EYE MOVEMENTS DURING REPEATED READING OF A TEXT *

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Accepted June 1989

The facilitation of eye movements was studied in two experiments involving a repeated reading paradigm. A text was read three times. Initial reading was immediately followed by the first repetition; the second repetition took place one week later. Recall task instructions were used to encourage a detailed reading of the text. The data were analysed sentence by sentence from the ‘first pass’ readings not including returns to earlier text locations. A general facilitation for all eye movement parameters was found. Repetition decreased the summed fixation time, the average fixation duration, the number of progressive fixations, and the number of regressions. Additionally, repetition increased saccade lengths. Experiment 2 further qualified the general facilitatory effect. The middle section of the text, being the most dense of information, was devoted the most visual attention by the readers. Moreover, it was also found to produce the largest degree of facilitation due to repetition. This was true with all other eye movement parameters except saccade length and average fixation duration. Average fixation durations were longer in the beginning of a text than in the end. This was true in all the three readings. Similarly, for each reading, highly important sentences received more visual attention than unimportant sentences.

Introduction

In the study of text comprehension, the prevailing paradigm is to analyse the reading process in situations where the reader is exposed to

* A preliminary report of these experiments was presented at the London meeting of the British Psychological Society, December, 1988. This research was supported by grants from the University of Turku and the Research Council for the Social Sciences (Academy of Finland) to the second author. The authors wish to thank Ralph Norman Haber, Jorma Tommola, and an anonymous reviewer for their valuable comments on this article. We also thank Jouni Vuorinen for statistical advice.

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the text only once. Little is known of the effects of repeated exposures to the same text. As Shebilske and Fisher (1983a) point out, this factor is potentially important because a text is often read more than once, particularly when the goal is to learn from it. The purpose of the present study is to investigate the effects of repeated reading by monitoring the reading process through readers' eye movements.

What predictions are plausible concerning the repeated reading of a text? A commonplace assumption is that reading is facilitated by repeated exposure to the text. Thus overall reading time should decrease due to repetition. It is less obvious, however, how the facilitation is reflected in the reader's information-seeking processes. Do fixations become shorter? Is the text read with fewer fixations while the average fixation duration remains the same? Does the number of regressions decrease?

The most likely prediction is that the average fixation time becomes shorter. There is abundant evidence that the duration of individual fixations reflects various cognitive processes called for by the reading of a text (for a review, see McConkie 1983). Furthermore, earlier studies (see Tinker (1965) for a review) have indicated that the mean fixation duration averaged over several fixations is also sensitive to, for example, the difficulty of the text: easy narrative prose is read, on the average, with shorter fixation durations than scientific prose. On the other hand, rereading a text should make comprehension easier. As a consequence, rereading should lead to accumulative facilitation in average fixation duration.

It can also be predicted that the number of regressions decreases as a function of text familiarity. At least part of the regressions can be assumed to reflect momentary comprehension difficulties. For example, Frazier and Rayner (1982) showed that ambiguous syntactic structures produce regressions back to the region of the text that disambiguates the sentence. The study of Carpenter and Daneman (1981) is another example of regressions being brought about by the ongoing comprehension process. Carpenter and Daneman found that the occurrence of regressions increased when a homograph was given an interpretation not matching the context. Regressions served the function of recovering from the erroneous interpretation. Consequently, if ongoing cognitive processes control the occurrence of regressions during reading, it would mean that as the text becomes more familiar through repeated reading, there should be less need to regress back in the text.
On the other hand, not necessarily all the regressions are controlled by the comprehension process. Shebilske (1975) pointed out that short corrective regressions frequently occur at the beginning of lines after return sweeps. A similar point is made by Pavlidis (1981) who suggests that regressions are mostly due to underlying deficits in the reader's visual tracking movements and therefore are not specific to the content. Hence, if this dysmetria in the oculomotor system were the primary cause for regressions, there would be no decrease in the number of regressions due to repeated reading.

Perhaps the most interesting question is whether the text is read with fewer fixations due to repetition. There is evidence that graphemic features of a text at least partially determine the locations of individual fixations. The 'preferred landing position' in a word tends to be towards the middle (see Rayner 1979; Hyönä et al. 1989; Underwood et al. in press). Thus readers send their eyes further when a longer word lies ahead than when a shorter word is located to the right of their fixation location (O'Regan 1979). Moreover, readers tend to avoid fixating the blank spaces (Abrams and Zuber 1972) as well as the region between sentences (Rayner 1975).

According to 'low-level control models' (Rayner and McConkie 1976), fixation locations are guided only by the visual characteristics of the text (see also Haber 1976). In the case of repeated reading, the low-level control model of eye guidance predicts that a visually identical text is read with approximately the same amount of fixations from time to time. That is, little facilitation is expected in the number of fixations due to repeated reading.

However, if also higher-level cognitive processes are responsible for eye guidance during reading, the number of fixations should decrease due to increased text familiarity caused by repeated reading of the same text. This would mean that, during some fixations, the text is processed further to the right and, hence, fewer fixations would be needed for going through the text.

To our knowledge, the only controlled study of eye movements during repeated reading is that by Shebilske and Fisher (1981). Judd and Buswell (1922) had their subjects read the same text twice but unfortunately with different instructions. During the first exposure, the two subjects of the Shebilske and Fisher (1981) study read the pertinent and less pertinent meaning units equally fast (280 vs. 288 words/min). During the second exposure they slowed down at the important units
In the present experiment the same text was read three times. The first two readings were performed in one continuous session. The third reading took place a week later. The eye movement parameters were analysed globally sentence by sentence.

Experiment 1

Method

Materials and apparatus

The text dealt with the history of architecture in the town of Turku. It consisted of 371 words in 36 sentences. The text was written in upper case and it was filmed on slides each having 4 to 5 lines. A total of 9 slides were used. In most cases a line comprised one whole sentence. With the viewing distance of 60 cm, one character space (3 mm) subtended a visual angle of about 20 min of arc horizontally. On the top of each slide there were the numerals 1 to 3. These were at equal distance from each other and delineated the maximum horizontal coordinates of a text line. Subjects were instructed to fixate the three numerals from left to right before starting reading each slide. The eye movements were recorded with an ASL Eye Trac Model 200, which is a limbus tracking device. The sampling frequency was 100 Hz. The measurement accuracy of the apparatus is 1 degree horizontally and 2 degrees vertically, as reported by the manufacturer. The experiment was controlled by an Apple II microcomputer. Fixations of less than 30 msec were discarded from the analyses.

Procedure

The subjects were 11 university students, of both sexes, and aged 20 to 27 years. All had intact vision. A head rest was used to control head movement artefacts. The subject operated the slide projector with a button located under the preferred hand. The first session consisted of two successive readings of the text with a 2–3 minute pause in between. Immediately after the second reading, the subject recalled the text orally. The subject was also asked questions concerning the text. The task was self-paced with the restriction that returning to a previous slide was prevented. The recording apparatus was calibrated prior to the first reading and between the first and second reading. The third reading took place a week afterwards and the subject was not informed about it before the session. Prior to the third reading, the subject recalled the text orally in order to activate its representation. He/she was again informed that questions will be asked after reading. In all three readings, the recall instructions emphasized the reading of details thus ensuring that the text was read carefully.
Table 1  
Eye movement parameters as a function of repeated reading in experiments 1 and 2. Data are First Pass sentence averages.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Summed fixation time per sentence (msec)</th>
<th>Fixations per sentence</th>
<th>Average fixation duration (msec)</th>
<th>Regressions per sentence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exp. 1</td>
<td>Exp. 2</td>
<td>Exp. 1</td>
<td>Exp. 2</td>
</tr>
<tr>
<td>1st</td>
<td>2766</td>
<td>2780</td>
<td>9.8</td>
<td>8.7</td>
</tr>
<tr>
<td>2nd</td>
<td>2502</td>
<td>2606</td>
<td>9.3</td>
<td>8.2</td>
</tr>
<tr>
<td>3rd</td>
<td>2250</td>
<td>2271</td>
<td>9.1</td>
<td>7.8</td>
</tr>
</tbody>
</table>

Results

Because the instruction emphasized memory recall, many subjects read either the whole slide or part of it twice before starting the next one. Therefore the data were analysed in two different ways. Firstly, all eye movements were taken into account, including frequent returns to the earlier text locations. Secondly, only those movements were included which resulted from the first reading of each sentence from the beginning to the end ('First Pass'). All results are given as sentence averages.

The overall reading rates regarding First Pass readings were 224 WPM, 247 WPM, and 275 WPM for the 1st, 2nd and 3rd reading, respectively. They are comparable to the reading rates for casual reading (see Tinker 1965). When also Rereadings were included, the reading rates for the 1st, 2nd and 3rd readings were 189 WPM, 214 WPM, and 227 WPM. The slower rates reflect the fact that, due to recall instructions, the text was read through carefully.

In the analysis based on all eye movements, the only significant effect was found for the average fixation duration, $F(2, 20) = 5.60, p = 0.012$, which decreased with repeated reading. The average fixation durations for the first, second and third reading were 251, 241, and 222 msec.

However, when the analysis was based on data from First Pass, all eye movement parameters displayed a significant effect related to repeated reading (see table 1). First, the summed fixation time per sentence shortened as a function of repetitions, $F(2, 20) = 8.64, p = 0.002$. Second, the number of fixations on a sentence differed in the three readings, $F(2, 20) = 11.78, p = 0.0004$. Only those fixations following a forward saccade were included in the measure, with the exception that the initial fixation on a sentence was always included. Thus, all the fixations preceded by a regression were excluded from the measure. This makes the number of fixations and the number of regressions independent measures.

Third, there was a decrease in the average fixation duration per sentence, $F(2, 20) = 6.41, p = 0.007$. And fourth, the number of regressions decreased, $F(2, 20) = 4.50, p = 0.024$. Corrective regressions following a return sweep were discarded from this analysis. No interaction was found involving repeated reading and the sentence factor with any of the eye movement parameters. This suggests that the effects of an increased familiarity with the text were not confined to some individual sentences.
Discussion

Facilitation due to repeated reading of a text appears to be reflected in all eye movement parameters. Fixation duration becomes shorter, the number of fixations decreases, and regressions become fewer. The reliability of the result is enhanced by the nature of the instruction which emphasized the reading of details. It is quite plausible that a more general instruction could have led to augmented effects.

In summary, the results suggest, firstly, that when both the surface features and the content of a text become familiar due to repeated exposure to the same text, there is less need for fixation time during reading. That is, the ease of rereading a familiar text is reflected in shorter average fixation durations. Not only are easy narrative texts read with shorter fixation durations than scientific texts (Tinker 1965), but also the same text is read, on the average, with shorter fixations when the text has become familiar during repeated reading. The major facilitation seemed to take place between the 2nd and 3rd reading (20 msec out of 31 msec).

Secondly, the results of experiment 1 suggest that visuographic features of the text are not alone responsible for eye guidance during reading. As noted earlier, the decrease in the number of the fixations due to repetition cannot be accounted for by the low-level control models. The fixation frequency also appears to be guided by higher-level comprehension processes. It seems that, due to facilitated comprehension through repeated reading, the text is processed further to the right on some fixations, thus resulting in fewer fixations needed for going through the text. Consequently, the results are compatible with the view that readers' eyes are guided by both visual and cognitive information (see Rayner and McConkie 1976; Haber 1976; McConkie 1983).

Thirdly, there is less need for regressions during rereading, compared to the initial reading of the same text. Thus, the regression frequency also seems to be affected by the relative ease of comprehension. The results are thus in accordance with the notion that regressions in reading are under cognitive control. However, this does not imply the total absence of momentary oculomotor dysfunctions resulting in occasional regressions. It is suggested, however, that the occurrence of regressions is not primarily caused by the dysmetria in the oculomotor system. This is because there is no reason to believe that repeated
exposure to the same text should somehow decrease the oculomotor dysfunctioning.

It is noteworthy that the repetition effects emerged only when first pass readings were separated from reinspections. Because of the instructions for detailed reading, our subjects had a strong tendency to reinspect parts of each slide before turning to the next. This masked the facilitation effect found in the first pass readings.

Finally, there were no signs in our data suggesting that only certain text locations would be responsible for the facilitation due to repetition. Shebilske and Fisher (1981) provided evidence suggesting that important meaning units are read slower and unimportant meaning units faster in the second reading compared to the initial reading. Applied to our data, this would mean that the unimportant text units would be responsible for our facilitation effect. However, the lack of interaction between repetition and the sentence factor in our data is at odds with this notion. Any firm conclusions would, however, be premature, since our text was not designed according to any specific structural schema.

Experiment 2

Experiment 2 served two purposes. First, we aimed at a replication of experiment 1 using another text, another eye movement device, and another typography for the stimulus text. Second, our intention was to further qualify the general facilitatory effect found in experiment 1. An answer is sought to the question whether the effect is spread out over the whole text, or whether there are specific text segments that are primarily responsible for the facilitation due to repetition.

What would be a plausible candidate for producing facilitation? As was pointed out earlier, Shebilske and Fisher (1981) offer one possibility. Their study suggests that the pertinence of the textual unit might play a significant role here. During the second reading of the text the two subjects of the Shebilske and Fisher study slowed down at important units (229 words/min) and speeded up at less important units (372 words/min). If the Shebilske and Fisher finding is generalizable, it would mean that the unimportant text units are responsible for the facilitation due to repeated reading. In their study, the relative importance was determined by another group of subjects who rated each textual unit according to its importance. We name this notion the importance hypothesis.

Another point of view similar to the meaning unit importance is offered by the so-called 'levels effect'. Using the recall paradigm, it has been established that those textual units that are high in the content structure of the text are recalled better than low-level units (see e.g. Thorndyke 1977). Thorndyke (1977) defined a typical story to
be composed of four sections: Setting, Theme, Plot and Resolution (see also Mandler and Johnson 1977). In a text hierarchy, the propositions of Setting, Theme and Resolution belong primarily to the two top levels, whereas the propositions making up the Plot-section primarily belong to the two low levels in the structure of a text. That is, the beginning section and the end section carry information more essential to the general gist of the story, whereas the middle section tends to contain more detailed information.

According to the so-called selective attention hypothesis (see Britton et al. 1979), the levels effect in recall is caused by more attention given to the high-level units than to the low-level units when reading the text. That is, memory for high-level information is enhanced by thoroughly elaborating it during the reading process. The empirical evidence supporting the selective attention hypothesis is rather equivocal, however. Cirilo and Foss (1980) found that high-level sentences in a narrative text took longer to read than sentences low in the textual hierarchy. This result was contradicted by Birkmire (1985), who observed an opposite trend. High-level information was read at a faster rate than intermediate- and low-level information. Britton et al. (1979) using paragraph reading times, did not find any levels effect.

The similarity of the importance hypothesis and the selective attention hypothesis is apparent. They both emphasize relative importance in controlling the amount of processing time allocated to different text units. These accounts differ in two respects: while the selective attention hypothesis ignores the possible effect of repetition, the importance hypothesis claims that the relative importance of text units is not a crucial factor in the initial reading, but in rereading, only. The other difference has to do with the method: the importance hierarchy is delineated: the importance hypothesis determines the relative importance of a meaning unit by using a subjective rating method, whereas the selective attention hypothesis rests on text grammar studies thus defining the importance theoretically, and independently of subjective ratings.

To sum up the above discussion, we put forward the following prediction: facilitation caused by repetition is due to the fast reading of the unimportant meaning units when rereading a text. That is, an interaction between meaning unit importance and repetition is predicted: important and unimportant text units are read equally fast during the initial reading, whereas in the second and third reading more attention is paid to the important units. Relative importance is determined by employing both subjective ratings and a text grammar approach.

Method

Subjects

Eighteen university students served as subjects (five men). All subjects had normal or corrected to normal vision.

Materials

The text was in Finnish and was entitled 'William Pitt as the Builder of the British Empire in the 18th Century'. Its length was 351 words in 48 sentences. Each line of text comprised a sentence. The length of the sentence was controlled, the mean length being 69.4 letters ($SD = 2.2$) ranging between 64–74 letters. This equalled 7.3 words per
sentence, on the average \((SD = 0.9)\). The text was displayed on a PC (Olivetti M24) screen and was seen as white against a dark background. Both upper- and lower-case letters were used. Three lines of text were presented at a time. With the viewing distance of 60 cm, one character space subtended a visual angle of 15 min of arc horizontally. The text lines were 2 cm apart, which equals to a vertical angle of 2 degrees. The text consisted of three functional sections: (1) Introduction, (2) Detailed Coverage, and (3) Conclusions. In the Introduction, William Pitt and his main policy, i.e., to raise Britain to a world power, were introduced. In the Detailed Coverage section, this main theme was specified by giving detailed pieces of information of how Pitt tried to reach his goal. The Conclusion summed up the end results of Pitt’s efforts. The Introduction consisted of 15 sentences, the mean length of which was 67.9 letters \((SD = 1.8)\) equalling 7.5 words \((SD = 0.81)\); the Detailed Coverage consisted of 20 sentences with the mean length of 70.4 letters \((SD = 2.0)\) and 7.1 words \((SD = 0.92)\); the Conclusion consisted of 13 sentences with the mean length of 69.5 letters \((SD = 2.1)\) and 7.5 words \((SD = 0.75)\).

The structure of the stimulus text is comparable to the Circle Island story used by Thorndyke (1977), which had four structural components: Setting, Theme, Plot, and Resolution. Setting and Theme correspond to our Introduction section, Plot to our Detailed Coverage section, and Resolution to our Conclusions section. Not unlike the Circle Island story, Detailed Coverage consisted of subgoal–attempt–outcome episodes (6 of them). In Thorndyke’s terms, Introduction and Conclusions occupy the two top levels and Detailed Coverage the two low levels in the text hierarchy.

Sixteen subjects who did not take part in the eye movement study rated each of the 48 sentences for their relative importance to the theme. A 4-point scale was used. Numeral 4 denoted a very important sentence and numeral 1 an unimportant sentence. To control for possible differences in the rating strategies, subjects were instructed to use every scale point at least eight times. In order to make the subjects read the text carefully before carrying out the importance rating, they had to write a 4- to 6-sentence summary of the text. This procedure forced the subjects to build up a mental representation of the main content of the text. This improves, we believe, the adequacy of the importance ratings. These summaries were not used in any of the following data analyses.

The total average of the importance ratings was 2.54. The sentence averages ranged from 1.13 to 3.88. For the eye movement data analyses, the sentences were grouped into two categories according to their importance: (1) High-importance sentences (HI)

![Table 2](image)

<table>
<thead>
<tr>
<th>Importance</th>
<th>Introduction</th>
<th>Detailed Coverage</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>3.20 (10)</td>
<td>3.03 (5)</td>
<td>3.01 (10)</td>
</tr>
<tr>
<td>Low</td>
<td>1.69 (5)</td>
<td>2.05 (15)</td>
<td>1.89 (3)</td>
</tr>
</tbody>
</table>
(the mean rating above the total mean), (2) Low-importance sentences (LI) (the mean rating less than the total mean). The mean length of the HI sentences was 7.4 words ($SD = 0.76$), and of the LI sentences 7.3 words ($SD = 1.01$). The HI group comprised 25 sentences, and the LI group 23 sentences.

The subjective importance rating confirmed the structural hierarchy: Detailed Coverage was rated less important than Introduction and Conclusions $F(2, 30) = 9.92, \ p = 0.0005)$. The average importance rating for the sentences making up the Introduction section was 2.70, for Detailed Coverage 2.29, and for Conclusions 2.75. The distribution of the HI and LI sentences over the three structural sections of the text is presented in table 2.

**Apparatus**

Eye movements were collected by an Applied Science Laboratories Model 1994. This monitoring system is video-based, and it tracks the pupil for horizontal eye movements and corneal reflection for vertical eye movements. The accuracy of the apparatus is 1 degree. Eye positions were sampled every 20 msec by an Olivetti M24 microcomputer. A chin rest was used to restrict head movements. Fixations less than 100 msec were excluded from the analysis; i.e., the minimum of five raw data points was required for a fixation (see Shebilske and Fisher (1983b) and Karsh and Breitenbush (1983) for the relevance of this issue). In the data reduction algorithm, a window size of 2.5 character spaces was employed. Thus two consecutive fixations less than 2.5 character spaces apart were combined to a single fixation.

**Procedure**

As in experiment 1, each subject took part in two sessions. In the first session, the subjects were asked to read the text twice in order to be able to write a summarizing essay about it afterwards. Reading was self-paced with the restriction that returning to a previous page was prevented. Prior to the reading, the eye movement device was calibrated for each subject. For the calibration, three numerals were used for each of three stimulus lines: one numeral in the place of the first character of a line, one in the centre, and one at the end of a line. There was a short pause followed by a calibration check between the first and second reading. After reading the text twice, subjects wrote a summarizing essay about the content of the text. The third reading took place about a week after the first session. The instruction was the same as in the first session. After the third reading, the essay the subject had written during the first session was handed to him/her, and he/she was asked to improve it.

**Results**

**Repetition**

The average reading rates were 163 WPM, 174 WPM, and 199 WPM for the 1st, 2nd, and 3rd reading, respectively. The rates are somewhat slower than those found in casual reading (see Tinker 1965).

Analogously to experiment 1, eye movements were grouped into First Pass Readings and Reinspections. First Pass was now defined more conservatively than in experiment
It included all the eye movements that fell on a sentence before moving to another sentence. Consequently, Reinspections included all the eye movements that took place after a regression from one line of text to a previously read line. In experiment 1, First Pass included only those eye movements resulting from the initial reading of a sentence from the beginning to an end; all the rest were Reinspections. In the following, all the results for First Pass and Reinspections are given as sentence averages.

(a) First Pass. An analysis of variance revealed a facilitation effect due to repetition for all eye movement parameters, thus replicating the results of experiment 1 (see table 1). First, the summed fixation time decreased with repeated reading \( (F(2, 34) = 18.57, \ p < 0.001) \), as did the number of fixations \( (F(2, 34) = 15.40, \ p < 0.001) \), the number of regressions \( (F(2, 34) = 5.91, \ p = 0.006) \), and the average fixation duration \( (F(2, 34) = 12.28, \ p < 0.001) \). Similarly to experiment 1, the average fixation duration primarily declined between the 2nd and 3rd reading (15 msec out of 20 msec). An analysis of contrasts (with Bonferroni correction) revealed that there was a reliable difference between 2nd and 3rd reading \( (F(1, 17) = 9.53, \ p = 0.007) \), but not between 1st and 2nd \( (F(1, 17) = 1.18, \ p = 0.29) \).

As in experiment 1, the number of fixations measure contains only those fixations that were preceded by forward saccades. Also analogously to experiment 1, corrective regressions following a return sweep were discarded from the number of regressions (see Shebilske 1975). Corrective regressions occurred in 43.7% of the text lines. The amount of corrective regressions did not vary as a function of repetition \( (F(2, 34) = 2.24, \ p > 0.10) \).

This time also the average saccade length for each sentence was computed. Only the forward saccades associated with First Pass readings were included in the measure. The saccade length was affected by repetition \( (F(2, 34) = 8.92, \ p = 0.0008) \). The average saccade length for the 1st reading was 10.7 character spaces, for the 2nd reading 11.4 character spaces and for the 3rd reading 11.7 character spaces.

The general facilitation may or may not occur parallelly in the eye movement parameters: sentences eliciting a drop in the average fixation duration are not necessarily read also with fewer fixations. In other words, there can be a trade-off between fixation duration and fixation frequency. An analysis was performed to test the idea. A design of two concurrent dependent variables clearly suggests the use of multivariate methods (MANOVA). Unfortunately, there were insufficient degrees of freedom for a MANOVA analysis. We bypassed the problem by creating a new variable, which took into account the relative change in two dependent measures, average fixation duration and fixation frequency (both progressions and regressions). This was employed by considering the quotient of the two variables. An ANOVA was performed for the quotient with two within-factors: repetition (3 levels) and sentence (48 levels). If there is an interaction between the two factors with the quotient as the dependent variable, it would suggest that the relative strength of facilitation due to repetition varies from sentence to sentence between average fixation duration and fixation frequency. However, the analysis showed that this seems not to be the case; the interaction was nonsignificant \( (F < 1) \). That is, on a sentence basis, when there is a drop in average fixation duration, the same drop seems to be true for fixation frequency.
(b) Reinspections. A separate ANOVA was computed on the eye movement data associated with Reinspections only. Repetition did not affect Reinspections reliably. The summed fixation time over a sentence for the 1st, 2nd and 3rd reading was 371, 421, and 260 msec \((F(2, 34) = 1.93, \ p = 0.16)\), and the number of fixations were 1.6, 1.8, and 1.1 for the 1st, 2nd, and 3rd reading, respectively \((F(2, 34) = 1.81, \ p = 0.18)\).

The number of fixations measure also included fixations preceded by regressions. The pooling was performed due to lack of data. For the same reason, the average fixation duration associated with rereadings was not computed.

(c) First Pass + Reinspections. Unlike in experiment 1, an ANOVA performed for the total eye movement data (the pooled scores of First Pass and Reinspections) showed a general facilitation effect. The total fixation time decreased due to repetition \((F(2, 34) = 11.57, \ p < 0.001)\). The total fixation times for 1st, 2nd, and 3rd readings were 3151, 3027 and 2531 msec. The total number of fixations, including all the fixations on a sentence, also decreased with repeated reading \((F(2, 34) = 7.80, \ p = 0.002)\), the sentence averages being 11.8, 11.4 and 10.1 for the 1st, 2nd and 3rd reading, respectively. The same was true of the average fixation duration \((F(2, 34) = 14.56, \ p < 0.0001)\). The respective means were 266 msec, 263 msec, and 248 msec.

Textual structure and importance

An ANOVA was performed to examine the effect of textual structure and the importance rating on the general facilitation due to repetition. Text structure had three levels: Introduction, Detailed Coverage and Conclusions; importance had two levels: High importance (HI) and Low importance (LI). Only the First Pass data were analyzed.

(a) Summed fixation time. The main effect of text structure proved reliable for the summed fixation time \((F(2, 34) = 15.29, \ p < 0.0001)\) suggesting that more fixation time was allocated on Detailed Coverage than on Introduction or Conclusions. The sentence means were 2480 msec for Introduction, 2727 msec for Detailed Coverage, and 2367 msec for Conclusions. The main effect of importance rating was also reliable \((F(1, 17) = 17.08, \ p = 0.0007)\), suggesting that HI sentences are read with longer summed fixation times (mean = 2584 msec) than LI sentences (mean = 2429 msec). The interaction text structure \(\times\) repetition proved reliable \((F(4,68) = 7.27, \ p = 0.0001)\). It suggests that Detailed Coverage produced the largest facilitation (755 msec) due to repetition; facilitation was somewhat smaller for Introduction (501 msec), and especially for Conclusion (250 msec). It is also worth noticing that for Detailed Coverage the facilitation primarily occurred between the 2nd and 3rd readings (515 msec out of 755 ms) whereas for Introduction the most facilitation took place between 1st and 2nd reading (331 msec out of 501 msec).

The interaction text structure \(\times\) importance was reliable \((F(2, 34) = 5.59, \ p = 0.008)\), suggesting that the superiority of HI sentences over LI sentences was clearest in Introduction (a difference of 295 msec), and not so clear in Detailed Coverage (78 msec), nor in Conclusions (92 msec). The interaction importance \(\times\) repetition was not reliable \((F(2, 34) = 2.54, \ p = 0.09)\). Finally, the three-way interaction text structure \(\times\)
Table 3

Summed fixation time (in msec) per sentence as a function of repetition (1st, 2nd, and 3rd reading), text structure (Introduction, Detailed Coverage, and Conclusions), and importance (High importance and Low importance).

<table>
<thead>
<tr>
<th>Trial</th>
<th>Introduction</th>
<th>Detailed Coverage</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HI</td>
<td>LI</td>
<td>HI</td>
</tr>
<tr>
<td>1st</td>
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</tbody>
</table>

importance × repetition proved reliable ($F(4, 68) = 3.95, p = 0.006$). It suggests that, in Introduction, HI sentences were read with longer summed fixation time, regardless of repetition, whereas in Detailed Coverage this was true only in the 1st reading, and in Conclusions in the 2nd reading. (See table 3.)

(b) Number of fixations. There was a reliable main effect of text structure on the number of fixations ($F(2, 34) = 19.55, p < 0.0001$). Again, Detailed Coverage was read with more fixations (8.7 fixations/sentence) than Introduction (8.0 fixation/sentence) or Conclusions (8.1 fixations/sentence). The main effect of importance was significant ($F(1, 17) = 6.60, p = 0.02$). HI sentences were read with slightly more fixations (8.3 fixations) than LI-sentences (8.1 fixations). The interaction text structure × repetition was significant ($F(4, 68) = 3.64, p = 0.01$). As with the summed fixation duration data, Detailed Coverage displayed the most facilitation due to repetition (the difference between 1st and 3rd reading was 1.34 fixations). It was as much as Introduction the difference of 0.81 fixations) and Conclusions (the difference of 0.57 fixations) produced together. Also similar to the summed fixation duration data, for Detailed Coverage the most facilitation occurred between the 2nd and 3rd readings, whereas for Introduction and Conclusions most of the facilitation took place between the 1st and 2nd readings.

The interaction text structure × importance ($F(2, 34) = 3.90, p = 0.03$) points out that HI sentences were read with more fixations than LI sentences only in Introduction. The interaction importance × repetition was unreliable ($F(2, 34) = 2.73, p = 0.08$), as was the three-way interaction text structure × importance × repetition ($F(4, 68) = 1.40, p > 0.10$). (See table 4.)

(c) Number of regressions. With the number of regressions, there was the main effect of text structure ($F(2, 34) = 11.98, p = 0.001$). Detailed Coverage was read with more regressions ($M = 1.52$) than Introduction ($M = 1.13$) or Conclusions ($M = 1.19$). The main effect of importance proved unreliable ($F < 1$). The interaction text structure × repetition was reliable ($F(4, 68) = 3.40, p = 0.01$). It was due to Detailed Coverage producing, again, the strongest facilitation due to repetition, while Conclusions did not produce any facilitation. The interaction text structure × importance ($F(2, 34) = 6.48, p = 0.004$) suggests that in Introduction HI sentences were read with more regressions (1.23) than LI sentences (0.93), whereas this was not the case in Detailed Coverage and
Table 4
Number of forward fixations per sentence as a function of repetition (1st, 2nd, and 3rd reading), text structure (Introduction, Detailed Coverage, and Conclusions), and importance (High importance and Low importance).

<table>
<thead>
<tr>
<th>Trial</th>
<th>Introduction</th>
<th>Detailed Coverage</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HI</td>
<td>LI</td>
<td>HI</td>
</tr>
<tr>
<td>1st</td>
<td>8.59</td>
<td>8.23</td>
<td>9.59</td>
</tr>
<tr>
<td>2nd</td>
<td>7.94</td>
<td>7.32</td>
<td>8.81</td>
</tr>
<tr>
<td>3rd</td>
<td>7.84</td>
<td>7.36</td>
<td>7.87</td>
</tr>
</tbody>
</table>

Conclusions. The interaction importance \( \times \) repetition was nonsignificant \( (F(2, 34) = 1.96, \ p > 0.10) \), whereas the three-way interaction proved reliable \( (F(4, 68) = 3.10, \ p = 0.02) \). It is due to HI sentences attracting more regressions in Introduction than LI sentences for each reading, whereas in Detailed Coverage this happened only in the 1st reading, and in Conclusions in the 2nd reading. (See table 5.)

(d) Average fixation duration. With the average fixation duration, text structure showed a reliable main effect \( (F(2, 34) = 11.99, \ p = 0.0001) \). It was primarily due to Conclusions obtaining the shortest average fixation durations. The average fixation duration for Introduction was 267 msec, for Detailed Coverage 264 msec, and for Conclusions 250 msec. The main effect of importance barely reached significance \( (F(1, 17) = 5.56, \ p = 0.03) \). HI sentences were read with slightly longer average fixation durations (263 msec) than LI sentences (258 msec). None of the interactions reached statistical significance. (See table 6.)

(e) Saccade length. The average saccade length was not affected by text structure \( (F < 1) \), or by importance \( (F(1, 17) = 2.77, \ p > 0.10) \). The only first-order interaction that approached significance was the interaction importance \( \times \) repetition \( (F(2, 34) = 3.21, \ p = 0.053) \). It is due to HI sentences being read in the 1st reading with slightly shorter saccades (10.4 character spaces) than LI sentences (11.0 character spaces). Also

Table 5
Number of regressions per sentence as a function of repetition (1st, 2nd, and 3rd reading), text structure (Introduction, Detailed Coverage, and Conclusions), and importance (High importance and Low importance).

<table>
<thead>
<tr>
<th>Trial</th>
<th>Introduction</th>
<th>Detailed Coverage</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HI</td>
<td>LI</td>
<td>HI</td>
</tr>
<tr>
<td>1st</td>
<td>1.40</td>
<td>1.28</td>
<td>1.98</td>
</tr>
<tr>
<td>2nd</td>
<td>1.20</td>
<td>0.83</td>
<td>1.40</td>
</tr>
<tr>
<td>3rd</td>
<td>1.11</td>
<td>0.68</td>
<td>0.91</td>
</tr>
</tbody>
</table>
Table 6
Average fixation duration (in msec) per sentence as a function of repetition (1st, 2nd, and 3rd reading), text structure (Introduction, Detailed Coverage, and Conclusions), and importance (High importance and Low importance).

<table>
<thead>
<tr>
<th>Trial</th>
<th>Introduction</th>
<th>Detailed Coverage</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HI</td>
<td>LI</td>
<td>HI</td>
</tr>
<tr>
<td>1st</td>
<td>281</td>
<td>272</td>
<td>274</td>
</tr>
<tr>
<td>2nd</td>
<td>272</td>
<td>267</td>
<td>270</td>
</tr>
<tr>
<td>3rd</td>
<td>259</td>
<td>249</td>
<td>249</td>
</tr>
</tbody>
</table>

Table 7
Average saccade length (in character spaces) per sentence as a function of repetition (1st, 2nd, and 3rd reading), text structure (Introduction, Detailed Coverage, and Conclusions), and importance (High importance and Low importance).

<table>
<thead>
<tr>
<th>Trial</th>
<th>Introduction</th>
<th>Detailed Coverage</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HI</td>
<td>LI</td>
<td>HI</td>
</tr>
<tr>
<td>1st</td>
<td>10.6</td>
<td>11.0</td>
<td>10.2</td>
</tr>
<tr>
<td>2nd</td>
<td>11.3</td>
<td>11.5</td>
<td>10.7</td>
</tr>
<tr>
<td>3rd</td>
<td>11.8</td>
<td>12.1</td>
<td>11.9</td>
</tr>
</tbody>
</table>

the second-order interaction reached significance ($F(4, 68) = 3.88$, $p = 0.007$). It suggests that while in Introduction LI sentences obtained longer saccades than HI sentences in each reading, in Detailed Coverage and Conclusions the same was true only in the 1st reading. (See table 7.)

Discussion

The average fixation durations, 270 msec, 265 msec and 250 msec, in the 1st, 2nd, and 3rd reading, respectively, are comparable to those usually found in reading (see Rayner 1978; Levy-Schoen and O'Regan 1979). The average saccade lengths, 10.7, 11.4 and 11.7 characters for the 1st, 2nd, and 3rd reading, respectively, are somewhat longer than usually found. In literature, the average saccade size is estimated to be around 8 characters (see Levy-Schoen and O'Regan 1979; Rayner 1978). This apparent difference can be explained by the greater length of Finnish words in comparison with, for instance, English words. It is caused by the fact that (a) Finnish has no articles, (b) most of the prepositions are substituted by case endings, and (c) compound words
made up of two non-derived nouns are frequently used (see Karlsson 1983; for compound words, see also Hyönä et al. 1989). In our story, the average word length was 9.5 characters. If the saccade size is measured in terms of words, the respective means would be 1.13, 1.20, and 1.23 words, per saccade in the 1st, 2nd, and 3rd reading. They are identical to the saccade sizes found previously (Judd and Buswell 1922; see also Levy-Schoen and O'Regan 1979). Consequently, it seems that the relative length of Finnish words results in longer saccades, compared to English, in terms of characters, but equal in length in terms of words.

The regression frequencies, 14.6%, 13.5%, and 12.3%, in the 1st, 2nd, and 3rd reading, respectively, also compare favourably with the estimates published previously (see Rayner 1978; Levy-Schoen and O'Regan 1979). All in all, it can be concluded that all the effects reported here are reliable, as far as the eye movement measurement itself is concerned.

It is worthy of notice, however, that our overall reading rates are somewhat slower than what is usually considered to be normal. There are two reasons for it. First, the reading rate is usually determined by using casual reading instructions, rather than the instructions for detailed reading we employed. Second, the tendency for long words in Finnish most likely underestimates the reading rate, when the latter is measured in words. If it is measured as fixation time per character, our reading rates, 40.1 msec, 37.6 msec, and 32.7 msec per character in 1st, 2nd and 3rd reading, respectively, are actually faster than, for example, what Inhoff (1983) has found (about 45–50 msec per character).

Experiment 2 replicated all the findings of experiment 1. The overall reading time decreased due to repetition. This was brought about by a decrease in the number of progressive fixations and regressions, as well as in the average fixation duration, and by an increase in saccade lengths. The data of experiment 2 differed from those of experiment 1 only in one respect. The subjects of experiment 2 reinspected the previously read text to a lesser extent during each trial than the subjects in experiment 1. This might be due to the slight difference in the instructions. In experiment 1 the subjects had to give an oral report of the textual content and answer some questions; in experiment 2 the subjects were asked to write a summary of the text. Whatever the reason might be, experiment 2 indicated that these reinspections did not diminish due to familiarity of the text, as could have been assumed.
The absolute facilitation rates were surprisingly similar between the experiments: for the summed fixation time the total facilitation was 516 msec and 509 msec per sentence in experiments 1 and 2. For the number of fixations the respective facilitation rates were 0.7 and 0.9 fixations, and for regressions the average facilitation per sentence was 0.3 and 0.4 regressions in the two experiments. The average fixation duration decreased 31 msec in experiment 1 and 20 msec in experiment 2 from the 1st to 3rd reading. In both experiments it was apparent that the average fixation duration decreased primarily during the 3rd reading. This suggests that fixation durations may be less prone to text familiarity than the other eye movement parameters. At least, a larger degree of familiarization seems to be needed for facilitation to occur.

Progressive saccades lengthened, on the average, by 1 character space per sentence from the 1st to the 3rd trial. This outcome is compatible with the view that during some fixations a familiar text is processed further to the right thus resulting in longer forward saccades. That is, the finding seems to suggest that a familiar text could be processed in larger chunks than an unfamiliar text. It could mean that words that required a fixation in the initial reading would be recognized from the parafovea without making a fixation on it. Or perhaps long words that initially required two fixations for recognition can be read with a single fixation. Both cases would result in a longer saccade. The question is potentially important in the light of the theory of eye guidance in reading. However, using a sentence level measure, the issue cannot be solved. Yet, a local analysis of individual saccades and fixations, which would be more informative, is beyond the scope of this article.

The importance hypothesis based on the Shebilske and Fisher (1981) study did not get consistent support. We defined the importance both phenomenologically and structurally. When operationalized phenomenologically as importance ratings, the data indicated that readers allocated slightly more visual attention to important sentences compared to relatively unimportant sentences. This meant a somewhat greater number of progressive fixations and slightly longer average fixation durations. However, there was no indication in the data that important and unimportant sentences would have been treated differently as a function of repetition. More specifically, we did not find, as Shebilske and Fisher (1981) did, that important text units would have been given more, and unimportant text units less visual attention in the
second or third reading, in comparison to the initial reading. In other words, there seems to be no consistent change in the reading strategy due to repeated reading, with regard to the phenomenologically experienced importance of various text units.

On the other hand, the finding that important sentences were given more visual attention was qualified by an interaction with text structure. It was mainly in Introduction where this ‘levels effect’ based on importance ratings appeared. In Detailed Coverage and Conclusions it was quite inconsistent between repetitions. This is very interesting, because in Introduction the discrepancy in the importance ratings between important and unimportant sentences was widest. Introduction included both the most important and, respectively, the least important sentences of the whole text. Hence, the finding that levels effect appears reliably only in Introduction points out that pertinent text units are allocated more visual attention during processing only, when highly important and highly unimportant text units are contrasted: for example, when sentences bearing contextually redundant information are compared to sentences revealing the main theme of the text. But again, it is noteworthy that the effect does not vary as a function of repetition.

The textual structure also affected readers’ eye movements, but not the way predicted by the selective attention hypothesis. The results show that it was the comparatively unimportant details, i.e., Detailed Coverage section, that attracted the most visual attention. It was read with longest summed fixation times and with most forward fixations and regressions. On the other hand, the relatively important conclusions were read with shortest average fixation durations. Furthermore, the effect of text structure was qualified by an interaction with repetition. The data showed that Detailed Coverage, in addition to attracting most visual attention, also produced the most facilitation due to repeated exposure. Additionally, for Detailed Coverage much of the facilitation was delayed until the third reading, while for Introduction and Conclusions the most facilitation occurred already in the second reading.

How can this failure to find an ‘importance effect’, based on the structure of the text, be accounted for? Should we conclude, in opposition to the selective attention hypothesis, that structurally important pieces of information actually demand less processing resources than details? That is the conclusion put forward by Birkmire (1985). We
argue that, with our data, such a claim would be premature because of two confounding factors that possibly counteract the levels effect. These are ‘theme change’ and ‘information density’, both of which perhaps make Detailed Coverage section more cumbersome to comprehend.

Lorch et al. (1987) have provided evidence showing that changing of theme momentarily slows down the reading process, because the change imposes higher demands on integration processes. Detailed Coverage consisted of six subthemes, which brought about frequent gaps in the local coherence inside the text unit. These gaps, in turn, may have slowed down the reading process, thus overriding a possible speeding up due to relative unimportance of the content.

The other possible confounding factor that may cancel out the importance effect is ‘information density’. Kintsch and Keenan (1973) demonstrated how reading times increase when the number of propositions in a sentence increases. In other words, the more information a sentence entails, the longer it takes to read. Kintsch and Keenan (1973) manipulated the proposition density of a sentence while keeping the number of words constant. It appears from their report that proposition density also covaried with the proportion of content versus function words in a sentence. In the example given in Kintsch and Keenan (1973: 259), in the low-density sentence 8 out 14 words (57%) were content words, while in the high-density sentence the proportion was 11 out of 16 (69%). However, Kintsch and Keenan (1973) did not measure proposition density as a proportion of content words, but their measure was based on a more theoretical notion of propositional text base proposed by Kintsch (1972). Undoubtedly however, the number of propositions covaries with the number of content words. (For other alternative accounts of the results of Kintsch and Keenan (1973), see Graesser et al. 1980.)

For simplicity, we applied the proportion of content words as a measure of information density. The post-hoc analysis revealed that Detailed Coverage was more dense of information (89% content words) than Introduction (79% content words) or Conclusions (83% content words).

Putting the two issues together, we propose that Detailed Coverage received the most visual attention, because its information density was high and because it contained several theme changes. As we proposed earlier, these effects perhaps cancelled out the importance effect that
was now in the opposite direction as predicted. If our argument is generalizable, it would be a plausible account for the controversial results concerning the selective attention hypothesis.

The above reasoning also applies to the finding that Detailed Coverage brought about the major contribution for the facilitation due to repetition. Being cumbersome to comprehend in the first place, the section provides a lot of room for the facilitation due to increased familiarity to occur. This probably also explains why in Detailed Coverage the facilitation continued to take place also in the third reading.

With average fixation duration, the effect of text structure was dissimilar to other eye movement parameters. First, there was no interaction visible between repetition and text structure. Second, also the main effect of text structure was dissimilar to other parameters. The beginning section was always, regardless of repetition, read with longest average fixation durations, while the ending section obtained the shortest average fixation durations. The finding is in concord with the data reported by Inhoff (1983). He showed that when a story with four structural constituents, Setting, Beginning, Goal Path and Ending (see Mandler and Johnson 1977), is read, more fixation time per letter was allocated to the Setting and Beginning sections than to the Goal Path and Ending sections. Using a visual mask the effect was even more pronounced.

A plausible explanation for our and Inhoff's finding is that in the beginning of the text the reader is required, in order to adequately comprehend the text, to activate his/her prior knowledge and concepts associated with the general theme of the text. The increased processing demands are then, in turn, reflected in the reader devoting comparatively more fixation time to the initial sentences. But as the reader proceeds in the text, and the concepts and background knowledge have become adequately activated, processing demands are reduced. Consequently, individual fixations become shorter. Interestingly, the effect does not seem to diminish with increased familiarity with the text: in all three repetitions the Introduction was read with longest average fixation durations. The absolute magnitude seems to diminish in the third reading, however, but this interaction is not reliable.

In summary, our main results can be presented in the following four points: (1) Repeated exposure to the same text produces a facilitation effect, which is reflected in shorter fixation durations, fewer forward
fixations, fewer regressions, and longer saccades. In other words, all eye movement parameters are, on a sentence-by-sentence basis, affected by increased familiarity. (2) Highly important sentences are devoted more visual attention than unimportant sentences, regardless of repetition. (3) Those sections of a text that are cumbersome to comprehend in the first place produce the most facilitation due to repetition. (4) For each successive reading, average fixation durations are longer in the beginning of a text than in the end.

References


