before moving away from it; look-from time is the accumulated time of look-back fixations initiated from the wrap-up region. As there was quite a bit of variability in the lengths of the sentence-final words, we included in the wrap-up region the two final words of each sentence.[2]

The data are presented in Table 6 for the first-pass fixation time and in Table 7 for the look-from fixation time. For the first-pass fixation time, the Sentence Type × Paragraph interaction proved significant, $F(1, 34) = 16.13$, $MSE = 26{,}289$; for topic sentences, mean fixation time on the wrap-up region was longer in the first than in the second topic sentence, whereas for the end sentences the pattern was reversed. This pattern held for all three reading strategies, as indicated by the nonsignificant Sentence Type × Paragraph × Cluster interaction, $F < 1$. The main effect of cluster, $F(2, 34) = 6.12$, $MSE = 278{,}848$, merely reflects the fact that fast linear readers had the shortest and the slow linear readers had the longest first-pass fixation times.

In the look-from fixation times (see Table 7), the Sentence Type × Paragraph interaction again proved significant, $F(1, 34) = 57.42$, $MSE = 53{,}501$. Similar to the pattern for first pass fixation times, readers looked back more from the wrap-up region for the topic1 and end2 sentences. However, there was also a significant Sentence Type × Paragraph × Cluster interaction, $F(2, 34) = 11.37$, $MSE = 53{,}501$. To further analyze the three-way interaction, we computed a separate analysis for the topic and end sentences. For the topic sentences, the Paragraph × Cluster interaction was clearly nonsignificant, $F < 1$, whereas for the end sentences a significant interaction emerged, $F(2, 34) = 22.49$, $MSE = 45{,}381$. For all three clusters, readers spent more time looking back from end2 than from end1 sentences; however, the difference varied greatly from the topic structure processors (699 ms) to the slow linear readers (302 ms) to the fast linear readers (72 ms). The finding that the topic structure processors initiated look-back fixations from the wrap-up region of the topic-final sentences complements the earlier characterization of Cluster 4 as including relatively long look backs from section-ending sentences (see Figure 4). Specifically, the findings for wrap-up effects demonstrate that topic structure processors tend to make long look backs upon completion of the final sentence of a section. Finally, the main effect of cluster, $F(2, 34) = 34.62$, $MSE = 211{,}916$, reflects the fact that topic structure processors generally looked back in text quite extensively, whereas fast linear readers looked back very infrequently.

Text Summaries

As the final step of the experimental session, participants were asked to write a summary of the first text 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 subordinate to the topic was identified in the summary protocol. Scoring reliability was excellent for both texts ($k = .94$ for the energy text; $k = .96$ for the endangered species text). Two measures of summary performance were computed for each participant (see R. F. Lorch, Lorch, & Inman, 1993): (a) the percentage of topics included in the summary (topic access) and (b) the correlation between the order of occurrence of topics in the summary and the order of the same topics in the text (topic order). The means and standard deviations for the two summary measures are given in Table 8 for the four clusters.

One-factor ANOVAs were conducted on the topic access and topic order measures; Cluster 2 was excluded from the analyses because it was composed of only three readers. The remaining clusters differed reliably in topic access; $F(2, 34) = 3.27$, $MSE = .02$. Pairwise contrasts revealed that fewer topics were included in the summaries of the slow linear readers than in the summaries of the topic structure processors, $t(34) = 2.43$, $SE = .07$. There was also a marginal difference between the fast and slow linear readers, with the fast readers including more topics in their summaries, $t(34) = 1.90$, $SE = .06$, $p = .066$. For topic order, the effect of cluster approached significance, $F(2, 34) = 2.59$, $MSE = .13$, $p = .09$. Pairwise contrasts showed that the topic structure processors remembered the order of topics better than the slow linear readers, $t(34) = 2.28$, $SE = .17$.

In sum, the topic structure processors constructed the best summaries and the slow linear readers constructed the worst.

Working Memory Span

After reading both texts, participants were administered the reading span test developed by Daneman and Carpenter (1980). A one-way ANOVA showed that the working memory span differed reliably between the clusters; $F(2, 34) = 6.90$, $MSE = .78$ (see Table 8). Pairwise contrasts established that topic structure processors had a higher average working memory span than both fast

[2] The length of the wrap-up region (in characters) turned out to be fairly similar for the different sentence types: 19.4 for topic1, 18.6 for topic2, 17.8 for end1, and 18.6 for end2.

Table 4
Mean Frequency of Look-From Fixations (Fixations/Character) as a Function of Sentence Type and Cluster Assignment

	Sentence type					
Cluster	Heading	Topic1	Other	End1	Topic2	End2
1. Fast linear readers	.024	.006	.010	.008	.010	.011
2. Nonselective reviewers	.258	.129	.126	.077	.110	.066
3. Slow linear readers	.042	.018	.020	.014	.016	.025
4. Topic structure processors	.209	.051	.045	.029	.035	.066

Note. Heading = topic heading; Topic1 = topic sentence of first paragraph of each topic; Other = all paragraph-medial sentences; End1 = final sentence of first paragraph of each topic; Topic2 = topic sentence of second paragraph of each topic; End2 = final sentence of second paragraph of each topic.

linear readers, $t(34) = 2.82$, $SE = .39$, and slow linear readers, $t(34) = 3.69$, $SE = .43$.

General Language Skills

General language skills were assessed by the grade in Finnish in the last high school report card; the grades vary between 4 (*fail*) and 10 (*excellent*). Average grades differed marginally across the clusters, $F(2, 34) = 3.02$, $MSE = 1.56$, $p = .06$ (see Table 8). Pairwise contrasts revealed a significant difference between fast and slow linear readers, $t(34) = 2.37$, $SE = .47$, and a marginal difference between slow linear readers and topic structure processors, $t(34) = 1.74$, $SE = .60$, $p = .09$. Slow linear readers generally had lower grades in Finnish than the readers assigned to the other two clusters.

Discussion

Our results demonstrate systematic individual differences in how adult readers process an expository text for the purpose of summarizing it. The nature of the differences among readers involves the ways in which they reprocessed information as they read; it did not involve the patterns of forward fixations on the first-pass reading of sentences. Looking at the results for forward fixations in Figure 1, slow linear readers are generally slower than other readers and topic structure processors show a tendency to pay extra attention to headings. However, the striking features of Figure 1 are that the profiles of the four clusters are very similar in shape and—with the exception of headings—there is very little variation in processing times on the different sentence types. All of the clusters show relatively slow processing of headings, but it seems unlikely that this result represents strategic processing associated with the topic relevance of headings (with the possible exception of Cluster 4). Rather, there are other reasons for the slow processing of headings during forward fixations. The fact that all fixation times were adjusted for length (in characters) 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). Also, the page initial position of headings may have contributed to the slower processing of headings independently of their relevance to the text's topic structure. Finally, the slow processing of headings may also reflect obligatory aspects of the processing of a new topic, such as the need to represent the new information (Gernsbacher, 1990).

The bases for distinctions among the four clusters involve the patterns of reinspections and look backs (see Figures 2, 3, and 4). Fast linear readers are unique in that they do virtually no reinspections. In the absence of reinspections and look backs, their overall reading rate is also considerably faster than that of the other subgroups. Fast and slow linear readers differ from the other two clusters in the frequency and duration of look backs, with both groups of readers doing very little looking back. Finally, topic structure processors are distinctive in that they are the only group to clearly demonstrate selectivity in their reprocessing (i.e., reinspections and look backs) of the different sentence types.

Several findings indicate that the clusters represent systematic individual differences in how readers process text. Most important, the cluster assignments were very consistent; 40 of the 47 readers received the same cluster assignment for both texts. Thus, it appears that readers are quite consistent in how they process texts

Table 5
Average Fixation Duration (in Milliseconds) and Reading Rate (Words/Minute) and Their Standard Deviations (in Parentheses) as a Function of Cluster Assignment

Cluster	*N*	Average fixation duration	Reading rate
1. Fast linear readers	19	209 (25)	231 (71)
2. Nonselective reviewers	3	206 (10)	109 (15)
3. Slow linear readers	11	224 (18)	133 (18)
4. Topic structure processors	7	211 (22)	139 (18)
Total	40	213 (23)	179 (71)

Table 6
Mean Gaze Duration (in Milliseconds) on the Wrap-Up Region as a Function of Sentence Type and Cluster Assignment

	Sentence type			
Cluster	Topic1	Topic2	End1	End2
1. Fast linear readers	537	478	580	596
3. Slow linear readers	785	772	725	812
4. Topic structure processors	686	626	552	727

Note. Topic1 = topic sentence of first paragraph of each topic; Topic2 = topic sentence of second paragraph of each topic; End1 = final sentence of first paragraph of each topic; End2 = final sentence of second paragraph of each topic.

Table 7
Mean Fixation Time (in Milliseconds) of Look-Backs Initiated From the Wrap-Up Region as a Function of Sentence Type and Cluster Assignment

Cluster	Sentence type			
	Topic1	Topic2	End1	End2
1. Fast linear readers	161	125	201	273
3. Slow linear readers	425	276	457	759
4. Topic structure processors	627	559	589	1,288

Note. Topic1 = topic sentence of first paragraph of each topic; Topic2 = topic sentence of second paragraph of each topic; End1 = final sentence of first paragraph of each topic; End2 = final sentence of second paragraph of each topic.

with similar structures when they are reading each text for the same purpose. In addition, the cluster assignments correlate roughly with two other indices of individual differences. Topic structure processors differed from readers assigned to other clusters in that they had larger reading spans. In addition, fast linear readers and topic structure processors performed better in high school Finnish than slow linear readers and nonselective reviewers.

If the clusters correspond to distinct global processing strategies, how do we characterize those strategies? First, about one half of the readers ($n = 19$) were designated as fast linear readers. These readers exhibited the fastest forward fixation times and did a minimal amount of reinspecting and looking back during reading. Their fast reading pace might be taken as an indication of superficial processing, but it appears, instead, that these readers are efficient, competent processors. We base this interpretation on the fact that—despite their fast reading—the summarization performances of the fast linear readers were at least as good as those of the slow linear readers and the nonselective reviewers.

Any interpretation of Cluster 2 must be considered highly tentative because less than 7% ($n = 3$) of all participants were assigned to this cluster. Cluster 2 readers are most notable for looking back extensively, but not very selectively during reading; hence the label "nonselective reviewers." They performed similarly to the fast linear readers with respect to the reading span test, but performed poorly in high school Finnish. Perhaps these readers have adopted a strategy of consistently reviewing the text (Goldman & Saul, 1990) to compensate for comprehension difficulties. Their respectable performance on the summarization task indicates that their extra effort is rewarded.

The slow linear readers of Cluster 3 represented about 25% ($n = 11$) of the study participants. Their slow reading is not due to frequent look backs to earlier sentences; rather, it is due to extensive reinspection of sentences during first-pass reading. Their slow and nonselective reading strategy probably reflects difficulties in comprehension, as indicated by the fact that their summarization performance was the poorest of all the clusters. These readers also performed more poorly in high school Finnish than the fast linear readers and the topic structure processors. It is interesting that the slow linear readers had the lowest working memory span scores of any of the groups. Perhaps the small working memory span of these readers is a contributor to their processing strategy, causing them to immediately reinspect sentences to compensate for rapidly lost information during sentence processing. Difficulties in processing individual sentences could, in turn, explain why the slow linear readers did not perform well on the summarization task. Namely, their sentence processing difficulties interfered with processing of the global structure of the texts.

Finally, Cluster 4 readers represent a bit less than 20% of the study participants. Their processing strategy is the only one that is selective with respect to topic structure. They pay close attention to headings as indexed by all measures of on-line processing. In addition, paragraph- and section-ending sentences appear to be points at which these readers integrate their evolving representation of the text. This topic structure processing strategy is an effective processing strategy as indicated by the superior performance of these readers in the summarization task. These readers scored highest on the reading span test, although we can only speculate about the source of this relationship. One possibility is that a large span is needed to support a processing strategy that is selective with respect to the global structure of the text. However, given that headings were visually distinct and spatially predictable in our experiment, a selective strategy that focused on headings would not seem to necessitate any special memory abilities. An alternative possibility is simply that the reading span measure reflects differences in the efficiency and intelligence of readers' verbal processing strategies (Carpenter & Just, 1989; Engle, Cantor, & Carullo, 1992; Kaakinen, Hyönä, & Keenan, in press).

The topic processing strategy represented by Cluster 4 corresponds to the processing strategy identified from averaged data in previous investigations (Hyönä, 1994; R. F. Lorch et al., 1985, 1987; Vauras et al., 1992). Furthermore, our finding that topic

Table 8
Means and Standard Deviations of the Two Text Summary Measures (Topic Access and Topic Order), Reading Span, and Grade in Finnish for the Four Clusters

Cluster	Topic access[a]		Topic order[b]		Reading span[c]		Grade in Finnish[d]	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
1. Fast linear readers	76.7	12.1	.65	.35	3.47	.87	9.21	.98
2. Nonselective reviewers	80.5	12.7	.64	.56	3.50	.50	7.67	2.52
3. Slow linear readers	66.1	17.3	.50	.45	3.00	.81	8.09	1.76
4. Topic structure processors	83.3	17.0	.90	.10	4.57	1.02	9.14	.90

[a] = percentage. [b] = Spearman correlation. [c] = number of correctly recalled words. [d] = grades vary from 4 (*fail*) to 10 (*excellent*).

structure processors produced the best summaries is consistent with the finding that sensitivity to topic sentences during reading is related to the quality of readers' summaries (R. F. Lorch et al., 1987). Our findings extend earlier research by demonstrating the use of a topic structure processing strategy under conditions that allow readers to look back to earlier parts of the text. The use of eye-tracking methods thus allowed us to observe that topic structure processors use the ends of text sections as a point from which to initiate regressions to topic relevant information earlier in the text (i.e., headings).

Although our findings confirm the topic processing strategy as an effective strategy for processing expository text, they are inconsistent with the suggestion that the topic processing strategy is the modal processing strategy of college readers. In fact, our study demonstrates that even among competent readers, qualitatively distinct reading strategies are clearly observable. Furthermore, more than 80% of our readers did not use a topic processing strategy and the most common strategy of all (i.e., the fast linear readers) showed little or no sensitivity to topic relevant sentences on any measure of processing. Given the evidence that the topic processing strategy may be the most effective processing strategy of those we have uncovered (at least, with respect to summarization), this result is somewhat disconcerting.

Finally, we would like to point to the usefulness of the eye-tracking method in studying global text processing strategies. This method has primarily been applied to study more local processes, such as word recognition and syntactic parsing. Very few researchers have used eye tracking to investigate individual reading strategies. A rare exception is the study by Olson et al. (1985), which examined reading disabled readers' local processing strategies. Olson and colleagues identified two individual reading styles, *plodder* and *explorer* readers. Plodders move forward with relatively short saccades without displaying many regressions between words or skipping over words. Explorers, on the other hand, frequently skip over individual words, display relatively more regressions to previous words, and make fewer intra-word progressive movements. As the level of analysis differs greatly between the Olson et al. study and our study, it is not possible to make direct comparisons between the observed reading strategies. However, both studies clearly demonstrate the usefulness of eye tracking as a method to study individual reading strategies.

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