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Cognitive load in hypertext reading: A review

Diana DeStefano *, Jo-Anne LeFevre

Centre for Applied Cognitive Research, Department of Psychology, Carleton University, 1125 Colonel By Drive, Ottawa, ON, Canada K1S 5B6

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Abstract

A process model of hypertext reading was used to generate predictions about the effects of hypertext features on cognitive processing during text navigation and comprehension. We evaluated the predictions of the model with respect to the extant literature, focusing on studies in which versions of hypertexts were compared. Consistent with our predictions, the increased demands of decision-making and visual processing in hypertext impaired reading performance. Individual differences in readers, such as working memory capacity and prior knowledge, mediated the impact of hypertext features. For example, readers with low working memory and low prior knowledge were usually disadvantaged in hypertext. Some benefits were observed for learners with low prior knowledge, however, if the hypertext structure was hierarchical and consistent with that of the knowledge domain. We also surveyed the effectiveness of structural features designed to reduce cognitive load, including graphical overviews, restricted access to links, and visible link types. Complex graphical overviews did not reliably enable learning and navigation, whereas navigational support from restricted access and visible link types were helpful. We identified gaps in the empirical literature and suggested future studies to investigate cognitive processes in hypertext reading.

Keywords: Hypertext; Working memory; Reading comprehension, Individual differences

1. Introduction

The ubiquity of computers in modern society has created a new genre of information that we refer to as *hypertext*. Hypertext can be defined broadly as a collection of

* Corresponding author. Tel.: +1 613 520 2600x2696; fax: +1 613 520 2539.
E-mail address: diana@davidridgeway.com (D. DeStefano).

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documents containing links that allow readers to move from one chunk of text to another. In general, educators have been enthusiastic about using hypertext to make reading interactive and have proposed that hypertext enables readers to develop rich, highly interconnected knowledge structures (Fiderio, 1988; Fredin, 1997; Jacobson & Spiro, 1995; Spiro & Jehng, 1990). However, the flexibility and interactivity proposed as advantages of hypertext result in a complex product that may increase cognitive load relative to processing of regular text. We reviewed the literature on the cognitive consequences of hypertext reading in order to test the hypothesis that activities specific to hypertext can increase cognitive load and impair learning.

Cognitive load is a construct with three measurable dimensions (Kirschner, 2002; Sweller, Chandler, Tierney, & Cooper, 1990; Sweller, van Merrienboer, & Paas, 1998): mental load, mental effort, and performance. In the present review, we were primarily concerned with mental load imposed by task demands but will use the terms mental load and cognitive load interchangeably. As detailed below, we used the theoretical construct of working memory to relate mental load to the specific cognitive processing that occurs during reading and navigating in hypertext. We hypothesized that activities central to hypertext reading that are not usually required in linear text, such as following links, may influence mental load either directly, as when readers are required to make decisions upon encountering links, or indirectly, as when following a link results in separation of related parts of a text and influences information integration. To preview our conclusions, the literature that we reviewed supports the view that hypertext presentation can often influence reading comprehension and navigation by increasing mental load.

1.1. Overview

This paper is organized in four sections. In the first section, we describe the research methodology used for this review and outline a theoretical model for understanding how hypertext and cognitive load are related. In the second section, we review the literature on the effects of links and link types on comprehension and navigation with respect to overall cognitive load as well as effects of hypertext on the development of situation models. In the third section, we examine the influence of structural features designed to facilitate navigation (e.g., graphical overviews) on hypertext reading. The fourth section provides a summary of the findings. Throughout the paper, we use the existing literature to evaluate the proposed model, identify gaps in the literature, and provide suggestions for future research.

1.2. Methods

The research methodology involved reviewing papers on navigation and learning in hypertext. We initially searched two databases (PsycInfo and ERIC) for the period 1990–2004 using the following keywords: hypertext navigation, hypertext reading comprehension, links, text structure, and text topology. Given our specific interest in how hypertext features influence cognitive demands, we selected empirical studies that compared reading performance for multiple versions of a text, usually several hypertext versions and a linear version. The citation sections of these studies were reviewed to locate additional studies of interest. The final sample consisted of 38 studies published in refereed journals and edited books between 1990 and 2004. These studies are marked with an asterisk in the list of references. Other studies were discussed where relevant, in particular studies on reading that did not involve hypertexts.

Before proceeding to our review, it is useful to identify some global similarities across studies and to specify the terminology that we used. First, unless otherwise noted, the participants in the reported studies were college or university undergraduate students, and texts were presented on computer screens. Second, linear texts were those with nodes of text connected by "Next" links, and sometimes also with "Back" links, such that the possible orders of reading were very limited. In contrast, hypertexts were those in which participants had many choices in sequencing their reading. Third, in hierarchical hypertexts, nodes were connected in a tree structure, with broader or superordinate topics at higher levels, and a larger number of more specific, subordinate, or subcategory topics at lower levels. Alternatively, in networked or nonlinear hypertexts, semantically related nodes were linked, such that a linked phrase could be connected to nodes anywhere in the hypertext database. In other respects, there was considerable variation across studies, particularly in the dependent measures that were reported. For this reason, we have noted whether researchers assessed efficiency (e.g., speed of navigation) or comprehension (e.g., score on a memory posttest).

Our approach was to cluster studies that were similar in terms of their experimental design. For example, there were five studies with measures of navigational efficiency that used multiple text versions in a between-groups design (i.e., participants performed in only one text condition). In another cluster, there were four studies comparing multiple texts in a between-groups design that measured reading comprehension and also included a measure of participants' prior knowledge of the domain (i.e., subject matter). We were unable to conduct statistical meta-analyses for the clusters of studies for two reasons. One was that studies in a given cluster varied in terms of task manipulations, for example, the types of texts that were compared. The second was that meta-analysis requires consistent reporting of effect sizes and variances, which were sometimes not provided. Our approach was to report patterns of results for each cluster.

1.3. Theoretical perspectives on cognitive load

Reading and navigating in hypertext are likely to place demands on working memory. Working memory is the set of mental resources that people use to encode, activate, store, and manipulate information while they perform cognitive tasks (Baddeley, 2003). Working memory theories provide a useful way of operationalizing the construct of cognitive load because a common assumption of working memory models is that a limited amount of information can be simultaneously processed (Baddeley & Logie, 1999; Miyake & Shah, 1999; Sweller et al., 1990). This feature of working memory models corresponds well to the assumption that increases in mental load are associated with reduced performance in hypertext reading. Two methodological approaches have been prominent in research on working memory and reading: the dual-task approach and the individual differences approach. In the sections below, research on hypertext is evaluated for each of these approaches to explore the relations between hypertext reading and cognitive load.

To organize our review and provide a framework for interpreting the complex pattern of results found in the literature, we developed a process model that captures our predictions of how hypertext features affect reading. We hypothesized that hypertext reading introduces a new set of cognitive requirements to the reading task, thereby increasing

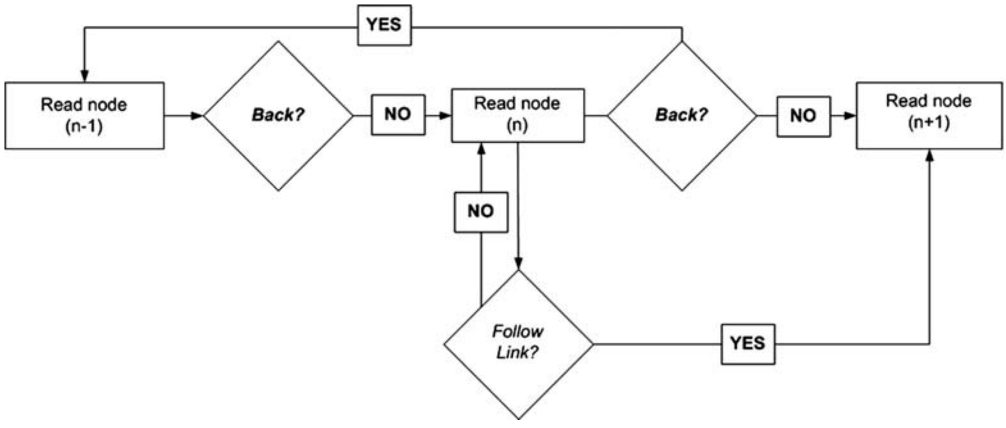

Fig. 1. A process model for hypertext reading.

working memory demands, and increasing mental load. Fig. 1 illustrates the sequence of steps involved in reading hypertext. For a linear text that has only *next* and *back* links, a reader at node (n) makes the decision to either go on to the next node ($n + 1$) or go back to the previous node ($n - 1$). On this view, linear text is the least demanding of cognitive resources. In contrast, hypertext with embedded links requires that readers make an additional decision at each link, indicated in the figure by the decision diamond marked 'Follow link?' The reader either chooses to go on to the linked text, node ($n + 1$) in the figure, or continues reading the text in the current node (n). A reduced number of possible paths are shown in Fig. 1 to keep the representation simple. We hypothesized that each decision about whether to follow a link requires cognitive resources and thus hypertext with more embedded links should produce greater cognitive load than hypertext with few or no embedded links.

Furthermore, every time a reader chooses to follow an embedded link, the text he or she encounters in node ($n + 1$) potentially functions as an interruption of the ongoing comprehension process. Comprehension involves the development of situation models (described more fully in Section 2.3). Situation models are complex mental representations formed when readers integrate the statements in the text with their knowledge (Kintsch, 1988). To the extent that the text in node ($n + 1$) is related to and enhances the developing situation model, the interruption may have minimal effect on comprehension. To the extent that the text in a linked node is unrelated to the text in node (n), disruption of the developing situation model may occur. Furthermore, because the reader will be faced with additional choices when he or she is processing the linked text, that is, to either return to node (n) or possibly to follow other embedded links, the disruption to developing comprehension may be severe. Based on this model, we predicted that situation model development should be better for hypertext structures in which links are restricted to closely related nodes, as in hierarchical hypertext.

Interruptions in reading are hypothesized to impair situation model formation, particularly when people are interrupted by demanding tasks (e.g., Lorch, 1993). This interference with the comprehension process may be a source of the disorientation that is a commonly reported problem in hypertext reading (Edwards & Hardman, 1989; Miall & Dobson, 2001; Nielsen, 1990). We used the process model shown in Fig. 1 to make several predictions. First, we predicted that hypertext with embedded links will increase cognitive load relative to linear text. Second, we predicted that hypertext with a greater number of embedded links will create greater cognitive load than hypertext with fewer links. Third, we predicted that link structure will influence cognitive load in hypertext because links to semantically distant information interfere more with comprehension than links to closely related information, such as that contained in a subordinate node of a hierarchy. Fourth, we predicted that one effect of increased cognitive load would be to disrupt formation of the situation model, resulting in poorer comprehension and a sense of disorientation among readers. In the next section, we tested these hypotheses by examining existing research in which hypertext features related to links and link structures were manipulated.

2. Comprehension and navigation in hypertext reading

One methodology that has been used to evaluate cognitive load in reading examines the impact of additional or "secondary" tasks on reading performance. To the extent that performance suffers in either task when two tasks are combined, researchers conclude that the two tasks demand overlapping cognitive resources (Baddeley, 1986). For example, to the extent that hypertext reading requires spatial cognitive resources, comprehension and navigation will be impaired when combined with additional spatial tasks, such as remembering visually presented shapes. Dual-task methodology has been used extensively to develop a multi-component model of working memory (Baddeley, 1986, 2003; Baddeley & Logie, 1999) and is frequently used to explore the working memory demands of complex tasks. According to Baddeley's model of working memory, an executive control system manages information processing and employs specialized subsystems for verbal and visual-spatial information. One way to examine working memory in hypertext reading is to differentially load the various subsystems of working memory. This approach was used in two studies of hypertext reading.

Wenger and Payne (1996) tested the impact of spatial and verbal loads on reading performance for a hypertext and a linear text. However, neither of the load tasks affected reading comprehension. Wenger and Payne also failed to show a reliable difference in reading comprehension for the hypertext versus the linear text in that their results were inconsistent across experiments when different texts were used (Experiment 1 vs. 2). Plass, Chun, Mayer, and Leutner (2003) examined the effects of visual and verbal loads on reading comprehension. Students read a story in a foreign language that they had been studying, and were required, in three of four conditions, to process annotations for some of the words in the text. In each of the three annotation conditions, students clicked an icon located next to the marked word. In the visual annotations condition, students viewed a corresponding image, such as an image of a school of fish for the German word, "Fischschwärme". In the verbal annotations condition, students viewed an English translation, for example, "school of fish." In two other conditions, students viewed either no annotations or both types of annotations sequentially.

Plass et al. found that reading comprehension was worse in the visual-annotations only condition as compared to the conditions with no annotations or both verbal and visual annotations. The visual image annotations, when presented alone, may have introduced confusion, especially for words that were difficult to depict visually, such as "irritated" and "instruct." Comprehension was equally good in the both- and no-annotations conditions, suggesting that reading comprehension was impaired by the content presented during the interruptions (i.e., ambiguous images), rather than by the interruption per se. Plass et al. argued that the visual annotations imposed a high cognitive load because students had to select the relevant information from the image to understand the vocabulary words.

More research using dual-task methodology could provide many important clues about the relation between reading of hypertext and cognitive load. First, future studies with concurrent tasks should compare multiple levels of concurrent task difficulty in terms of number and complexity of items. For example, it seems likely that interruptions from longer verbal items than those used by Plass et al. could potentially impair comprehension because the research literature on interruptions during reading suggests that interpolated material can interfere with text processing (Glanzer, Dorfman, & Kaplan, 1981). Second, manipulations that vary the relevance of the interpolated items to the reading task could provide useful information. For example, comparisons of the effects of semantically related and unrelated interruptions would be useful in assessing the prediction that links in a networked hypertext may affect reading more than links in a hierarchical hypertext.

2.1. Evidence for decision-making as a source of increased cognitive load in hypertext reading

Because there were few studies that used the dual-task methodology, we examined other research in which factors such as number of links varied, hypothesizing that such manipulations were likely to have similar effects on hypertext reading as combining reading with a secondary task. For example, we hypothesized that the number of links per node in hypertext studies would be related to decision-making load, and that readers faced with more choices would show impaired comprehension. Consistent with this hypothesis, some researchers have reported better factual recall from reading linear texts as compared to hypertexts (Barab, Young, & Wang, 1999; Eveland, Cortese, Park, & Dunwoody, 2004). Number of links also appears to be an important variable, and one that is of particular interest to hypertext designers. Zhu (1999) compared readers' learning from hypertexts with either 3–7 links per node or 8–12 links per node. Learning was better when the hypertexts had fewer links, as measured by performance on a multiple-choice test and a written summary. Readers in the condition with fewer links also rated the hypertext system more positively. These results support the hypothesis that increasing the number of links may increase cognitive load and impair learning.

Several researchers tested the impact of number of links on navigational efficiency, which may serve as a measure of how well readers can process a text's structure. In studies of electronic menu navigation, people were asked to locate a text target, such as a word in an online dictionary. People were slower to make each menu selection as the number of choices increased (Jacko & Salvendy, 1996; Landauer & Nachbar, 1985). Visual search for text targets was slower in pages with many links as compared to fewer links (Parush, Shwartz, Shtub, & Chandra, 2005). These findings provide additional support for the hypothesis that the number of links (and therefore the accompanying decision-making requirements) may be an important source of cognitive load in hypertext to the extent that slowed performance reflects increased task difficulty.

Other studies that compared hypertexts with different numbers of links, and thus different levels of decision-making difficulty, did not simultaneously manipulate or control for breadth (number of choices at each level), depth (number of levels), and topology (shape, e.g., an increasing number of choices at each level as depth increased). In addition to these variables, the types of links available in hypertext must be considered. Strictly hierarchical hypertexts allow readers to navigate to superordinate or subordinate topics only, resulting in a limited number of links and only a few link types. In contrast, networked hypertexts have several types of semantic links that connect related nodes (e.g., cause-effect, category-example, item-definition), usually in addition to other link types such as "Back." Thus, a networked hypertext, or one that combines hierarchical and semantic links, has both more links and more link types than a strictly hierarchical hypertext. As described below, there were several studies that compared navigation performance in hypertexts that varied in the number, types, and structure of links.

In several studies, navigation performance was measured as the speed with which participants could navigate to find answers after an initial period of browsing a text (Lin, 2003; McDonald & Stevenson, 1996, 1998; Mohageg, 1992; van Nimwegen, Pouw, & van Oostendorp, 1999). Consistent with our hypothesis that reading is impaired as decision-making demands increase, McDonald and Stevenson (1996) found that navigation performance declined as the number of links increased. They compared three text topologies: linear (fewest links), strictly hierarchical hypertext (intermediate number of links), and nonlinear hypertext (greatest number of links). Participants in the linear condition navigated to find answers faster than those in the hypertext conditions because they simply had to click "Next" until they arrived at the screen with the answer. The more interesting comparison was between the hierarchical and the nonlinear hypertexts, which showed that participants were faster to find information within a hierarchically structured text that had fewer links. van Nimwegen et al. (1999) compared navigation performance in hierarchical hypertexts with hypertexts that had lateral links added to connect nodes at the same level of the hierarchy. Also consistent with our hypothesis, readers were slower to locate target information in the text that included lateral links, and deviated more from the optimal path to the target information. Such results support the view that networked hypertexts will not necessarily enhance a reader's experience, at least in terms of efficiency of navigation.

Other studies comparing speed of navigation in various hypertext topologies yielded varied patterns of results (Lin, 2003; McDonald & Stevenson, 1998; Mohageg, 1992). Mohageg (1992) compared reading times for a hierarchical hypertext with a "combination" hypertext that had twice as many links (same as the hierarchical plus some lateral links), and found that speed to navigate to a target piece of information was the same for the two texts. McDonald and Stevenson (1998) also did not find differences in navigation times for hierarchical hypertext as compared to a hypertext that had additional links. Lin (2003) found that older readers navigated faster in a networked text with 70 links than a hierarchical hypertext with 26 links but they also traversed more unnecessary links. Thus, the effect of number of links was inconsistent across studies although there was little evidence that more links led to better performance. The mixed results support our argument that the relevant variables will have to be systematically manipulated to provide adequate comparisons. In a previous review, Unz and Hesse (1999) also noted that the effects of link structures (e.g., hierarchical vs. nonlinear) on navigation were mixed across studies.

In contrast to these inconsistent findings with respect to number of links, the effect of adding semantic links was more consistently negative. In four of the five studies, navigation was slower in hypertexts that included semantic links than in those that were strictly hierarchical (McDonald & Stevenson, 1996, 1998; Mohageg, 1992; van Nimwegen et al., 1999). Semantic links may have obscured the hierarchical nature of the texts. These studies suggest that the type of links, rather than the sheer number, may be an important factor in comprehension. Researchers have not yet addressed the question of whether readers' cognitive load is influenced when they encounter a greater number of link types. More generally, the variability in the existing research suggests that variables such as breadth, depth, and topology may all be relevant to navigational efficiency (Bernard, 2002). Other research on menu and website navigation suggests that users perform best with a large number of choices on introductory screens (i.e., top levels), and fewer choices at deeper levels of a hierarchy (Parush & Yuviler-Gavish, 2004). Thus, it will be critical to manipulate text topology in future studies of hypertext reading.

Restricting a reader's navigational choices might reduce decision-making demands. Shin, Schallert, and Savenye (1994) found that restricting the amount of freedom that second-graders had in navigating a hypertext yielded better learning for students with low prior knowledge. Students who had high prior knowledge performed equally well with restricted and unrestricted paths. Paolucci (1998) found that fifth-graders learned more about ecosystems when they navigated in a branching hypertext with 50 links than in a networked hypertext with 173 links. In the networked hypertext, links were relatively unstructured, allowing for a "high degree of self-direction" (p. 133). In the branching hypertext, decisions at choice points resulted in selection of a path, and access to some nodes was blocked until certain higher-level nodes had been accessed. Thus, restricted navigation was related to better learning in grade-school students. However, this benefit could be attributed to better-structured text sequences rather than to reduced decision-making demands.

In sum, although there was some evidence that having more choices slows navigation (McDonald & Stevenson, 1996; van Nimwegen et al., 1999), the impact of decision-making on comprehension has not been tested using direct manipulations of decision-making load. Hierarchical structure of a text usually helped navigation whereas obscuring the inherent hierarchical structure of the information by adding lateral links sometimes impaired navigation (van Nimwegen et al., 1999). Restricting the number of possible paths through a text helped some young readers (Shin et al., 1994; Paolucci, 1998). However, more studies are needed to explore the effects of text topology and numbers and types of links on reading comprehension. In sum, the available literature provides some support for the hypothesis that decision-making demands, operationalized as number of links and types of links, negatively affect reading processes in hypertext but considerably more research is needed.

2.2. Individual differences in cognitive capacity and hypertext reading

An alternative approach to studying cognitive load examines the relation between an individual's cognitive capacity and performance on a complex task such as reading (Daneman & Merikle, 1996). Individuals vary in their ability to temporarily store and process verbal information. Furthermore, people who score higher on verbal working memory tasks are more skilled readers; that is, they are better at reading comprehension (Daneman & Carpenter, 1983; Daneman & Merikle, 1996). To measure cognitive capacity in a working memory framework, researchers have developed tasks such as reading span, in which participants process sentences for comprehension and also memorize the final word of each sentence for later report (Carpenter, Miyake, & Just, 1995; Daneman & Carpenter, 1980; Daneman & Merikle, 1996). People who can remember long sequences of sentence-final words have high spans and thus large working memory capacity. Readers with low spans are poorer readers for a variety of reasons, including a reduced ability to integrate text with stored knowledge (Seigneuric, Ehrlich, Oakhill, & Yuill, 2000; Singer, Andrusiak, Reisdorf, & Black, 1992; Yuill, Oakhill, & Parkin, 1989). Based on the individual-differences view of working memory, we predict that, to the extent that hypertext features increase cognitive load, people with less working memory capacity should experience more difficulty reading hypertext than those with more capacity. For readers with low working memory capacity, available mental resources will be quickly exceeded by the additional demands of hypertext.

In a study of paper texts, Budd, Whitney, and Turley (1995) showed that readers with low working memory (WM) spans benefit from structured texts and from organizers that highlight text structure. They tested high- and low-WM span students on comprehension of texts for which topic sentences were either present or absent. Budd et al. found that the two groups of students performed equally well when topic sentences were included in the text, but that low-WM span students performed more poorly when topic sentences were absent. Low-WM readers needed more structured texts for learning, and thus hypertexts, which are often less structured than linear texts, may not be appropriate for low-WM readers. Budd et al.'s results suggest that, in hypertext reading, learners with low WM spans may be disadvantaged because text fragments are typically presented without the benefit of topic sentences or other introductory material.

If text integration is more difficult in hypertext, then low-WM span readers should be particularly impaired by hypertext as compared to linear text presentations. Lee and Tedder (2003) compared posttest scores of high-, medium-, and low-WM span students who read one of three texts: linear, hierarchical hypertext, or networked hypertext. Recall of facts mentioned in the text was highest for the linear text, and the advantage of the linear text was greatest for low-WM readers. These results are consistent with the hypothesis that low-span readers are disadvantaged in hypertext.

Studies of hypertext reading across different age groups are of great interest for understanding the role of cognitive load in hypertext reading because children and older adults tend to have lower working memory capacities than young adults (Fry & Hale, 1996; Salthouse, 1994). Thus, if adding hypertext features results in increased working memory demands, reading performance should be especially impaired for older adults and children as compared to young adults. Older adults are particularly susceptible to distracting material while reading (Connelly, Hasher, & Zacks, 1991), and so may experience greater difficulty in hypertext than younger adults. In one study of older adults, ages 57–67 years, participants used either a hierarchical hypertext, or a networked hypertext with a larger number of links connecting semantically related nodes (Lin, 2003). After browsing the hypertext, participants navigated to find specific pieces of information. Lin found that participants traversed fewer unnecessary links in the hierarchical than in the networked hypertext, suggesting that the hierarchical structure of the hypertext was helpful for forming a representation of the text's structure. However, readers' comprehension was not directly tested, so this study did not address the question of whether older readers experience particular difficulty with text integration in hypertext. In another study of older adults, ages 62–80 years, Lin (2004) found better posttest memory for readers of hierarchical than networked hypertexts, and suggested that hierarchical topologies should be provided for older adults. Future studies of older and younger readers should measure both WM spans and hypertext performance to determine the conditions under which hypertext demands typically exceed memory limitations.

Additional studies are needed to determine the sources of potential difficulties for low-WM readers in hypertext. The problems experienced by low-WM readers may stem partly from limitations in their ability to store verbal information over short periods of time (MacDonald, Just, & Carpenter, 1992). With the flexible sequencing of hypertext, related sentences are likely to be read further apart in time than in linear texts, and individuals who are poor at keeping verbal representations active in memory may be particularly disadvantaged. Alternatively (or in addition), readers with low working memory spans may have problems that are not tied to verbal memory specifically, but rather to more global executive functions (Baddeley, 1986, 1996; Rabbitt, 1997). Executive functions include decision-making, coordination of task demands, and inhibition of irrelevant information. These varied processes are all likely to be required in hypertext reading. To understand how working memory supports learning from hypertext, future studies of individual differences in hypertext should include measures of both memory spans and executive functions. To isolate the effect of memory load on reading performance, we suggest manipulating the amount of intervening text between related sentences. Increasing the amount of intervening material should impair reading as measured by tests of factual recall and reading comprehension. Decision-making load can be manipulated by requiring simple responses during reading, such as judging auditory tones as high- or low-pitched, a task which engages the executive component of working memory (Klauer & Stegmaier, 1997).

It may also be useful to consider how individual differences in working memory relate to reading strategies. Linderholm and van den Broek (2002) found that readers with high working memory capacity spend more time reflecting on their understanding through metacognitive comments, whereas low span readers use less demanding strategies such as verbatim repetitions of sentences. These results suggest that low span readers may be more affected by increased verbal demands of hypertext because their reading strategies involve more verbal repetition. Thus, the influence of working memory on reading performance is likely to be related to what learners are doing while reading.

In addition to working memory, other cognitive abilities and styles have been tested in relation to reading performance in studies using paper texts. Lodevijks (1982) measured two characteristics of high school students: reasoning ability, which is a measure of executive function (Oberauer, Suß, Schulze, Wilhelm, & Wittmann, 2000), and field-independence, a cognitive style related to imposing structure during perception rather than depending on external cues (Witkin, Moore, Goodenough, & Cox, 1977). Students with high reasoning ability and/or high in field-independence learned better when they chose a sequence for reading a set of passages on related topics, whereas students with low reasoning ability or those classified as field-dependent (who rely more on external cues), learned better when teachers provided sequences in which passages should be read. Similarly, readers with high prior knowledge benefit from sequencing the material for themselves, whereas readers with low prior knowledge benefit from a logically sequenced text (McNamara, Kintsch, Songer, & Kintsch, 1996). Thus, the flexibility offered by hypertext may be beneficial for readers who are positioned to structure their own learning activities, either due to their learning style or to their prior experience in the knowledge domain.

In recent hypertext studies, measures of some aspect of individual differences in cognitive processing have been included. Graff (2003) measured wholist-analytic cognitive style, the tendency to process information as integrated wholes or discrete parts. He reported that for participants who navigated in a nonlinear hypertext with semantic links, those who were intermediate on this dimension learned the most, as measured by written essays. This result suggests that a flexible cognitive style, neither strongly analytic nor wholist, may be beneficial when reading texts with semantic links. For those who navigated linear or hierarchical texts, cognitive style did not predict learning. One interpretation of these findings is that linear and hierarchical texts are appropriate for a wide range of learners, whereas networked texts may be suitable for readers with a flexible cognitive style. Schwartz, Andersen, Hong, Howard, and McGee (2004) investigated the role of metacognitive skills (e.g., strategies for learning, monitoring of one's understanding) in learning from hypertext in older children, ages 9–17 years. Half of the participants navigated from a puzzle map, and half from a hierarchical outline of keywords. Learning was poorer in the puzzle map condition, suggesting greater cognitive demands when navigating from the map. Self-rated metacognitive skills were a significant predictor of learning for participants in the puzzle map condition only, suggesting that the ability to organize and monitor one's own learning becomes more important when hypertext structures are more demanding to process, for example, when hierarchical text structures are not provided.

The ability to structure one's own learning appears to be important to managing the demands of hypertext reading. Consistent with this suggestion, Hailey and Hailey (1998) found that students who had grade averages in the A range learned equally well from hypertext and linear text, whereas students who had grade averages in the B and C ranges were disadvantaged in the hypertext conditions, as measured by errors on a comprehension test. Similarly, Recker and Pirolli (1995) found that hypertext instruction was only beneficial to participants who were able to quickly learn lessons in computer programming. One interpretation of these findings is that better students are likely to be able to adapt to the demands of hypertext, whereas students who have difficulty structuring their own learning are better served by traditional, linear texts, or by hypertexts with reduced numbers of choices. Making the learning task harder by requiring readers to structure the text may have benefits for some learners (Lodevijks, 1982; McNamara et al., 1996), whereas the increase in difficulty may overwhelm less able learners. This conclusion is consistent with the prediction from cognitive load theory that it is sometimes beneficial to increase "germane" cognitive load to induce deeper processing and better learning, but only when these increases are within the individual's processing abilities (Kalyuga, Ayres, Chandler, & Sweller, 2003; Sweller et al., 1998). McEneaney (2003) investigated whether less able readers, as measured by prior performance on a university admissions test, were disadvantaged by hypertext presentation. Both high- and low-ability readers were poorer at locating answers to specific questions using an electronic hypertext than a print version. Low-ability readers were not differentially impaired, and thus there was no evidence that poorer readers are especially disadvantaged in hypertext. However, McEneaney cautioned that additional studies should use larger sample sizes for increased power, and experimental measures of reading ability rather than previously administered test results.

In sum, there was some evidence that individual differences in working memory mediate the effects of hypertext and that some groups of readers who typically have lower working memory capacity benefit from having structured sequences of reading. For example, older readers navigated more efficiently and remembered more in hierarchical than networked text. For readers with low capacity, making the topic sentences of each node salient may enhance reading comprehension in hypertext. In addition to working memory, other cognitive abilities and styles interact with the ability to learn from hypertext. Some learners benefit from structuring their own learning, and other learners perform better when structured texts are provided. These individual differences must be considered in hypertext design, possibly by matching hypertext structure to cognitive abilities or styles. The role of executive functions related to the control of information processing should be further explored in hypertext studies using paradigms in which hypertext reading comprehension and executive functions are separately assessed.

2.3. The development of situation models in hypertext reading

Reading comprehension involves creating complex mental representations that have been referred to as *situation models* (Kintsch, 1988; Zwaan & Radvansky, 1998). According to the construction integration model of van Dijk and Kintsch (1983, 1988), the situation model is a representation in memory of the objects, characters, and relations described in the text, integrated with existing knowledge. When people read a text, they generate at a first level what are called textbase representations, or representations of the propositions in the text. People can use textbase representations to verify propositions that were expressed in the text. However, to answer questions that involve inferencing or combining disparately presented facts, people must construct and consult a situation model. When readers can answer inference or "implicit" questions correctly, they have comprehended the text at a deeper level than tested by factual recall questions. To represent multiple situations, people construct and maintain multiple models (Johnson-Laird, 1983).

Many text characteristics influence development of the situation model. For example, people understand texts better when propositions with related arguments are close together in the text (Charney, 1994). One explanation of this finding is that the related propositions can be held simultaneously in working memory while integration of those propositions into situation models can be performed, thus enabling comprehension. Given that hypertext reading may be affected by many of the same variables as linear reading, we applied the construction integration model as a framework for hypertext research, in line with other recent endeavors (Shapiro, 1998, 1999).

We predicted that flexible sequencing in hypertext may interrupt the development of situation models because readers will encounter propositions that are unrelated to those held in working memory more frequently than in linear text. Existing literature on the effects of interruptions on reading comprehension is consistent with the view that interruptions are likely to decrease readers' comprehension (Glanzer et al., 1981, Glanzer, Fischer, & Dorfman, 1984; Lorch, 1993). After an interruption, critical text information must be reinstated in working memory in order to successfully continue the development of the situation model (Lorch, 1993). When people follow links, they may lose track of where they are in the text, of their reading goals, of the larger context for the node, or of material activated in working memory. Loss of context, or of other information stored in working memory, may impair the development of rich, accurate situation models.

There was some evidence that hypertext as compared to linear presentation causes confusion (Miall & Dobson, 2001) and impairs reading comprehension (Barab et al., 1999; Beishuizen, Stoutjesdijk, & Zanting, 1996). Miall and Dobson examined the impact of links on the reading of modernist short stories. Two groups of participants read the same sections of a story in the same order. In the linear condition, participants advanced to the next screen using "Next" links. In the pseudo-hypertext condition, participants chose one of three links embedded in the text to continue reading, which they were told would allow them to control the sequence of the story. However, all three links led to the same text being presented as was presented when participants in the linear condition clicked "Next". Miall and Dobson found that people in the pseudo-hypertext condition were more likely to report confusion than those in the linear condition. They also found that pseudo-hypertext readers spent more time reading each node and made more comments on the mechanics of reading (e.g., that they disliked reading from the computer screen or found it distracting). Miall and Dobson concluded that links detract from the experience of reading literary texts.

Barab et al. (1999) compared learning about geography in a linear text versus hypertext. In both conditions, students were allowed unlimited time to prepare for a reading comprehension test. Students in the linear condition scored higher than those who read hypertexts. Conclusions based on these findings are qualified, however, in that linear readers may have covered more of the information than hypertext readers because they could only move backwards and forwards through the text. This factor needs to be controlled in future research because the development of situation models is certain to be impaired when readers do not cover all of the material. Beishuizen et al. (1996) found no differences in learning from a linear text and a hypertext when the task was to study for an exam. In sum, results of studies comparing linear texts to hypertexts did not support the view that hypertext was better for learning, and sometimes it was worse because students may have missed important information. However, some studies suggest that hypertext may be beneficial for specific purposes, such as generating a semantic network (Jonassen & Wang, 1993) or perceiving the interrelatedness of concepts (Eveland et al., 2004). Eveland et al. found that although factual recall was poorer for nonlinear than linear texts, readers of nonlinear texts gave higher ratings of the relatedness of the concepts presented. Eveland et al. referred to this relatedness measure as knowledge structure density (KSD), and argued that KSD measures learning because knowledge consists of linkages of concepts in memory.

A strong possibility is that hypertext is only beneficial for learning for some readers. According to the construction integration model, having prior knowledge helps because the reader can connect new information to a structure that already exists in long-term memory. Hence, hypertext readers with high prior knowledge may be better able to process fragments of text that are out of sequence because they can connect each fragment to existing knowledge whereas low-knowledge readers may have no existing structure to help them choose a reading sequence. Several researchers have explored the role of prior knowledge in learning from hypertext (Balcytiene, 1999; Calisir & Gurel, 2003; Potelle & Rouet, 2003; Shin et al., 1994). Shin et al. asked second-graders to use a full-access hypertext or a limited-access version in which navigation was restricted. They reported that students with high prior knowledge of the topic learned equally well in either text, whereas students with low prior knowledge benefited from limited access, suggesting that they benefited from more structure and fewer choices. Similarly, three other studies did not support the hypothesis that high-knowledge readers would benefit from the flexibility of hypertext as compared to low knowledge readers.

Calisir and Gurel (2003) found that students with a high level of knowledge comprehended three versions of a text equally well: linear text and two hypertexts. In contrast, students with a lower level of knowledge comprehended hypertexts better than the linear version. In this particular study, the hierarchical structure of the two hypertexts seemed to aid comprehension. Balcytiene (1999) found that low-knowledge readers were more likely to benefit from hypertext as compared to a paper text when the task was to learn how to identify Gothic pieces of art, whereas high-knowledge students showed no effect of text version. Potelle and Rouet (2003) asked high- and low-knowledge students to navigate a hypertext from a hierarchical map, a semantic network map, or an alphabetical list of topics. As measured by their accuracy on questions that required inferences, low-knowledge readers developed better situation models using a hierarchical map than either a network map or an alphabetical list, whereas high-knowledge students were unaffected by the navigation device. These three studies suggest that low-knowledge students benefit from hypertext that transparently conveys the structure of the text content. Thus, some students were worse when they had more choices, but there was no evidence that students with high knowledge derived benefit from the flexibility of hypertext. However, we should not reject the prediction from the construction integration model that high-knowledge readers are better able to learn from hypertext because their navigation and integration are guided by prior knowledge. One problem with the studies reviewed was that high-knowledge readers showed good comprehension in all the experimental conditions, so that although they outperformed low-knowledge readers, the low-knowledge readers were more likely to show differences across experimental conditions.

Future studies should manipulate interruptions in hypertext reading to test the impact of interruptions on the development of situation models. For example, the length and type of interruption could be manipulated. The impact on reading comprehension should increase with length of interruption and with increasing complexity of the reader's tasks. Low- and high-knowledge readers could be tested for their resilience in the face of interruptions, with high-knowledge readers expected to be more resilient due to their ability to use prior knowledge to guide creation of the situation model or decision processes during hypertext reading. With respect to the hypothesis that hypertext features may increase cognitive load, the research reviewed in this section is consistent with the view that load is moderated by text structure. Hierarchically structured hypertexts may have decreased extraneous cognitive load, producing benefits for the low-knowledge readers by illustrating text structure.

The construction integration model can also be applied to conceptualize the role of links in reading. The model developed by van Dijk and Kintsch (1983) predicts that the presence of unlabeled links will not aid reading comprehension. A link does not serve to develop the situation model: a link tells merely that more information is available, but not how the linked text is related to other elements of the situation model. The underlined text may be made more salient, but salience alone does not strengthen the relations that are expressed in the situation model. In contrast, the model predicts that *labeled* links, indicating what type of information is available, might support development of the situation model because labels could alert the reader that the destination information should be incorporated into the current situation model, or that the link leads to a new topic and thus requires the formation of a new situation model.

One way to provide information about a destination node is to open a pop-up window when a link is clicked. The effects of pop-up windows containing link preview information were tested in three studies (Cress & Knabel, 2003; Jonassen & Wang, 1993; Zhao, O'Shea, & Fung, 1994). Cress and Knabel measured learning when participants interacted with a complex, hierarchical hypertext on system theory. They also reported navigation measures, such as number of pages opened and frequency of backtracking. In the link preview condition, clicking on a link opened a new window containing a summary of the destination node. After viewing this summary, the reader either chose to go back or to continue to the destination node. Students in the link preview condition learned more than those who did not see previews. Zhao et al. (1994) obtained a similar result when readers saw descriptions of the destination node by placing the cursor over underlined text fragments, as compared to a control condition without visible link types. Cress and Knabel suggested that link previews helped provide context for the destination information, activating existing concepts in the reader's knowledge structure and enabling integration. They also reported that students in the link preview condition navigated backwards less frequently, suggesting that they were better oriented in the text.

Consistent with these findings of enhanced learning, two other studies suggested that link labels are helpful for navigation (Baron, Taguesutcliffe, Kinnucan, & Carey, 1996; Campbell & Maglio, 1999). Campbell and Maglio (1999) placed icons of red, yellow, or green traffic lights next to links to indicate the estimated connection speed to destination nodes. They found that the presence of the traffic light icons improved Web navigation. Baron et al. (1996) compared navigation of three hypertexts. One version contained organizational links only (e.g., "Next", "Previous," "Beginning of section", "Beginning of document"). The other two versions had the same organizational links plus content-based links that expressed three kinds of relations between nodes: semantic (e.g., similar topic), rhetorical (e.g., explanation) and pragmatic (e.g., instruction to the reader). The content-based links were labeled in one condition and unlabeled in another condition. In the labeled condition, a one-word descriptor, such as "definition" or "contrast," was placed in parentheses next to the linked text. Baron et al. hypothesized that link labels "may act as cues to enable interpretation and lead to more informed navigational choices" (p. 899). One of the dependent measures was accuracy of locating information in a time-limited situation. Accuracy was highest in the labeled links condition. Accuracy did not differ between the organizational-links-only and unlabeled links conditions, however. These results suggest that labeling links can enhance navigation performance.

Jonassen and Wang (1993) tested the effect of a pop-up window that described the relationship between two nodes (e.g., *A* is an example of *B*). They compared text recall after readers navigated in one of three hypertexts. In one condition, readers navigated from a semantic map. In two other conditions, readers navigated from a list of topics, either with or without pop-up windows. In contrast to the other studies that used pop-up windows, Jonassen and Wang found that pop-up windows neither helped nor impaired text recall as compared to the other two conditions. Thus, pop-up windows were helpful for navigation and enhanced comprehension when they cued the destination content (Baron et al., 1996; Cress & Knabel, 2003; Zhao et al., 1994) or signaled the amount of potential distraction (Campbell & Maglio, 1999), but did not necessarily affect text recall if they merely indicated the type of relation between nodes (Jonassen & Wang, 1993).

These results provide some suggestions for future research. For example, icons placed next to links could be used to signal to the reader the relation between the current node and the target information. Link labels could indicate to the reader what kind of information to expect and thus simplify or reduce the decision-making load introduced by the link. For example, a "definition" link would lead to a definition of the linked term. Other links could provide information about context, for example, connection to a higher-level topic. Various link typologies have already been developed. For example, Parunak (1991) proposed a typology of links that included "orientation" links for *location* and *circumstance*, and "implication" links that describe logical connections such as *causation* and *purpose.*

We propose that mentally preparing to integrate information of a certain type can enhance comprehension and decrease cognitive load (cf. Baron et al., 1996). However, care will be needed in designing systems of link icons that readers can comprehend and use in deciding whether to follow links. Further, the number of different icons must be limited so that they remain discriminable and are easily learned. Otherwise, identifying link types could also contribute to increased cognitive load.

2.4. Summary

Across the variety of research examined in this section, there was ample evidence that decision-making demands create additional cognitive load for hypertext readers. However, the load associated with decision-making did not bear a straightforward relation to the number of choices presented at each decision point, nor to the total number of possible links in a text. We propose that decision-making load should be investigated using systematic manipulations of link numbers, text topologies, and link types. There was some evidence for better construction of situation models when low-knowledge students worked with certain hypertext versions as compared to a linear text (Balcytiene, 1999; Calisir & Gurel, 2003). Readers with high prior knowledge were typically unaffected by variations in hypertext features. The advantage for the low-knowledge learners in hypertext appeared related to the way that hypertext can be used to draw attention to the hierarchical structure of an information domain, which perhaps is not beneficial to high-knowledge learners who have already internalized this hierarchical structure. Further research using text variables that are known to affect the formation of situation models (e.g., familiar vs. unfamiliar topics) would be useful in examining the relations among cognitive load, situation model construction, and hypertext features.

In general, readers' performance was better when hypertexts had hierarchical structure. When readers first encounter a hypertext, they are likely to rely on the hierarchical structure for navigation, and to find shortcuts (e.g., use lateral links) only if they become sufficiently familiarized with the hypertext (Leventhal, Teasley, Instone, & Farhat, 1994). Hierarchical structure may also facilitate the development of situation models, especially if readers are not able to retrieve an appropriate structure from their stored knowledge. We recommend that when the information domain lends itself to hierarchical organization, hierarchical structure should be made salient. Other kinds of structure may be useful for other types of text content, such as narratives. Only one study that used narrative texts (Miall & Dobson, 2001) was identified in our search process, however, so additional research is necessary to determine how links affect reading for different text genres.

Consistent with Dillon and Gabbard (1998), we conclude that lower ability students will often need more guidance in learning from hypertext than higher ability readers, especially if the hypertext has not been optimally structured. We recommend more research exploring the use of restricted numbers of links to decrease cognitive load and enhance learning. Restricted access to linked information may be helpful to readers who have difficulty managing concurrent demands, such as those with low working memory spans. Link labels that indicated position in a hierarchy did not affect learning (Shapiro, 1998), but link labels that indicated the type of information contained in a destination node enabled efficient navigation (Baron et al., 1996; Cress & Knabel, 2003) and learning (Cress & Knabel, 2003; Zhao et al., 1994). Thus, there was evidence that link labels can be used to help people develop situation models.

3. Relations between cognitive load and interface features in hypertext

Designers of hypertext are sensitive to the view that readers often find hypertext disorienting. To help with management of the cognitive demands in hypertext, designers have used various interface features to help readers determine where they are in a text, which parts they have read, and how to get where they want to go. A common technique has been to provide graphical or "structural" overviews that show the topics and the links that connect them. Typically, a box containing the node title represents each node, the boxes are connected with lines, and readers navigate by selecting a title within the overview.

Graphical overviews may be helpful for some tasks. de Jong and van der Hulst (2002) compared learning from three versions of a hypertext. They reported that participants who viewed a visual overview that displayed the inherent structure of the domain learned more than those who saw other overviews that were inconsistent with the structure of the domain. Based on a meta-analysis of seven studies reported between 1988 and 1993, Chen and Rada (1996) reported that readers' effectiveness, tested using measures such as factual recall, was higher when graphical overviews were provided. However, in several studies not included in Chen and Rada's analysis, the availability of graphical overviews did not improve factual recall or navigation (Dias & Sousa, 1997; Heo & Hirtle, 2001; Jonassen & Wang, 1993; Nilsson & Mayer, 2002; Schwartz et al., 2004). Jonassen and Wang (1993) presented linked topics either in lists ("unstructured") or in a map with linked boxes showing how the topics were connected. Recall of facts in the text was lower in the map than in the list condition. Nilsson and Mayer (2002) also found that the presence of a map of the linked topics did not enhance users' performance. After a study period, map users were slightly less efficient at finding answers in the test phase of the experiment than those in the no-map condition. Nilsson and Mayer suggested that when maps were available, users were less involved in learning and were less likely to build representations of the overall structure of the hypertext. Hence the usefulness or importance of structural overviews in hypertext may depend on interactions with other factors.

One factor that influences the usefulness of structural overviews is the prior knowledge of the reader. In two studies of hypertext reading, readers who had a high amount of prior knowledge of the topic were not affected by whether a structural overview was available, and performed well in all text versions, whereas low-knowledge readers were affected by the overviews (Hofman & van Oostendorp, 1999; Potelle & Rouet, 2003). In both studies, readers answered two types of questions: an easier type that required memory for details presented in the text, and a harder type that required inferences, or integrating the text with prior knowledge (i.e., formation of situation models). Potelle and Rouet (2003) found that low-knowledge readers answered more inference questions correctly when they navigated from a hierarchical map than from either an alphabetic list of topics or a semantic network map. Hofman and van Oostendorp (1999) also reported an advantage on inference questions for low-knowledge readers who navigated from an ordered list of topics as compared to a semantically organized map (i.e., a schematic diagram that indicated causal relations). Hofman and van Oostendorp argued that the structural overview had drawn attention away from the details of the text, thus leading to poorer situation models and hence lower ability to answer questions involving inferences. High-knowledge readers can rely more on prior knowledge to construct situation models and thus may be less affected by the way the text is presented. These findings collectively suggest that when low-knowledge readers are asked to generate situation models and make inferences, graphical overviews may be more distracting than helpful.

Results reported by Wright, Hull, and Black (1990) suggest that another reason that graphical overviews are not consistently helpful to readers is that readers may not know when to consult the overviews for help in constructing situation models. Wright et al. (1990) provided hypertext readers with access to a diagram that illustrated the relations among the characters described in a text. Wright et al. found that when participants were allowed to consult the diagram from any screen, they rarely chose to consult the diagram while reading the text and thus the diagram did not affect reading. In contrast, when the computer intermittently presented the diagram as participants clicked to go the next screen, text comprehension was enhanced. One interpretation of these results is that the decision-making required when the diagram was freely available served as an extraneous cognitive load (Sweller et al., 1998). On this view, the cognitive load of decision-making may have negated the usefulness of the structural overview.

More generally, the cognitive load involved in processing complex visual information may counteract any potential benefit of graphical overviews. Heo and Hirtle (2001) reported that readers preferred visually simple overviews to more complex ones when the task was to search for information in a hyperlinked database. One of the four overviews that they tested was a hyperbolic map. In this overview, the region of the text that was being actively explored was shown as an interconnected web of node titles, whereas non-active regions were diminished in size on the screen, with little or no detail about links within those regions. Although enlargement of the active area enabled easier viewing in the hyperbolic map overview, participants preferred a simple, outline-style overview with familiar symbols ("+" and "−") for expanding and minimizing parts of the outline. None of the four graphical overviews enhanced navigation performance, however. Schwartz et al. (2004) also reported poorer learning for children who navigated from a puzzle map than a hierarchical outline of keywords, and argued for greater cognitive load in the puzzle map condition.

In sum, efforts to ameliorate working memory demands by providing overviews have not been uniformly successful. When overviews are visually complex, the increase in cognitive load required to use the overview may detract from the overall processing in a limited-capacity system, consistent with the predictions of working memory models (e.g., Baddeley & Logie, 1999). Interestingly, removing some of the decision-making demands on the reader enhanced the usefulness of overviews (Wright et al., 1990). This finding is consistent with our hypothesis that readers have more cognitive resources available when decision-making demands were reduced. In creating new overview styles, designers should consider that people tend to prefer styles that are familiar and they may need significant time and experience to learn how to use new tools. Thus, innovative and complex overview styles may only be appropriate when the learner is expected to interact with the information over many sessions.

To promote the development of rich, accurate situation models, hypertext designers have created features that are intended to increase the salience of the structure of the text and of logical connections between propositions (Britt, Rouet, & Perfetti, 1996; Niederhauser, Reynolds, Salmen, & Skolmoski, 2000; Shapiro, 1998, 1999). For example, Niederhauser et al. (2000) developed an interface feature that they named "compare and contrast". They provided a hierarchically organized hypertext that contained information about two psychological theories of learning. The text was organized into two main sections, one on behaviorism and one on constructivism. The two parts of the text were designed to be symmetrical. For example, a subheading on the behaviorism side described the argument that knowledge is objective, and the corresponding constructivist subheading described the argument that knowledge is relative. By clicking on a special icon at the top of the screen, readers could jump directly from the "knowledge is objective" to the "knowledge is relative" screen. Niederhauser et al. hypothesized that readers who used this compare-and-contrast feature frequently would show greater understanding of the text because they would actively integrate information across the two main sections.

Niederhauser et al. (2000) allowed readers to navigate the text as they chose. Readers were classified into three groups based on their use of the compare-and-contrast feature: extensive, minimal, or none. The dependent measure was a posttest score that combined accuracy on a multiple-choice test and the proportion of concepts included in an essay. Contrary to their predictions, Niederhauser et al. found that posttest scores were lower for students who used the compare-and-contrast feature more frequently. They suggested that "the increased *cognitive load* associated with reading in a hypertext environment may have interfered with learning" (p. 250). Readers who scored higher on the posttest tended to read the text in a sequential manner, working across and down each branch, rather than using the compare-and-contrast feature to jump between the two halves of the text. These more successful readers used a traditional strategy that did not require much decision-making, and may have had more mental resources available for integrating and understanding the material. However, the conclusion that decision-making load impaired reading comprehension remains speculative because this load was not manipulated or measured.

Shapiro (1998) also tested the effect of a feature that provided explicit information about a text's structure. Students read one of three texts: linear, highly structured hypertext, or unstructured hypertext. The highly structured and unstructured hypertexts contained the same links and were hierarchically organized. In the highly-structured condition, each page contained various markers that were intended to inform the reader about the structure of the text. For example, a text fragment on "Introduction to Realism" was marked on the right side of the screen with "3rd level", indicating that this text was at the third level of the hierarchy. An icon of an arrow pointing up was used to mark the links that led to superordinate topics in the hierarchy. In the unstructured condition, all links were presented at the bottom of the page and were not categorized or specially marked in any way. Shapiro predicted that students in the unstructured condition would process the text more actively, create better situation models, and show more learning. As predicted, students in the unstructured condition scored higher on an essay than those in the highly structured condition, and students who read the linear text scored in between the two hypertext groups. Shapiro argued that the readers of the unstructured hypertexts did the most work of integrating during reading because they had to make decisions about navigating, which requires active processing, but they did not have structural cues available. For the readers of highly structured hypertext, the availability of structural cues may have made it less likely that they would actively construct a model of the text's structure (see Nilsson & Mayer, 2002, for a similar argument). Thus, there was some evidence that students learned better from hypertext than from linear text, but that the presence of structural cues hindered rather than helped learning.

Rather than providing a structural overview that showed links between nodes, Shapiro (1999) presented readers with simpler representations that she called interactive overviews.

An interactive overview was a set of labeled icons from which readers navigated to short texts about animals and their habitats. To investigate the role of prior knowledge, readers were pretested to ensure that they had low knowledge of ecosystems functioning and relatively high knowledge of animal families. Half of the learners saw an "ecosystems interactive overview" that was color-coded so that subtopics in the same ecosystem (e.g., desert-dwellers) had the same color (one of three colors). In contrast, in the "animal families interactive overview", subtopics in the same animal family (e.g., reptiles) had the same color (one of four colors). An important finding was that readers who interacted with the ecosystem interactive overview produced better situation models of ecosystems, as measured by accuracy in answering inference questions, than readers who used the animal families overview. Readers who used the ecosystems overview tended to fully explore the nodes within an ecosystem before moving on to explore another ecosystem, suggesting a connection between navigation behavior and the development of situation models. In contrast, the overview type did not affect learning about animal families, for which prior knowledge was high. It seems that a simple feature, such as color-coding related nodes, may be more beneficial to the development of situation models for unfamiliar material than complex structural overviews that depict relations between nodes such as causal relations (e.g., Hofman & van Oostendorp, 1999). However, the color-coding technique might not transfer well or scale up to more complex texts.

In sum, features added to hypertext to make explicit the text's structure did not enhance reading comprehension (Niederhauser et al., 2000; Shapiro, 1998). Some researchers have argued that the availability of explicit information about the text's structure may decrease the reader's motivation to form an internal mental representation of the structure. In contrast, there was some evidence that less explicit organizers can be used to enhance comprehension by guiding readers' navigation (Shapiro, 1999). Organizing materials in a way that encourages people to explore a related set of texts before moving on to another set may help people to form situation models, consistent with the notion that reading related propositions close together in time is important for reading comprehension.

4. Discussion

The ubiquity of hyperlinked information as a medium for presenting content raised the issue of how reading processes are affected by the features that distinguish hypertext from linear text. Minimally, the presence of links in text introduces decision-making processes and interruptions to reading that can either enrich the reading experience and/or increase the complexity of the comprehension process. In the present paper, we reviewed the available literature on how hypertext features influenced cognitive processes in reading, with a focus on comprehension and navigation. We used theoretical frameworks from cognitive psychology, such as the working memory model and the construction integration model of reading, to relate mental processing to features of hypertext. The goal of this review was to explore the hypothesis that the effects of hypertext on reading performance would be related to the cognitive load introduced by various features such as links requiring decisions.

We identified 38 experimental studies in which hypertext features were manipulated and/or hypertext was compared to linear text. We examined the effects of these manipulations on reading comprehension and navigation. In some studies, comparisons were made to linear text whereas in others, different features of hypertext, such as graphical overviews, were explored. In general, we found that hypertext features that introduced novel structures or required additional processing (e.g., navigating from semantic maps) decreased readers' comprehension relative to linear texts or hypertexts without these features. In many cases, the visual processing required to process semantic maps detracted from comprehension rather than enhancing it. Even when designers provided features that were intended to make conceptual relations explicit, such as causal relations, graphical overviews did not reliably aid the construction of accurate situation models. According to the framework we presented, many features of hypertext resulted in increased cognitive load and thus may have required working memory capacity that exceeded readers' capabilities. This conclusion is supported by the finding that the various manipulations were often most detrimental to the reading processes of less-knowledgeable readers and for readers with low working memory capacity. Thus, there was considerable evidence that at least some features of hypertext can lead to poorer performance compared to traditional linear presentation and that the reduced performance was linked to cognitive load.

The news was not all bad, however. Hypertexts that were structured to capitalize on the inherent organization of the domain (usually hierarchical structures for informational content) often resulted in better comprehension, memory, and navigation. These benefits were most evident for less knowledgeable readers, who seemed particularly influenced by the way that hypertext can illustrate the conceptual structure of a text. Some of the simpler organizational aids (e.g., hierarchical graphical overviews) also enhanced readers' performance, although as these increased in complexity they were either not used or detracted from navigation and understanding. In general, learners with low prior knowledge were more affected (both positively and negatively) than more knowledgeable readers by structural manipulations such as link structures (e.g., hierarchical versus networked), the presence of graphical overviews, or the restriction of navigation within the hypertext.

Notably, our review uncovered very little support for the idea that hypertext will lead to an enriched experience of the text. Our focus was on comprehension and navigation, however. Few of the studies that we reviewed considered affective factors such as engagement or enjoyment, and none explored long-term comprehension and memory for information presented in various text formats. More studies will need to include a wider range of objective and subjective measures that explore the reading experience related to various hypertext features. In the few studies that included participants' subjective impressions along with their objective performance, complex hypertext features were generally not preferred (e.g., Heo & Hirtle, 2001), and led to reports of disorientation and confusion (Miall & Dobson, 2001). There may be cases in which enrichment or complexity of the hypertext experience is more desirable than maximizing comprehension and ease of navigation. In educational applications, however, students are expected to learn from their reading as well as be entertained. It will be important, therefore, to establish principles of good hypertext design for learning that are consistent with our understanding of human cognition but without neglecting issues of motivation and interest. These challenges are well-suited for multi-disciplinary research involving psychologists, educators, and computer scientists (cf. Rapp, Taylor, & Crane, 2003). The results of the present review for hypertext are consistent with the conclusions reached by Mayer and Moreno (2003) for multimedia education. Designers need to consider cognitive load to ensure that hypermedia provide at least as good a learning environment as more traditional text.

This is an exciting time in hypertext research. Designers are looking for concrete and specific suggestions as to how material should be presented to maximize learning and enjoyment. Our results indicate that an important step is to integrate knowledge about the cognitive processes involved in reading into a model of learning from hypertext. Our review suggests that a more complete model will need to include learner characteristics such as prior knowledge, working memory capacity, and ability to impose structure on information. Based on learner characteristics, individuals would be predicted to have different strategies for navigating and comprehending hypertext. An explicit model that includes decision processes, working memory load, and situation model construction will facilitate development of guidelines for hypertext design, particularly for educational materials. To advance this research agenda, we have proposed the following manipulations in studies of hypertext: (1) structural variables (breadth, depth, topology, link previews, restricted access) affecting decision-making load, (2) decision-making load using secondary tasks, (3) variables mediating the effect of interruptions on situation model formation (semantic relatedness, length of interruption), and (4) measures of working memory and executive function to identify the mental subsystems that are engaged in hypertext reading.

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Diana DeStefano, Ph.D., is a postdoctoral researcher in the Geomatics and Cartographic Research Centre at Carleton University.

Jo-Anne LeFevre, Ph.D., is a Full Professor in the Department of Psychology and the Institute of Cognitive Science and the Director of the Centre for Applied Cognitive Research at Carleton University.