How Prior Knowledge and Text Coherence Affect Eye Fixations in Hypertext Overviews

Ladislao Salmerón (lalo@ugr.es)
University of Granada - Department of Experimental Psychology, Campus de Cartuja, s/n.
18071 Granada, Spain

Thierry Baccino (baccino@unice.fr)
University of Nice Sophia-Antipolis – LPEQ - 24, Av des Diables Bleus
06357 Nice, France

José J. Cañas (delagado@ugr.es)
University of Granada - Department of Experimental Psychology, Campus de Cartuja, s/n.
18071 Granada, Spain

Abstract

Graphical overviews are text devices aimed to foster learning by conveying in a schematic way the text structure. Despite its importance in current learning systems such hypertext, psychological research does not agree on how overviews affect comprehension. Little is known about how hypertext readers process graphical overviews, and how this processing influence comprehension. In the present paper we report an experiment using the eye-movements technique aimed to explore the role of prior knowledge and coherence on the visual processing of graphic overviews. Results reveal that both variables influence visual processing of graphical overviews and that this processing systematically affected what was learned from hypertext.

Introduction

Current psychological models describe text comprehension as the process of acquiring a coherent mental representation of the text. This representation is build at different levels: a macrolevel of text general organization, and a microlevel of subordinate text content (e.g. Kintsch, 1998). In lineal texts, authors use a specific presentation order to signal text organization to readers (e.g. important ideas are displayed at the beginning of the text, and are discussed in detail in successive sections). However, in non-linear systems like hypertext reading order of text sections is not fixed by authors, so readers have to rely on other text features to form a coherent macrolevel representation of the text. Different hypertext devices assist readers in this task, like graphical overviews conveying text structure. However, current psychological research does not agree on how overviews affect hypertext reader's comprehension (Salmerón, Cañas, Kintsch & Fajardo, 2005), and there exist evidence for positive, null and negative effects. Researchers have identified important issues not addressed in prior research that could be responsible of the current confusing situation (e.g. Dillon & Gabbard, 1998). Indeed, little is known about how hypertext readers process graphical overviews, and more importantly, how different processing strategies influence text comprehension. In this paper, we first review relevant literature on the topic to draw hypotheses on the processes involved on visual processing of overviews. Next, we describe an experiment aimed to test these hypotheses using the eye-movements methodology. Finally, we discuss current confusing results in light of the experiment data, and propose future research lines.

Graphical overview processing strategies

Reader's prior knowledge and text coherence are main factors affecting comprehension (Kintsch, 1998). Thus, we will first explore how both factors are involved in hypertext overview processing. Readers with prior knowledge on a text topic can activate it in order to help building a coherent text representation, or whenever a text difficulty arises. In hypertexts, high knowledge readers can make use of their existing knowledge to organize the different sections of the text. By contrast, low knowledge readers must rely on different hypertext features to organize their text representation. Therefore, we can hypothesize that low knowledge readers would visually process overviews more often than their high knowledge counterparts. Some works studying prior knowledge and eye movements reveal a similar effect: readers provided with prior knowledge information perform fewer and shorter regressions than those without background information (Kaakinen, Hyönä & Keenan, 2003; Wiley & Rayner, 2000).

Text coherence refers to the extent to which a reader is able to understand the relations between ideas in a text. Coherence properties come from those text features that help readers to understand and link ideas on it. In hypertext, reading order has coherence properties that could influence its comprehension easiness. In general, if pupils mainly 'jump' between semantically related sections, they will understand better than if they 'navigate' between unrelated parts (Salmerón et al., 2005). Therefore, we can expect that readers of an incoherent ordered hypertext would process overviews more often in order to overcome comprehension difficulties derived from coherence breaks on the text. Supporting this

hypothesis, prior research has found that pupils reading ill-ordered texts perform more and longer refixations (i.e. fixations after the first pass reading) to the segments resolving the text incoherence (Vauras, Hyönä & Niemi, 1992; see also Rink, Gámez, Díaz & de Vega, 2003).

How overview processing relates to text comprehension

As described in the previous section, prior knowledge and coherence are well known factors facilitating comprehension. However, when considering both factors in the same reading situation, an interaction arouses. Low knowledge readers learn more from a highly coherent text than from an incoherent one, whereas readers with high domain knowledge actually learn more from a less coherent text (McNamara, E. Kintsch, Songer & W. Kintsch, 1996; McNamara & Kintsch, 1996). The explanation for this effect is that unknowledgeable readers cannot fill in gaps in the incoherent text without explicit guidance about relationships among information items; on the other hand, knowledgeable readers who are overguided will not actively use their own prior knowledge to form a complete representation of the text.

In other words, prior knowledge is only beneficial when the reader activates it in order to form a text representation. This knowledge activation can be induced by features in the text (i.e. low coherence), but also be prevented by it (i.e. high coherence, an easy text). Similarly, hypertext overviews could prevent knowledgeable readers from using their existing knowledge to organize a coherent text representation (Shapiro, 1998). Therefore, we would expect that high knowledge readers devoting more processing to the text overview will comprehend less than those focusing on their existing knowledge (thus processing less often overviews). However, overviews could also facilitate comprehension for those readers which do not posses prior topic knowledge, by helping them to build a coherent representation of text macrostructure. Therefore, low knowledge readers that process more actively graphic overviews will actually learn more than those that do not process them.

These effects could be modulated by text coherence. Prior works have suggested that a text support feature such as graphical overviews can be beneficial only when text imposes extra difficulties for learning, for example, when pupils read a text in a low coherent order (Mayer, 1978). Otherwise, overviews would not provide added information, thus could be unhelpful to readers.

We will test these hypotheses in an experiment where participants read several texts that included graphical overviews, while their eye-movements were recorded.

Experiment

In the current experiment we will explore two sets of hypotheses concerning reader's processing strategies of graphical overviews, and its relation with learning from text.
Overview processing strategies:

1. Readers visually process graphical overviews for a longer time when they have low prior knowledge on text topic (compared to those with higher prior knowledge),
2. and when they read a low coherently ordered text (compared to those reading a high coherently ordered text).

Processing strategies and text comprehension:

3. A positive relation holds between amount of time of visual processing of graphical overviews and text comprehension for low knowledge readers,
4. whereas a negative relation exists for high knowledge readers, in both cases only when reading a low coherently ordered text (no effect is expected for high coherent texts).

Method

Participants Thirty-two third-year psychology students from the University of Nice Shopia-Antipolis participated in the study for class credit. All participants were native speakers of French with normal or corrected-to-normal visual acuity. Data of 4 participants was excluded from analyses because of incomplete or inaccurate recordings. Hence, reported analyses are based on data of 28 participants.

Materials and Procedure Participants read a total of 20 expository texts (plus one practice text). Half of these texts were on topics highly related to the participant's field of study (e.g. 'Forgetting', 'Learning'), and the other half were texts on other disciplines (e.g. 'Italian Renaissance', 'Eclipses'). Experimental texts were relatively short (M = 234 words, SD = 17, for the psychology texts; M = 259 words, SD = 18, for the other disciplines texts) and followed a hierarchical organization consisting on five sections (see Appendix for a sample text). There was an introductory passage, two sections on two main topic issues, and other two sections giving examples of each two main issues. In each section, no explicit reference to other sections was made. For each text there was a coherently ordered version, that was presented as follows: introduction, topic issue 1, continuation / example of topic issue 1, topic issue 2, continuation / example of topic issue 2; and a incoherently ordered version, that read as follows: continuation / example of topic issue 2, continuation / example of topic issue 1, topic issue 2, topic issue 1, introduction. In addition, all texts were presented with a unique graphic overview that depicted the hierarchical structure of the text (Figure 1). The overview was available during all reading on the upper part of the screen, and each text was presented one section at a time on the bottom part of the screen, with the participant indicating when he / she wanted to move to the next section by pressing a key. The preceding section disappeared when new section was presented. Although presentation of text was self-paced, the order in which sections appeared was fixed by the experimenter, rather than chosen by the participant, as would normally be the case for hypertext. This was done in order to avoid noise in comprehension measures introduced by participants following heterogeneous reading orders (Salmerón et al., 2005). Students were instructed to read each text carefully enough to answer some comprehension questions after reading all texts. There were two open ended

questions for each text: one that referred to a single statement presented in one section (text-based question) and another which answer required to link at least two ideas presented in two or three separate sections. Comprehension questions were presented after all readings were finished, in the same individually randomized order in which texts were read. Finally, participants rated their prior knowledge on the topic texts prior to the experiment in a scale between 0 (no prior knowledge) to 10 (high prior knowledge).

Apparatus Eye movements were recorded by a Tobii 1750 eye-tracking system. Data was registered binocularly at a rate of 50 Hz. Participants were seated approximately 60 cm from the presentation screen. Their head movements were restricted by means of a chinrest.

Design The experiment followed a 2 x 2 x 5 x 2 within-subjects design with prior knowledge (low and high), text coherence (low and high), section order (first to last section) and zone (overview and text) as factors. Experimental manipulation of familiarity was compared to participant's rated prior knowledge. Supporting the experimental grouping, participants declared having more prior knowledge before the experiment for psychology texts (M = 5.1, SD = 1.84) than for texts on other disciplines (M = 2.87, SD = 1.59), t(54) = 4.82. Dependent variables included first-pass and second-pass fixations of overview headings and text, in addition to success rate on text-based and inferential questions.

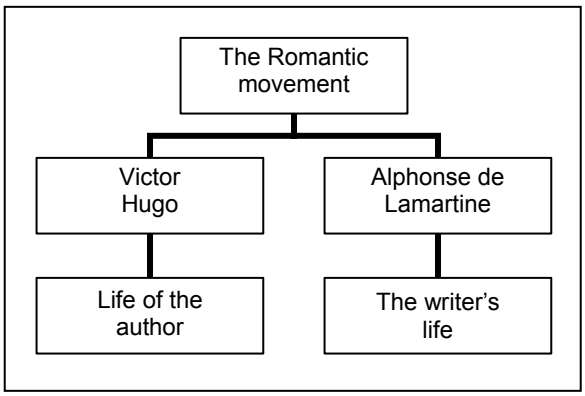

Figure 1: Sample graphical overview for the 'Romantic movement' text.

Results

Eye-movements data Before the statistical analyses, eye-movements data were weighted on the basis of the number of characters in each critical zone. Two main zones were considered: the graphical overview and the text. For the prior, we first analyzed five regions corresponding to the section headings presented in the overview, and afterwards data was collapsed into a single value. In addition, individual distributions were analyzed in order to detect outliers (fixation times 2 SD above or below the participant's mean). Those values (between 1.2% and 2% of data) were replaced by the participant's mean fixation time. For each dependent measure, prior knowledge (2) x text coherence (2) x section order (5) x zone (2) ANOVAs were performed. For all analyses, differences declared as significant had $p < .05$.

First-pass fixation duration. Main effects of prior knowledge, $F(1,27) = 119$, $MSe = 92.7$; section order, $F(4,108) = 13.7$, $MSe = 63.3$ and zone, $F(1,27) = 2573.4$, $MSe = 481.8$ were observed. As expected, first-pass fixations were longer for low prior knowledge texts. Fixations were longer for the text than for the graphical overview. In addition, a linear function described results for section order, $F(1,27) = 34.6$, $MSe = 89.1$. Processing time for text sections decreased as readers advanced through successive sections. Significant interactions were found between prior knowledge x zone, $F(1,27) = 32$, $MSe = 32.6$, and section order x zone, $F(4,108) = 35.9$, $MSe = 58.3$. Two second order interactions help to qualify these results: prior knowledge x section order x zone, $F(4, 108) = 5.1$, $MSe = 51.4$, and prior knowledge x section order x coherence, $F(1,27) = 3.1$, $MSe = 48.6$. Concerning the first one, results showed that the effect of processing time of section order x zone hold true for low knowledge readers, $F(1,27) = 36.7$, $MSe = 119.6$, but not for high knowledge, $F(1,27) = 3.8$, $MSe = 77.9$, $p < 0.1$. That is to say, low knowledge readers devoted more processing time to the graphical overview at the first encountered section, but this pattern reversed on the following ones (second to fifth presented section). But high knowledge readers devoted similar processing time to both zones at the first section, and after they focus mainly on the text. Finally, regarding the prior knowledge x section order x coherence interaction, results showed that on the first section presented high knowledge readers processed longer low coherent texts, $F(1,27) = 6.1$, $MSe= 34.8$, but no coherence effect appeared for low knowledge readers, $F < 1$.

Second-pass fixation duration. ANOVAs with this dependent variable revealed main effects of prior knowledge, $F(1,27) = 91.1$, $MSe = 378$, section order, $F(4,108) = 44$, and coherence, $F(1,27) = 5.5$, $MSe= 470$. The two firsts were similar than those observed in the analyses with first-pass fixation duration: there were longer processing for low knowledge readers and a linear decreasing function of section order. Regarding the coherence main effect, low coherent texts were reprocessed longer than the high coherent ones, as predicted. In addition, significant interactions were found between prior knowledge x section order, $F(4,108)= 4.8$, $MSe = 244$, prior knowledge x zone, $F(1,27) = 14.6$, $MSe = 172$, and section order x zone, $F(4,108) = 10.4$, $MSe = 303$. An interpretation of these effects must wait until the mediating effect of a third variable is considered on two significant second order interactions: prior knowledge x section order x zone, $F(4,108) = 4.2$, $MSe = 202$, and prior knowledge x section order x coherence, $F(4,108) = 2.7$, $MSe = 171$. Regarding the first interaction, low knowledge readers reprocessed longer the overview than the text on the first section presented, $F(1,27) = 26.6$, $MSe = 495.9$, but no difference was found for the subsequent four sections, $F < 1$. By contrast, high knowledge readers showed no difference for the first two sections, $F(1,27) = 1.5$, $MSe = 347.8$, but longer reprocessing of the text for the later sections (third to

fifth), F(1,27) = 15.3, MSe = 242.5. Finally, concerning the prior knowledge x section order x coherence interaction, results showed an effect opposed to that found for first-pass data: on the first section presented high knowledge readers showed no coherence effect, F <1, but low knowledge readers reprocessed longer low coherent texts than the high coherent ones, F(1,27) = 6, MSe = 579.6.

Comprehension data The relation between overview processing and text comprehension was explored through a series of multiple regression analyses. For each set of data resulting from crossing the variables prior knowledge (low and high) and coherence (low and high), a multiple regression analysis with the forward stepwise method was performed, for each dependent variable (success rate for text-based and inference questions), with first-pass and second-pass fixation duration for the two zones considered (overview and text) as predictors. Section order presentation was not considered here with the aim to keep a trade-off between the informativeness and clarity of the regression formula.

Regression analyses with score on text-based questions clearly supported our hypotheses. For the two high coherence groups, no variable predicted comprehension, whereas for the low coherence groups, the variable second-pass fixation duration of the graphic overview resulted to be the only significant predictor. More concretely, for low knowledge learners reading low coherent texts a positive relation between variables was observed, R^2 = 0.18, F (1,26) = 5.73, whereas for high knowledge pupils reading low coherent texts a negative relation aroused, R^2 = 0.25, F (1,26) = 8.83. Finally, regression analyses with score on inference questions showed an unexpected result: a negative relation between second-pass fixation duration of the graphic organizer and comprehension for the high knowledge and high coherence group, R^2= 0.28, F (1,26) = 10.28. No other predictors resulted significant for this dependent variable.

Discussion

The experiment reported in this paper identifies key factors affecting visual processing of graphic overviews, and helps to understand how this processing is related to the learning gain from a text.

In general, results support our claims that prior knowledge and coherence are main factors not only in comprehension, but also in processing graphical overviews. Both processing and reprocessing is longer for low prior knowledge readers than for high knowledge (Kaakinen et al., 2003; Wiley & Rayner, 2000), and reprocessing is also longer for low coherently ordered text than for high coherent texts (Vauras et al., 1992; Rink et al., 2003). In addition, results show several interactions that help us understand overview processing. Results suggest that readers find graphic overviews useful mainly at early stages of the reading. This effect is particularly evident for readers faced with unfamiliar texts, in which they devote more time to both process and reprocess graphic overviews than the text itself. Furthermore, results suggest that readers look at graphic overviews in order to overcome problems associated to the construction of a coherent representation of text macrostructure. This is clearly shown by the interaction between prior knowledge and coherence, on the first-pass and second-pass fixation data. Immediately after starting reading a new text, high knowledge readers seem able to identify an incoherently ordered text, thus they devote more processing time (i.e. first-pass fixations) to both the graphical overview and the text than to coherently ordered texts. By contrast, data suggest that low knowledge readers need more time to identify an incoherent ordered text, so they only devote more time to the ill-ordered materials after a first processing of it (i.e. longer second-pass fixations).

Results also give support for a direct relation between visual processing strategies of overviews and learning from text. As expected, these strategies are particularly important for low coherently ordered texts (Mayer, 1978). This could be the fact of most hypertext reading, provided that a coherent order is not systematically followed by a majority of these readers (Salmerón, Kintsch & Cañas, in press). Data of the reported experiment reveal that those readers of unfamiliar texts that reprocess the graphic overview during more time end up comprehending the text better (measured by the text-based questions). By contrast, an opposite effect holds for readers of familiar texts, which suggest that a 'long reprocessing strategy' (i.e. longer second-pass fixations on the graphical overview) prevents knowledgeable readers from activating their existing knowledge to fully comprehend a text.

In addition, results show that longer reprocessing is also detrimental for high knowledge learners reading coherently ordered texts, as measured by inference questions. An easy explanation could be that this result just revealed a lack of activation of existing knowledge, as was considered the case for low coherent texts. However, from a theoretical point of view, high knowledge readers are not induced to engage in an active processing of text by a high coherent text (McNamara et al., 1996; McNamara & Kintsch, 1996). Therefore, either if readers just focus on the text or if they reprocess longer the overview, they would not necessarily further activate their existing knowledge, at least not to the extent to which they will when reading an incoherent text. Therefore, learning differences observed could not be associated to a disparity in knowledge activation. A second possible explanation is that the fact that high knowledge readers learning less reprocessed for longer the overview could be interpreted as a miscomprehension signal. That is to say, that these readers could have experienced comprehension problems during their reading, thus they tried unsuccessfully to understand from the overview the miscomprehended parts. It is interesting to note that this effect holds only for inference questions, intended to assess comprehension at deeper levels (i.e. situation model). The fact that readers rely mainly on that representation in order to assess their comprehension during reading (Rawson, Dunlosky, & Thiede, 2000), and not on the textbase representation assessed by the text-based questions, gives some support to this interpretation.

However, given the correlational nature of the analyses relating processing and learning, we should be cautious about the conclusions drawn here. In order to clarify the nature of the unexpected effect on the negative relation between duration of second-pass fixations and inference questions for

familiar coherent texts, the eye-movements technique could be combined with a think aloud procedure. We would expect that readers of familiar high coherently ordered text reprocessing for longer the overview might express more comprehension problems on the think aloud protocols than those reprocessing less the overview.

The present work takes part of a research approach that looks to maximize our knowledge on the field of (hyper)text comprehension by looking up at individual differences on strategic processing (e.g. Hyönä, Lorch & Kaakinen, 2002). By exploring these processes with the eye-tracking methodology we aim to clarify the confusing empirical data on the field of hypertext comprehension. In this sense, the current work can exemplify how two different experiments using similar procedures can lead to different results, if they do not take into account readers' strategic processing. In fact, that was the case in most of the research exploring the effects of overviews in hypertext comprehension revised in Salmerón et al., 2005). For example, two similar experiments using hypertext overviews could provide different comprehension outcomes if by any chance the distribution of readers following the previously described 'long reprocessing strategy' were unequally distributed between conditions and / or experiments.

Acknowledgments

This research was funded by research Grant AP 02-1503 and research Project Rayuela-SEJ2004-05430/PSIC from the Spanish Minister of Education.

References

Dillon, A., & Gabbard, R. (1998). Hypermedia as an educational technology: A review of the quantitative research literature on learner comprehension, control, and style. *Review of Educational Research, 68*, 322-349.

Hyönä, J., Lorch, R. F. & Kaakinen, J. K. (2002). Individual differences in reading to summarize expository text: evidence from eye fixation patterns. *Journal of Educational Psychology, 94,* 44-55.

Kaakinen, J. K., Hyönä, J. and Keenan, J. M. (2003). How prior knowledge, WMC, and relevance of information affect eye fixations in expository text. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*, 447-457.

Kintsch, W. (1998). *Comprehension: A paradigm for cognition*. New York: Cambridge University Press.

Mayer, R. E. (1978). Advance organizers that compensate for the organization of text. *Journal of Educational Psychology, 71*, 880-886.

McNamara, D. S., Kintsch, E., Songer, N., & Kintsch, W. (1996). Are good texts always better? Interaction of text coherence, background knowledge, and levels of understanding in learning from text. *Cognition and Instruction, 14,* 1-42.

McNamara, D. S., & Kintsch, W. (1996). Learning from text: effect of prior knowledge and text coherence. *Discourse Processes, 22*, 247-288.

Rawson, K. A., Dunlosky, J., & Thiede, K. W. (2000). The rereading effect: Metacomprehension accuracy improves across reading trials. *Memory & Cognition, 28*, 1004–1010.

Rink, M., Gámez, E., Díaz, J. M., & de Vega, M. (2003). Processing of temporal information: evidence from eye movements. *Memory & Cognition, 31*, 77-86.

Salmerón, L., Cañas, J. J., Kintsch, W., & Fajardo, I. (2005). Reading strategies and hypertext comprehension. *Discourse Processes, 40,* 171-191.

Salmerón, L., Kintsch, W. & Cañas, J. J. (in press). *Reading strategies and prior knowledge in learning with hypertext*. Memory & Cognition.

Shapiro, A. M. (1998). Promoting active learning: The role of system structure in learning from hypertext. *Human-Computer Interaction, 13,* 1-35.

Vauras, M., Hyönö, J., & Niemi, P. (1992). Comprehension coherent and incoherent texts: Evidence from eye movement patterns and recall performance. *Journal of Research in Reading, 15,* 39-54.

Wiley, J. & Rayner, K. (2000). Effects of titles on the processing of text and lexically ambiguous words: Evidence from eye movements. *Memory & Cognition, 28*, 1011-1021.

Appendix

Sample of an unfamiliar text. The organization of sections is identified in brackets. Original texts were written in French.

[Introduction] *Victor Hugo*

Victor Hugo is a model of writers of the Romantic movement. As the rest of Romantics, he loved nature and exotism, and liked to be considered as an exiliate of society. Indeed, he conceived poets as prophets. He mastered French vocabulary better than any other writer. The richness and variety of his works is astonishing.

[Continuation / example of topic issue 1] *Life of the author*

The author wrote poetry, novels, literary essays and political pamphlets. During a long period he believed in Monarchy. Indeed, he became friend of Louis-Philippe who crowned him lord of France. He was against dead penalty, and he always defended liberty and rights of poor people.

[Topic issue 2] *Alphonse de Lamartine*

Alphonse de Lamartine was born in Macon in 1790. After living the most part of his childhood in Milly, he moved to Italy, and afterwards he started working with Louis XVIII. He started writing during this period of his life. His first book, "Poetic meditations", was the first book of the Romantic movement in French literature.

[Continuation / example of topic issue 2] *The writer's life*

Religious topics play an important role in his poetry. However, the dead of his daughter Julia in 1832, and his increasing politic engagement, changed the nature of his faith, and the poet became supporter of a liberal Christianism.