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Interaction between prior knowledge and concept-map structure on hypertext comprehension, coherence of reading orders and disorientation

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ABSTRACT

The study examined the interaction effects of prior knowledge and hypertexts structure (network vs. hierarchy) on comprehension. Comprehension was investigated analyzing jointly three dependent variables: comprehension outcomes, coherence of the reading sequences and feelings of disorientation. The results supported most of the assumptions showing an interaction effect on each measure. For low prior knowledge readers, a hierarchical structure improved comprehension performance, helped them to follow coherent reading sequences and reduced their feelings of disorientation. For high prior knowledge readers, comprehension performance and feelings of disorientation were not affected by the type of structure. Moreover, prior knowledge was a relevant resource to cope with the cognitive requirements of reading non-linear texts. In the network condition, prior knowledge supported better comprehension, led the readers to follow more coherent reading sequences and limited their feelings of disorientation. The discussion dealt with processes based on prior knowledge involved in hypertext comprehension, and stressed the need for conducting further investigations on the nature of the on-line inferences and on relations between performance, navigation and disorientation.

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1. Introduction

For 20 years hypertext systems have received more and more interest as instructional devices. As for more classic learning materials (e.g. learning from texts), prior domain knowledge plays a main role in comprehension and learning (for the literature reviews see, Amadiou and Tricot, 2006; Dillon and Gabbard, 1998; Shapiro and Niederhauser, 2004; Shlechter, 1993). Prior knowledge is a relevant resource for coping with cognitive demands entailed by learning from hypertexts (Scheiter and Gerjets, 2007; Scheiter et al., 2009). Because hypertexts organize information in a non-linear way, readers have to control their reading, evaluate their information needs and seek information by selecting links (Shapiro and Niederhauser, 2004). Reading non-linear information causes discontinuous processing of hypertext contents (Storror, 2002) and may hamper the construction of a coherent mental representation of hypertext contents, because readers experience difficulties establishing semantic relations between information nodes (Salmérón et al., 2005, 2006). Converse to a network structure, a more linear or hierarchical structure is usually expected to reduce navigational and comprehension difficulties (DeStefano and Lefevre, 2007; Potelle and Rouet, 2003; Scheiter and Gerjets, 2007). Indeed, either such a structure guides navigation (e.g. a linear structure allows only backward and forward jumps) or it conveys a represen-

tation of content organization as a concept map for instance. Concept maps are classically defined as meaningful representations of concepts and their relations; they are “a schematic device for representing a set of concept meanings embedded in a framework of propositions” (Novak and Gowin, 1984, p. 15).

Inquiring into the effects of prior knowledge according to the type of structure on hypertexts comprehension allows understanding of how a knowledge base might help readers to cope with these requirements and difficulties. Outcomes measures provide indications on the level of performance, yet, they do not provide an exhaustive understanding of the underlying cognitive mechanisms. To study difficulties and cognitive processes during hypertexts comprehension, additional data is needed. Firstly, recording and examination of navigation behaviors should allow inferring the underlying cognitive processes. Because comprehension involves semantic processing to construct coherent and elaborated mental representations (Kintsch, 1988), studying how readers construct their reading sequences should inform on the on-line inferences drawn by readers. Secondly, taking into account the disorientation in hypertexts experienced by readers should inform about the processing which causes difficulties and may hamper comprehension. Readers' disorientation refers to difficulties knowing where they are in a hypertext and how to reach a target location (Conklin, 1987). Because disorientation is mainly measured and examined in research on information seeking tasks (e.g. McDonald and Stevenson, 1996), empirical evidences of disorientation in hypertext comprehension tasks are required.

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Hence, the current study aims firstly to use jointly the measures of comprehension outcomes, navigation and disorientation in order to improve our understanding of the effects of prior domain knowledge and hypertext structures on hypertexts comprehension. Secondly, the study proposed to use different measures of navigation (measures of coherence of reading sequences) in order to identify the types of cognitive processes engaged during hypertexts reading.

1.1. Prior knowledge and comprehension outcomes

In the literature about hypertexts, the interaction effects between the level of prior knowledge and the type of hypertext structure received much interest (e.g. Amadiou et al., 2009a; Calisir et al., 2008; Potelle and Rouet, 2003; Scheiter and Gerjets, 2007). Most of the studies investigating the effects of prior knowledge used global measure of comprehension or learning. The majority of the empirical results confirmed a lack of effect of the different hypertext structures for high prior knowledge readers and a positive effect of guiding structures, such as hierarchical structures, for low prior knowledge readers (Calisir and Gurel, 2003; Gay, 1986; Lee and Lee, 1991; Patel et al., 1998; Recker and Pirolli, 1995; Shin et al., 1994). A concept representation of the contents (de Jong and van der Hulst, 2002) as well as a structure limiting navigation (Kerwin, 2006) supports low prior knowledge readers' performance. However, the nature of the comprehension processes remains unclear in this set of studies because only a global measure of comprehension performance was considered.

For 10 years, several studies have attempted to infer the nature of the comprehension processes on the basis of the assessment of different levels of texts representation: text base and situation model (Kintsch, 1988). The text-base is a representation implying text propositions explicitly mentioned in texts while the situation model is a representation implying information from both texts and readers' prior knowledge base. In order to construct an elaborate situation model, readers have to infer relations between elements of texts information. Usually, the assessment method of situation models in hypertext comprehension consists of questions requiring inferential activity to connect different information from different nodes (Amadiou et al., 2009a; Madrid et al., 2009; Salmerón et al., 2005). Within this framework of the Construction-Integration model, it may be expected that prior knowledge would mainly promote inferences to construct deep representation of hypertexts contents, that is, a good situation model. Unfortunately, the results on the levels of texts representation have a low consistency and do not support this assumption. Studies indicated that prior knowledge supports comprehension only at the situation model level (Amadiou et al., 2009a; Hofman and van Oostendorp, 1999; Mishra and Yadav, 2006; Müller-Kalthoff and Möller, 2006; Salmerón et al., 2006 second experiment; Shapiro, 1999); conversely, other studies showed a positive effect of prior knowledge only at the text base level (Le Bigot and Rouet, 2007; Salmerón et al., 2005, 2006 first experiment); and finally, other studies pointed out a positive effect of prior knowledge on both levels of representation (Müller-Kalthoff and Möller, 2003, 2004; Potelle and Rouet, 2003).

This state of the art highlights inconsistent results that may be explained by the heterogeneous methodologies of the studies (e.g. complexity of comprehension tasks, features of hypertexts, knowledge domains, etc.). Therefore, it is necessary (a) to continue investigating the levels of texts representation and (b) to investigate additionally the on-line comprehension processes rather than examining outcomes measures only. Indeed, our comprehension of the cognitive processes would benefit from additional investigations on readers' navigation that provide information about on-line processes engaged in construction of texts representations.

1.2. Prior knowledge and navigation

Studying reading behaviors would give more reliable information about the nature of on-line cognitive processes than alone outcomes measures. The methods used to assess navigation usually imply either quantitative measures (e.g. number of opened nodes, navigation patterns) or qualitative measures (e.g. interviews). The research on navigation indicated that high prior knowledge readers exhibited a deep and elaborate navigation, consisting in exploration of a topic in detail, while low prior knowledge readers explored different topics superficially, for example conducting systematic or shallow explorations (Carmel et al., 1992). This shallow exploration would help low prior knowledge readers to understand the relations between the main topics of a hypertext. Last et al. (2001) confirmed that low prior knowledge readers used less elaborate strategies, more based on the hypertext structure (methodical and exhaustive pathways) whereas high prior knowledge readers used elaborate strategies searching familiar contents or those related to his/her interests. High prior knowledge readers follow more structured navigation patterns (Ford and Chen, 2000; Mishra and Yadav, 2006; Rezende and de Souza Barros, 2008). These studies provide important findings explaining how prior knowledge may support navigation in hypertexts. Nevertheless, the lack of cognitive model does not allow interpreting the cognitive processes during navigation. Furthermore, because most of the results come from qualitative studies (Last et al., 2001; Mishra and Yadav, 2006; Rezende and de Souza Barros, 2008), the development of quantitative measures of navigation should increase the reliability of the findings and should allow comparisons between studies.

Since a few years, studies have used texts comprehension models (Kintsch, 1988) to investigate cognitive processes engaged in establishing semantic connections between concepts (between text sections) to construct a coherent mental model of contents. Coherence in reading hypertexts refers to the strength of the semantic relations between the text sections. A high coherence between two text sections (e.g. sharing similar concepts) helps the reader to incorporate the textual information from the text section into what has been previously read. A low coherence between text sections lead readers to generate necessary inferences to maintain coherence and may consume the resources of the reader (Foltz, 1996). Two text sections may share different types of semantic relations, for instance, temporal-causal, referential (argument overlap) or spatial relations (Zwaan and Radvansky, 1998).

A recent experiment on coherence of reading sequences in a hypertext with a network concept map (Amadiou et al., 2009a) confirmed that prior knowledge supported more coherent reading sequences (navigation respecting the temporal-causal relations between text sections). The studies which focused on referential coherence (Salmerón et al., 2005, 2006) did not corroborate any effect of prior knowledge on the coherence of the reading sequences. Nevertheless, the results obtained by Salmerón et al. (2005) revealed that low prior knowledge benefited from high coherent reading sequences (only on the situation model measures) whereas high prior knowledge readers benefited from low coherent reading sequences (only on the situation model measures). These findings stressed that prior knowledge might promote deep processing of hypertexts when readers encounter coherence gaps. It supports inferential activity to fill in the coherence gaps and thus a deeper subsequent comprehension.

Therefore, experiments should be carried out on the coherence of reading sequences with demanding hypertexts (i.e. non-linear structures like a network structure) that does not guide reading sequences as a hierarchical hypertext for instance. Furthermore, the previous studies focused on different types of navigation coherence and tested only one measure of coherence. Assessing coher-

ence of navigation according to different measures should inform about the nature of the semantic relations that readers attempt to establish.

1.3. Prior knowledge and disorientation

Taking into account disorientation would shed light on the demanding processing involved in reading non-linear information because disorientation results from problems in constructing the pathway across a hypertext. Measurement of disorientation received much attention in information search tasks with hypertexts (Gwizdzka and Spence, 2007; McDonald and Stevenson, 1996; Otter and Johnson, 2000). Unfortunately, only a few studies have investigated disorientation in comprehension or learning tasks with hypertexts (e.g. Lee, 2007), even if many authors argue that disorientation problems may explain outcomes (e.g. Mohageg, 1992; DeStefano and LeFevre, 2007).

In a hypertext with low guidance (e.g. network structure), it is usually expected that high prior knowledge readers experience less disorientation than low prior knowledge readers, because they have a previous mental representation of the studied domain. However, results of quantitative studies have highlighted a lack of impact of prior knowledge on disorientation or closed difficulties. For instance, Calisir and Gurel (2003) or Calisir et al. (2008) showed that the perceived control by readers of document processing was neither affected by prior knowledge nor by the type of hypertext structure. Other works have only shown the main positive effects on disorientation of hierarchical structure conveyed by concept maps, but no effects of prior knowledge (Amadiou et al., 2009a; Müller-Kalthoff and Möller, 2003). In comprehension or learning tasks, only qualitative studies concluded on the positive effect of prior knowledge on disorientation. For example, Mishra and Yadav (2006) showed that the lowest prior knowledge participant encountered more disorientation problems – assessed by interviews – than the other participants and followed low structured navigation patterns.

To conclude, because a few studies only have measured disorientation more empirical data is required. Then, studies have used qualitative measures of disorientation limiting comparisons between studies, and other studies used measures reflecting difficulties but not disorientation-oriented (e.g. perceived control). According to Cress and Knabel (2003), disorientation may be structural or conceptual. Structural disorientation refers to difficulties in the processing of physical space (e.g. location of the position in the physical space, representation of the previous path) whereas conceptual disorientation refers to the users' difficulties to meaningfully link the different concepts conveyed by a hypertext. Therefore, the studies dealing with the comprehension processes should focus on the conceptual disorientation rather than on the structural disorientation because comprehension implies mainly conceptual processing (Kintsch, 1988).

1.4. The present study – hypotheses

Three dependent variables were measured for the investigation of hypertexts comprehension processes: comprehension outcomes, coherence of reading sequences and feelings of conceptual disorientation. The comprehension outcomes reflects the constructed mental representation; the coherence of reading sequences reflects the type of on-line processes supporting the establishing of semantic relations between text sections (i.e. information nodes); the feelings of conceptual disorientation reflect the experienced difficulties in navigating through the semantic space. Processing non-linear information in hypertexts requires readers to identify semantic relations between the main concepts of the contents in order to construct a coherent and interconnected men-

tal representation of the contents. Reducing non-linearity of hypertexts by using hierarchical structure would reduce difficulties in processing the semantic contents.

For low prior knowledge readers (LK readers), it was hypothesized that a network structure would hamper comprehension, in particular the construction of a situation model (i.e. deep comprehension) because it requires demanding processes to establish semantic relations between text sections of a hypertext. While a network structure would entail low coherent reading sequences, a hierarchical structure would guide the reading sequences helping readers to maintain coherence exploring text sections which belong to a same topic. Low prior knowledge readers were expected to be more disoriented in a network structure compare to a hierarchical structure.

With respect to high prior knowledge readers (HK readers), the main assumption was that prior knowledge would be a resource to help to cope with the demands of non-linear information processing. In a network structure, HK readers would conduct inferences to construct a good situation model. Therefore, HK readers were expected to outperform LK readers in a network structure and no effect on the type of structure was expected for HK readers. Moreover, it was hypothesized that prior knowledge would support more coherent reading sequences indicating an inferential activity. The HK readers should identify concepts belonging to a same subtopic (category) and their semantic relations. Therefore, they should read a set of related concepts before reading other concepts. They should experience less conceptual disorientation than the LK readers. The synthesis of the hypothesis is presented in Table 1.

2. Methods

2.1. Participants

Thirty-seven University of Toulouse undergraduates (second year) volunteered to participate in the experiment (5 males and 32 females). The mean age was 20.57 years ($SD = 1.64$). All participants were enrolled in psychology courses. Therefore, all participants were unfamiliar with the virology domain.

2.2. Materials

2.2.1. Learning task and materials

A course in the domain of virology was designed for the experiment (in collaboration with an assistant professor of biology). It dealt with the multiplication cycle of the Human immunodeficiency virus (HIV). Unlike others viruses, the HIV topic was chosen in order to promote interest and involvement in the learning task. The contents described how the HIV infects a human cell to produce new viruses. The topic was made up of different concepts (elements, events and actions). The instructional hypertext consisted of 25 text sections (total number of words = 1202). Because

Table 1

Synthesis of the expectations on the effects of both independent variables on the dependent variables.

	Network structure	Hierarchical structure
Low knowledge readers		
Comprehension outcomes	Low	High
Coherence of reading sequences	Low	High
Disorientation	High	Low
High knowledge readers		
Comprehension outcomes	High	High
Coherence of reading sequences	High	High
Disorientation	Low	Low

the aim of this experiment was to study reading sequences, the local coherence of the text sections was as explicit as possible to reduce the comprehension difficulties of each text section. To do that, the requirements of anaphor resolution were limited (repetition of arguments, keeping the same terms), as well as the requirements of establishing relations between ideas (e.g. using of connectors).

Two interactive concept maps were designed. The text sections and concepts were strictly the same in both instructional conditions. The structures of the concept maps were different, reflecting two different organizations of the document: a hierarchical structure vs. a network structure (see Fig. 1a and b).

The hierarchical structure gave a short presentation of the HIV at level 1, the macro-information at level 2 (the cell, the virus and the main stages of the process), the sub-elements and sub-stages at levels 3 and 4. The macro-information was made up of five groupings: (a) description of the virus (b) description of the infected cell (c) entrance of the virus into the cell (d) production of the elements of the virus and (e) departure of the new viruses from the cell. The network structure presented the concepts without any groupings. However, the concepts were connected by relational links reflecting semantic relations, like causal, temporal or spatial relations (rather than organizational links as in the hierarchical structure). In both structure conditions, clicking on a link of the concept map opened a text section and then a link below the text led back to the map where a new concept (or the same concept) could be opened.

2.2.2. Prior knowledge assessment

Each participant was asked to report what he/she knew about the HIV and other viruses and their infectiousness process. None of them had prior knowledge about the viruses and their infectiousness processes. Even if all the participants were unfamiliar with the infectiousness topic, they were given a pre-test of eight questions to determine their level of prior knowledge in the cell biology domain. Indeed the participants had received courses of biology during high school and undergraduate psychology. The questions dealt with the main features of human cells because HIV infects human cells using their characteristics. Each correct answer received 1 point (each partial answer received 0.5 point). An example of a prior knowledge question was as follows: what is the main function of the ribosome? (Expected answer: allowed translation from mRNA to proteins). Based on the median score of the prior knowledge test ($Md = 2.5$; from 0 to 8), the participants were split into two groups: the high prior knowledge group (HPK group,

$N = 18$, $M = 3.99$, $SD = 1.19$) and the low prior knowledge group (LPK group, $N = 19$, $M = 1.70$, $SD = 0.86$).

2.2.3. Comprehension performance measure

The comprehension performance was assessed measuring the two levels of text representation: the text base and the situation model. All questions required short answers and dealt with anatomical and functional information of the infectiousness process.

The text-based questions required the participants to remember information explicitly mentioned in a text section consisting of one or two sentences. An example of a text-based question was as follows: to answer the question “what are the actions of the gp proteins during the fusion of the envelope?” the information from only one text section was “. . . the gp proteins pierce the membrane and attach it to the envelope. . .”. Sixteen short questions assessed the text-base representation (Cronbach's alpha = .71).

The inference questions, assessing the situation model, required the participants to establish concept links between two or more text sections (the participants had to possess a representation of implicit relations between concepts). The concept links could be spatial relations (readers infer that an element belongs to an anatomical structure), temporal relations (readers infer a temporal sequence between events or actions), or causal relations (readers infer causes or consequences of an event or an action). For example, to answer the inference question “Why the viral RNA must be coded in viral DNA?” the participants needed to infer the relation between information conveyed by two different nodes: “. . . the enzyme ‘A’ constructs a first DNA strand from the viral RNA. Next, from the first viral DNA strand, the enzyme constructs a second identical viral DNA strand. Thus, the genetic information of the virus is transformed into viral DNA” and “The viral DNA strands enter the nucleus. Inside the nucleus, a viral enzyme, the enzyme ‘B’ acts, randomly cutting the cell's DNA. Then, the enzyme ‘B’ splices the viral DNA in the middle of the cell's DNA. Thus, the viral DNA is integrated into the cell's DNA”. The expected answer was “because the genetic information of the virus must be in DNA to be integrated to the cell's DNA”. Fifteen inference questions assessed the situation model representation (Cronbach's alpha = .79).

2.2.4. Reading on-line measure

The reading sequences were recorded with the freeware “Tracur Internet 0.02.0027”. The freeware recorded for each participant the reading sequence of the text sections and the time spent reading each text section and the concept map.

In the text comprehension research domain, coherence may be defined as the capacity of readers to understand relations between

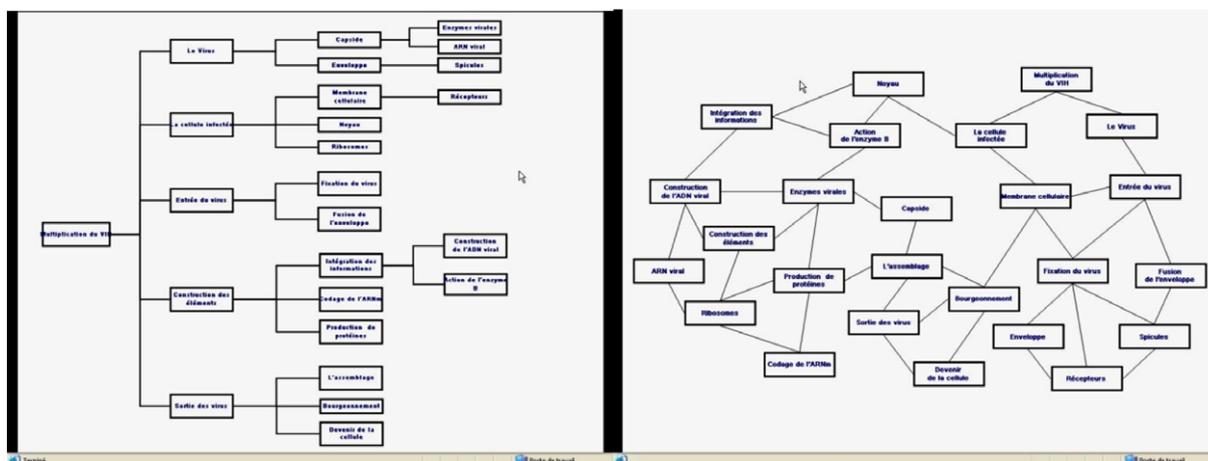


Fig. 1. Hierarchical concept map (on the left), network concept map (on the right).

the ideas of a text. The global coherence refers to relations between information chunks that are organized and interrelated into higher chunks (Graesser et al., 1994). The global coherence is reached if incoming information may be connected to the macrostructure or earlier read information. To establish coherence, readers have to infer relations between text sections. Thus a coherent reading sequence is a reading sequence that helps readers to organize ideas in a macrostructure thanks to a limited demand to infer relations between text sections. In network structures, the coherence of reading sequences indicates how the readers are able to construct relations between text sections. In other words, the measured coherence should provide information on the inferences used by the readers.

Because different types of coherence exist, the present experiment used two measures of coherence. Firstly, a thematic coherence of the reading sequences was assessed. This coherence was based on the hierarchical organization of the text sections because the hierarchy conveyed a macrostructure of the domain. It reflected reading of text sections belonging to the same category (i.e. topic). A jump between two text sections was highly coherent (i.e. it was scored by 1) if both text sections belonged to the same category and if they were at the same ordination level or if one was directly subordinate or superior to the other one. The distance between two text sections was scored according to the path required to go from one to the other. One point was given for each intermediate text section to access the other text section. A mean thematic coherence score was computed for each participant's reading sequence. The more the coherence score tended to "1", the more coherent was the reading sequence.

Secondly, the infectiousness process by viruses is a knowledge domain that implies temporal-causal relations between elements. Therefore, a temporal-causal coherence of the reading sequences was assessed measuring the distance between the participants' reading sequences and the chronological sequence of the multiplication cycle of the virus. For instance, when a participant jumped from text section A to text section C or from text section C to text section A, the distance was recorded as "2". A move respecting exactly the temporal-causal sequence (e.g. from text section D to text section E or text sections E–D) received a distance score of "1". This coherence measure was only computed for the reading of the text sections belonging to the three last categories of the hierarchy, because they dealt with the steps and sub-steps of the infectiousness process. As for the thematic coherence, a mean temporal-causal coherence score of "1" reflected high coherence.

2.2.5. Conceptual disorientation measure

Feelings of conceptual disorientation were measured using a part of the set of subjective rating scales designed by Ahuja and Webster (2001). The scales were modified according to our material, and assessed the perceived difficulty. Three 7-point rating scales (1 = "Completely disagree", 7 = "Completely agree") were selected to assess disorientation. The scales corresponded to "your difficulty with: (a) I experienced difficulties to understand the relationships between the different pages of the document [rating of 1–7] (b) I experienced difficulties to know which page to consult next [rating of 1–7] (c) I experienced difficulties to know my location in the lesson [rating of 1–7]. The three disorientation scales showed a strong reliability (Cronbach's alpha = .86). A mean disorientation score for each participant was computed from the three rating scales.

2.3. Design and procedure

Participants were tested in groups of 1–5. The duration was roughly 60 min. The participants were randomly assigned to the hierarchical structure condition or to the network structure condi-

tion. Firstly, the participants filled out the template assessing knowledge about the viruses and prior knowledge about human cells. A *t*-test indicated that the average prior knowledge score did not differ significantly between the hierarchical structure group ($M = 2.71$, $SD = 1.34$, $N = 19$) and the network structure group ($M = 2.92$, $SD = 1.76$, $N = 18$), $t(35) = 0.40$, $p = .69$.

Then, participants were instructed to learn the materials in order to understand the HIV multiplication cycle. They had 30 min maximum to learn the materials (a clock was available during the learning task in order to help the participants control their learning pace). Before starting, they were instructed on how to use the hypertext. The instructions stressed that they had to study the hypertext's contents to answer a series of questions at the end of the study session. After learning the text, participants rated their feelings of disorientation. Then they performed the text-based questions followed by the situation model questions. The participants had no time limit for answering the questions.

3. Results

For the statistical analyses, 2×2 (structure \times prior knowledge) between-subject factorial ANOVAs were conducted on the measures. The partial eta-squared (partial η^2) was used as the measure of effect size.

3.1. Learning outcome measures

A 2×2 ANOVA was applied to the comprehension data (text base and situation model scores) and the statistical results are given in Table 2. The means and standard-deviation of the text-based questions are shown in Fig. 2a. As indicated in Table 2, the scores of the text-based questions were not affected by the type of structure. However, the HK group ($M = 0.51$, $SD = 0.16$) outperformed the LK group ($M = 0.36$, $SD = 0.18$). Because the interaction was also significant, pairwise comparisons were conducted. They revealed a positive effect of the hierarchical structure for the LK group ($p < .05$), but there was no effect of the structure for the HK readers (*ns*). Moreover, the HK readers outperformed the LK readers only in the network structure ($p < .005$). There was no significant effect of prior knowledge in the hierarchical condition (*ns*).

As far as the situation model scores are concerned, the means and standard-deviation of the inference questions are shown in Fig. 2b. Only a significant interaction effect was observed on the situation model scores. As expected, the hierarchical structure had a positive effect on the inference questions scores for the LK group ($p < .05$), whereas there was no effect of the structure for the HK group (*ns*). Moreover, the HK readers had higher performances than the LK readers in the network structure ($p < .05$), but there was no effect of prior knowledge in the hierarchical structure (*ns*).

In sum, the analyses conducted on the scores of the text-based and inference questions revealed similar results. Comprehension was affected at both levels of text representation by the structure for the LK group and by the prior knowledge in the network condition.

3.2. Reading sequences

The reading times were analyzed in order to control the processing durations of the map and the text sections. The mean and standard-deviations are presented in Table 4. 2×2 ANOVAs computed on the three reading times did not reveal any significant effect (all $p > .10$). Then analyses were conducted on each coherence score of the reading sequences (the statistical results are gi-

Table 2
Source table of 2×2 independent-measures ANOVA for text base and situation model scores.

	ANOVA				Pairwise comparisons			
	Subject	Structure	Prior knowledge	Structure \times prior knowledge	Structure effect		Prior knowledge effect	
					LK	HK	Network	Hierarchy
Text base scores								
df	33	1	1	1	1	1	1	1
MSE		–	0.21	0.12	0.14	–	0.31	–
F		1.28	8.00**	4.44*	5.39*	0.46	11.88**	0.27
Partial η^2		–	0.20	0.12	0.14	–	0.27	–
Situation model scores								
df	33	1	1	1	1.00	1.00	1.00	1.00
MSE		–	–	0.15	0.15	–	0.17	–
F		0.69	1.37	4.58*	4.52*	0.84	5.35*	0.48
Partial η^2		–	–	0.12	0.12	–	0.14	–

* $p < .05$.
** $p < .01$.
*** $p < .001$.

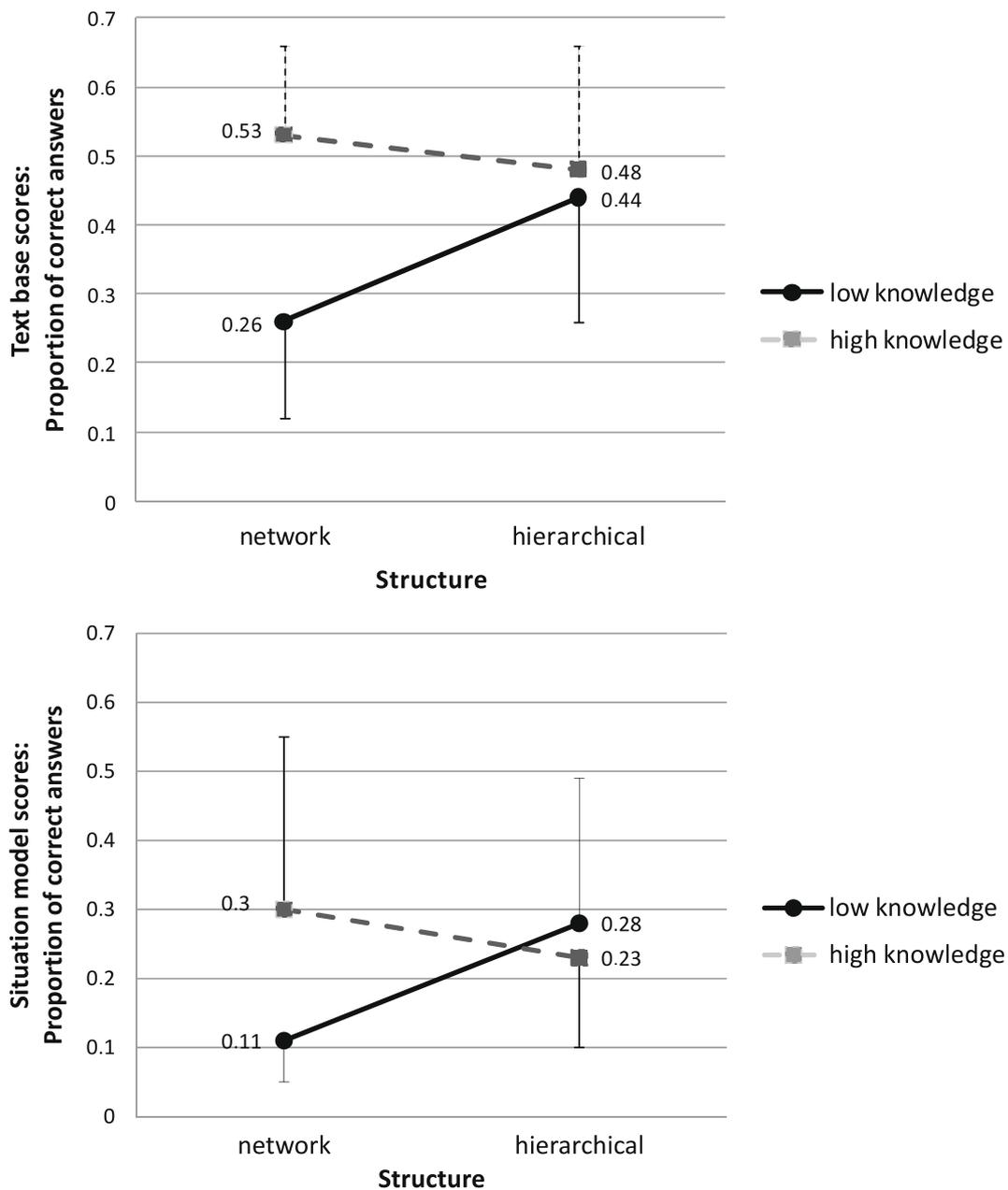


Fig. 2. Proportion of correct answers for text-based questions (text base scores) and for the inference questions (situation model scores).

Table 3Source table of 2×2 independent-measures ANOVA for thematic and temporal-causal coherence of reading sequences.

	ANOVA				Pairwise comparisons			
	Subject	Structure	Prior knowledge	Structure \times prior knowledge	Structure effect		Prior knowledge effect	
					LK	HK	Network	Hierarchy
Thematic coherence scores								
df	33	1	1	1	1	1	1	1
MSE		5.35	–	0.18	3.83	1.74	0.09	0.08
F		267.23***	0.02	8.80**	191.42***	87.28***	4.69*	4.12*
Partial η^2		0.89	–	0.21	0.85	0.73	0.12	0.11
Temporal-causal coherence scores								
df	33	1	1	1				
MSE		3.93	–	–				
F		51.47***	2.23	1.20				
Partial η^2		0.88	–	–				

* $p < .05$.** $p < .01$.*** $p < .001$.

ven in Table 3). The means and standard-deviations are given in Table 4.

A 2×2 ANOVA conducted on the thematic coherence scores of the reading sequences did not reveal any effect of prior knowledge (*ns*). Obviously, the hierarchical structure favored ($p < .001$) more coherent reading sequences ($M = 1.75$, $SD = 0.14$) than the network structure ($M = 2.52$, $SD = 0.17$). As expected, there was a significant interaction ($p < .01$). The hierarchical structure supported more coherent reading sequences than the network structure for the LK readers ($p < .001$), as well as for the HK readers ($p < .001$). Besides, as was hypothesized, the HK readers followed more coherent reading sequences than the LK readers with the network structure ($p < .05$). Interestingly, the reverse effect was observed with the hierarchical structure; the HK readers' reading sequences were less coherent than the LK readers' reading sequences ($p = .05$).

A 2×2 ANOVA conducted on the temporal-causal coherence scores indicated only that the reading sequences were more coherent in the hierarchical condition ($M = 1.51$, $SD = 0.24$) than in the network condition ($M = 2.16$, $SD = 0.32$) ($p < .001$). There was neither effect of prior knowledge, $F(1, 33) = 2.23$, *ns*, nor significant interaction, $F(1, 33) = 1.20$, *ns*. Hence, the results showed that only the thematic coherence was affected by prior knowledge.

3.3. Feelings of conceptual disorientation

The mean and standard-deviations of the disorientation ratings are presented in Fig. 3. The 2×2 ANOVA conducted on the mean scores of disorientation (the statistical results are given in Table 5) revealed that the hierarchical structure significantly reduced the feelings of disorientation for all the participants ($p < .001$) (network: $M = 4.39$, $SD = 1.55$; hierarchy: $M = 2.58$, $SD = 1.29$). Prior knowledge did not impact on the feelings of disorientation (*ns*), but the interaction was significant ($p < .05$). On the one hand, the hierarchical structure exerted a positive effect only for the LK read-

ers group ($p < .001$). The difference between both structures was not significant for the HK group (*ns*). On the other hand, the feelings of disorientation tended to be reduced by prior knowledge in the network structure ($p = .083$), and there was no effect of prior knowledge in the hierarchical condition (*ns*).

4. Discussion

The present experiment explored comprehension of non-linear information conveyed by hypertexts and the effects of prior domain knowledge on the comprehension processes. Three dimensions of comprehension were assessed jointly: comprehension outcomes, coherence of reading sequences and feelings of disorientation. Combining these three measures was expected to provide added information about the comprehension processes. The comprehension outcomes indicated the level of elaboration of the hypertext content representation. The coherence of reading sequences indicated the nature of inferences used by the readers. The feelings of disorientation indicated the difficulties experienced by the readers, and thus, stressed the degree of cognitive demand required by the comprehension processes. Overall, the obtained results on the three types of dependent variables confirmed our assumptions.

4.1. Comprehension outcomes

The results on the comprehension outcomes were consistent with our assumptions. The analysis of the comprehension outcomes yielded two main findings. Firstly, the non-linear document with a hierarchical structure supported better comprehension for the low prior knowledge readers. Therefore, a hierarchical representation of hypertexts is required to reach high performance in search tasks (Danielson, 2002; McDonald and Stevenson, 1998) as well as in comprehension tasks from hypertexts. As far as the

Table 4

Reading times and coherence of reading sequences.

	LK readers		HK readers	
	Network $n = 9$ M (SD)	Hierarchy $n = 10$ M (SD)	Network $n = 9$ M (SD)	Hierarchy $n = 9$ M (SD)
Total reading time (s)	1692 (246)	1761 (66)	1751 (152)	1677 (245)
Reading of the map (s)	377 (89)	440 (166)	366 (149)	433 (120)
Reading time of the text sections (s)	1316 (235)	1324 (201)	1385 (180)	1244 (222)
Thematic coherence (the most coherent = 1)	2.59 (0.14)	1.69 (0.12)	2.44 (0.17)	1.82 (0.13)
Temporal-causal coherence (the most coherent = 1)	2.28 (0.33)	1.53 (0.28)	2.05 (0.25)	1.49 (0.24)

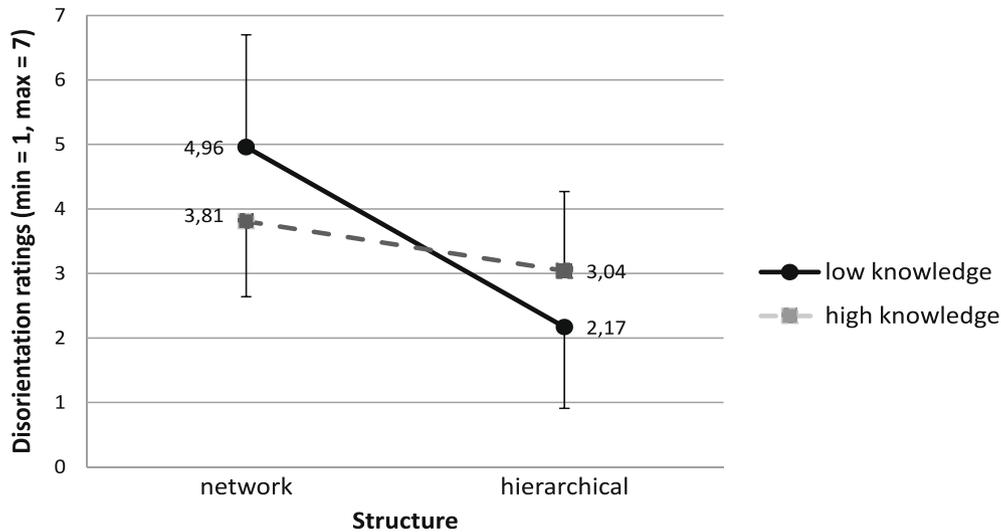


Fig. 3. Mean disorientation ratings (min = 1–max = 7).

high prior knowledge readers were concerned, there was no effect of the structure, suggesting that high prior knowledge helped readers to cope with the demands of reading non-linear texts. Secondly, prior knowledge acted only in the network structure; no impact on performance was observed in the hierarchical structure. Therefore, prior knowledge would support comprehension processes when readers are required to establish semantic relations between text sections in the non-linear document. This finding is consistent with previous studies (Patel et al., 1998; Potelle and Rouet, 2003; Shin et al., 1994) that showed positive effects of prior knowledge only in the condition of highly non-linear hypertexts. Despite the fact that the participants in this research had little prior knowledge about the domain under study (they only had some basic knowledge of biology), our findings attested that prior knowledge plays the role of a relevant resource in improving comprehension of non-linear texts.

The present study revealed similar effects of the prior knowledge and the hypertext structure on both levels of text representations (text base and situation model). This result that is consistent with previous works (Müller-Kalthoff and Möller, 2003; Potelle and Rouet, 2003) suggests that the levels of text representation were strongly embedded. That is, a deep and interconnected representation of the contents may be relevant for retrieving explicit information. This finding highlights limits of using such levels of texts representations. Examining others dimensions of the texts representations is required. For instance, the macrostructure of texts representations would be more affected by prior knowledge than the microstructure (Le Bigot and Rouet, 2007; Potelle and

Rouet, 2003). Furthermore, the similar result patterns between text base and situation model scores stress that the examination of on-line processes is essential.

4.2. Coherence of reading sequences

On-line data confirmed the previous result on the comprehension outcomes and provided additional input for understanding how the processes based on prior knowledge permit the comprehension of non-linear information. The analyses of the reading sequences revealed that the level of prior knowledge predicted the level of coherence of the reading sequences. The main result stressed that high knowledge readers followed more thematic coherent reading sequences in the network structure. Prior domain knowledge helped readers to identify semantic groups of texts and to read a set of texts belonging to the same category when they are faced with a highly non-linear document. This finding is consistent with other previous studies showing that high prior knowledge learners would be more active in their navigation (Carmel et al., 1992; Last et al., 2001).

In comparison with these previous studies, our study pointed out that high knowledge readers' active navigation may be based on establishing and maintaining coherence between the text sections (i.e. pieces of information) and not only on processing detail or interest information. Hence, studying how readers construct coherence of reading orders is relevant and promising to investigate hypertext comprehension. Also interestingly, the analyses conducted on the temporal-causal coherence of the reading se-

Table 5
Source table of 2 × 2 independent-measures ANOVA for the disorientation ratings.

	ANOVA				Pairwise comparisons			
	Subject	Structure	Prior knowledge	Structure × prior knowledge	Structure effect		Prior knowledge effect	
					LK	HK	Network	Hierarchy
Disorientation ratings								
df	33	1	1	1	1	1	1	1
MSE		29.48	–	9.40	37.04	–	5.93	–
F		15.85***	0.10	5.05*	19.91***	1.46	3.19#	1.93
Partial η ²		0.32	–	0.13	0.38	–	0.09	–

* p < .05.
 ** p < .01.
 *** p < .001.
 # p = .083.

quences did not reveal any effect of the level of prior knowledge contrary to a previous study (Amadiou et al., 2009a). In the current study, the readers would have drawn inferences more to structure a thematic organization of the contents than to construct the temporal-causal sequence of the events. This finding suggests that the readers may run different types of on-line inferences. That is consistent with the argument of Zwaan and Radvansky (1998) about the existence of different situation models in texts comprehension. For narrative texts, they claimed that readers would control five different dimensions: protagonists, temporality, spatiality, causality and intentionality. Hence, various dimensions of coherence should also be examined and tested in hypertexts comprehension using different measures of similarity between hypertexts' nodes (Katsanos et al., 2008).

Besides, our findings indicated that prior knowledge supported semantic processing to construct coherent reading sequences with the proviso that the structure is highly cognitively demanding (i.e. network structure). Readers conducted processes to identify and elaborate semantic relations between text sections in a hypertext when the structure did not guide their reading sequences. Our study proves that high prior knowledge helps readers to cope with the cognitive requirements to process hypertexts leading them to construct semantic relations between hypertexts contents. This result may also explain the differences between our findings and the findings obtained by Salmerón et al. (2005, 2006) that indicated no effect of prior knowledge on the coherence of reading sequences. The hypertexts designed for their experiments provided guiding structures (matrix or hierarchy), thus, they did not promote active navigation. Readers may follow similar reading sequences based on the hypertext structure (exhaustive and methodical exploration of hierarchical structures) whatever their level of prior knowledge (e.g. Shapiro, 1999; Zeller and Dillenbourg, 1997).

In our study, an unexpected effect of prior knowledge on the thematic coherence was observed in the hierarchical non-linear document. Interestingly, the high prior knowledge readers followed less coherent reading sequences than the low prior knowledge readers in this condition. This result is different from Shapiro's results (1999) which indicated that low as well as high prior knowledge learners followed reading sequences centered on the displayed categories of an overview. Our result suggests that the high prior knowledge readers were more active in their navigation following reading sequences less based on hierarchy.

4.3. Disorientation

The analyses conducted on the feelings of disorientation also validated our assumptions. The result pattern of disorientation was similar to the result patterns of the comprehension outcomes and the reading sequences. The disorientation expresses the cognitive demands imposed by processing non-linear information. The network structure entailed higher disorientation than the hierarchical structure and high prior knowledge reduced disorientation. Therefore, processes based on prior knowledge help readers to cope with the cognitive demands imposed by hypertext reading. Whereas the previous studies failed to prove effects on perceived disorientation of both hypertexts structures and prior knowledge (Amadiou et al., 2009a; Calisir and Gurel, 2003; Calisir et al., 2008; Müller-Kalthoff and Möller, 2003; Patel et al., 1998), our results confirmed an interaction effect of prior knowledge and hypertext structure on disorientation in comprehension tasks. One explanation is that our study focused more on measures of conceptual disorientation rather than structural disorientation. Therefore, the results indicated that assessing conceptual disorientation may be more sensitive to the manipulated factors for hypertexts comprehension tasks.

Nevertheless, the disorientation construct needs more elaboration and the development of assessment methods. Nowadays, the diversity of assessment methods used hampers comparisons between the studies and may underline a diversity of measured concepts. Our study provided evidences in favor of assessing a conceptual dimension of disorientation.

4.4. Towards an integrated model of variables

In the current study, the examination of cognitive processes engaged in hypertexts comprehension according to the types of hypertext structure and the readers' prior knowledge was conducted including three dimensions of hypertexts processing (comprehension outcomes, navigation and disorientation). The patterns of the results were consistent with our expectations and stressed that comprehension performance, on-line processes and perceived difficulties depended on structure and prior knowledge. Our findings indicated that hypertexts comprehension implied conceptual processing required to construct a reading sequence (establishing semantic relations between text sections) as well as to construct a representation of the conceptual space of hypertexts to avoid conceptual disorientation. The patterns of the results might suggest that the feelings of conceptual disorientation expressed difficulties for establishing coherence during reading and that the comprehension outcomes depended on the on-line semantic processes. Readers failing to process semantic relations between texts sections should construct low elaborated mental representations. Nevertheless, our study did not supply evidences about the causal relations between these three examined dimensions.

Therefore, replicating the study only with a network structure and with more participants should allow to test the relations between the variables using a causal analysis. A model of hypertext comprehension could be designed on the basis of such results. It could be predicted that the coherence of the reading sequences and the disorientation would be mediating variables explaining the effects of prior knowledge on the comprehension outcomes.

5. Conclusions

The aim of this study was to investigate the effects of prior knowledge and hypertexts structure on comprehension, navigation and disorientation. The findings indicated that hierarchical structures support comprehension helping readers to maintain coherence during reading and limiting conceptual disorientation. Conversely, a network structure imposes more demanding processes and damages comprehension. However, prior knowledge plays the role of a crucial resource to reach a good comprehension, to maintain coherent reading sequences (thematic coherence) and to avoid conceptual disorientation. Prior knowledge helps readers to identify and select the contents needed in order to address conceptual difficulties. High prior knowledge readers were more able to process successively contents belonging to a same conceptual category.

The study has several implications. Designing effective instructional hypertexts for low prior knowledge readers requires taking into account readers' navigation and disorientation. Overviews (e.g. concept maps) may entail reading sequences based on overview structure and thus promote high or low coherent reading sequences. Therefore, designers of instructional hypertexts should keep in mind that overviews provide both a representation of the content organization and a guide to navigate cross hypertexts (e.g. systematic reading of the structure). Moreover, for high prior knowledge readers, overviews should offer a free navigation in order to allow them to construct actively reading sequences.

From a methodological point of view, the current study indicated that measuring conceptual disorientation is a sensitive mea-

sure of the conceptual difficulties experienced by readers. As well as for the information search tasks, disorientation appears as a relevant construct to study navigation difficulties in hypertexts comprehension tasks. The study showed also the reliability of coherence measures in order to examine navigation elaboration. Besides, the study proposed to conduct different measures of navigation through the use of different measures of navigation coherence. Testing different measures of navigation coherence provides information about the reading strategies conducted during hypertexts reading. Nevertheless, further investigations are required to identify more accurately the cognitive processes supporting coherent reading orders. Analysing selection processes of links would also inform about the type of inferences based on prior knowledge that allowed construction of coherent reading sequences. In addition, future research should identify more accurately specific elements of hypertext comprehension task that require high cognitive resources. For instance, Amadiou et al. (2009b) highlighted recently that measuring cognitive load linked to specific processing (e.g. concept-map structure) by subjective and objective (e.g. eye fixation duration) measures may supply further information on requiring processing of a concept map.

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