

# TESIS DOCTORAL

TOWARDS A HYPERTEXT COMPREHENSION MODEL:

THE ROLE OF READING STRATEGIES AND COGNITIVE LOAD

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HACIA UN MODELO DE COMPRESION DE HIPERTEXTO:

EL PAPEL DE LAS ESTRATEGIAS DE LECTURA Y LA CARGA COGNITIVA

Tesis Doctoral realizada por:

**Rafael Ignacio Madrid López**

Dirigida por:

**José J. Cañas Delgado.**

Departamento de Psicología  
Experimental y Fisiología del  
Comportamiento.

Universidad de Granada.

**Herre Van Oostendorp.**

Department of Information and  
Computing Sciences  
Utrecht University

(The Netherlands)

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# INDICE

DEDICATORIA.....	7
AGRADECIMIENTOS / ACKNOWLEDGMENTS.....	9
ENGLISH SUMMARY.....	11
MAIN PUBLICATIONS.....	17
SOBRE LA ORGANIZACION DE LA TESIS.....	19
CAPITULO 1. Introducción. La lectura de hipertexto.....	21
1.1. Definición y breve historia del hipertexto.....	23
1.2. Tareas cognitivas relacionadas con la lectura de hipertexto.....	24
1.2.1. Tareas de lectura.....	26
1.2.2. Tareas de navegación.....	29
1.2.3. Tareas de gestión.....	30
1.3. Variables implicadas en la comprensión de hipertexto.....	31
CAPITULO 2. Efecto de las características del procesamiento en la comprensión de hipertexto.....	33
2.1. Papel de las estrategias de lectura.....	35
2.1.1. Estrategias de lectura entendidas como conducta de navegación... 36	
2.1.2. Estrategias de lectura entendidas como regla de decisión..... 37	
2.1.3. Mecanismos de influencia de las estrategias de lectura en la comprensión..... 38	
2.2. Papel de la carga cognitiva.....	40
2.2.1. Carga cognitiva y aprendizaje: La Teoría de la Carga Cognitiva... 40	
2.2.2. La carga cognitiva en la comprensión y aprendizaje con hipertexto..... 42	
CAPITULO 3. Variables predictoras de las características del procesamiento de los usuarios.....	45

3.1.	Efectos del diseño del sistema hipertexto .....	47
3.1.1.	Sistemas de ayuda y soporte a la navegación .....	48
3.1.2.	Número de enlaces en la página.....	51
3.2.	Efectos de las características de los usuarios .....	51
3.2.1.	Conocimiento previo .....	52
3.2.2.	Habilidades cognitivas .....	53
3.3.	Relación entre estrategias de lectura y carga cognitiva .....	54
3.3.1.	La estrategia de lectura puede afectar a la carga mental de la tarea. .....	54
3.3.2.	La carga cognitiva de la tarea puede afectar a las estrategias de lectura .....	56
CAPITULO 4. Justificación y objetivos de la tesis.....		57
CAPITULO 5. Resumen de resultados.....		65
5.1.	Estudio I: Habilidades cognitivas predictoras de las estrategias de lectura y el papel de estas en la comprensión de hipertexto.....	67
5.1.1.	¿Cuáles son las variables relacionadas con las estrategias de lectura que pueden predecir unos buenos resultados de comprensión?.....	67
5.1.2.	¿Qué habilidades cognitivas son importantes y cuál es su papel como predictoras de las estrategias de lectura? .....	68
5.1.3.	Relación entre habilidades espaciales, estrategias de lectura y comprensión.....	69
5.2.	Estudio II: El efecto del diseño del hipertexto en la carga cognitiva y la comprensión. El efecto mediador de las estrategias de lectura .....	70
5.2.1.	Estudio IIa: Efecto de número de enlaces y apoyo a la navegación en la carga cognitiva y la comprensión .....	70
5.2.2.	Estudio IIb: El papel mediador del orden de lectura en la carga cognitiva y la comprensión.....	72

5.3. Estudio III: Efecto del conocimiento previo de los lectores y las estrategias de lectura en la carga cognitiva .....	73
CAPITULO 6. General discussion and conclusion.....	77
6.1. The effect of user processing characteristics on comprehension .....	81
6.1.1. Reading strategies: decision rules and navigation behavior .....	81
6.1.2. Cognitive load.....	84
6.2. Relation between user processing characteristics: Reading strategies and cognitive load.....	84
6.3. The role of user and system variables as predictors of user processing characteristics .....	87
6.3.1. The effect of user variables .....	87
6.3.2. The effect of system variables .....	90
6.4. Conclusions .....	93
6.4.1. Theoretical implications .....	93
6.4.2. Methodological implications .....	95
6.4.3. Practical implications .....	96
REFERENCES.....	99
APPENDIX I.....	117
APPENDIX II. ....	153
APPENDIX III. ....	193



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## ENGLISH SUMMARY

Hypertext, thanks to the extensiveness of Internet use, is replacing traditional linear printed text as the main information media. Their impact in important areas such as education, journalism, communication and commerce over the last decade is obvious and their use is present in the daily life of most people in modern countries. Thus, there is a need for a new online digital literacy that can provide readers with the skills needed in this new digital age. This online digital literacy has been conceptualized not as an issue of technology and information, but as a reading issue (Coiro, 2009).

Together with the speed and ubiquitous access to information, there is a claim that hypertext improves the learning and comprehension processes compared with linear text. However, the advance of hypertext has not been accompanied by research results supporting this claim (Chen & Rada, 1996; Dillon & Gabbard, 1998; Shapiro & Niederhauser, 2004). Therefore, it is important to analyze how readers comprehend the information presented in hypertext to obtain an understanding of the real benefits of using hypertext for comprehension and learning.

From a user-centered perspective (Unz & Hesse, 1999), the most important research objective in hypertext comprehension is to understand the interaction process, that is, how the user interacts with the hypertext system in order to gain knowledge. Our literature review has shown evidence that both user and system variables affect hypertext reading. User variables such as prior knowledge, cognitive abilities and experience with computers, and system variables as the number of links shown by the system, the provision of navigation support and the system structure determine comprehension and, what is more important for the aim of this thesis, the way in which readers process the hypertext.

We propose a hypertext comprehension model (see Figure 1) in which the interaction between the hypertext user and the hypertext system can be defined through user processing characteristics. These user processing characteristics have two components:

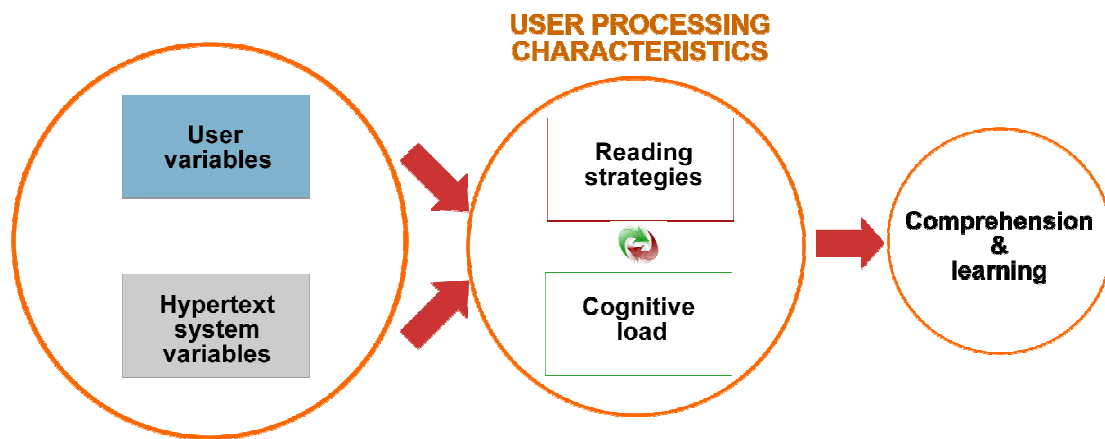
### 1) A behavioral component: hypertext reading strategies

The behaviour of users during hypertext use is an important research topic, since hypertext systems allow readers to control the presentation of information that they contain (Scheiter & Gerjets, 2007). Users exert this control through reading strategies, which have been examined from two different (although complementary) perspectives. Firstly, a set of studies have focused on the reader's navigation behaviour, identifying different navigation patterns in order to describe and analyze their effect on comprehension. From this perspective, variables such as the reading order of pages, the amount of information accessed or the use of navigation tools can be used to objectively define the reading strategies followed by hypertext readers. Secondly, another set of studies consider reading strategies as implicit decision rules that readers follow to select which parts of a set of hypertext documents to read and in which order (Salmerón, Cañas, Kintsch & Fajardo, 2005; Salmerón, Kintsch & Cañas, 2006a). There are different decision rules that hypertext readers can use, which have different effects on comprehension based on their prior knowledge. For example the coherence strategy (reading the hypertext node most related with the previously read one in order to maintain text coherence) and the interest strategy (reading first the most interesting nodes for the user, delaying the less interesting ones) have been identified.

### 2) A cognitive component: cognitive load

Cognitive load in hypertext reading can be seen as the amount of cognitive resources required by the hypertext reading task. Traditionally, there are two different approaches for considering the role of cognitive load in hypertext reading. From the first approach, hypertext features increase overall cognitive load if compared with linear text which could lead to disorientation and hinder comprehension (Conklin, 1987; DeStefano & LeFevre, 2007). From the second approach, that of the Cognitive Load Theory (Sweller, 1988; Sweller, van Merriënboer & Paas, 1998; Zumbach, 2006), hypertext features can increase overall cognitive load if compared with linear text but their effect on comprehension and learning depends on the tradeoff between different types of cognitive load: intrinsic (depending on the interactivity of materials and prior knowledge), extraneous (detrimental for learning) and germane cognitive load (the extra resources devoted to active processing and deep learning).

We propose that both behavioral and cognitive components influence mutually and determine hypertext comprehension and learning. Our research has shown that different reading strategies lead to different levels of cognitive load and, on the other hand, we assume that the availability of cognitive resources affects the selection and development of reading strategies.



**Figure 1. Hypertext comprehension model proposed**

Both reading strategies and cognitive load can be predicted by an interaction between user and system characteristics. The main objectives of this dissertation are:

1. To analyze the mediating role of user processing characteristics on hypertext comprehension. Do the reading strategies performed and cognitive load experienced by hypertext readers affect comprehension outcomes? If so, which are the specific mechanisms by which these effects occur?

2. To determine which specific user and system variables affect which user processing characteristics. Do individual differences in variables such as cognitive abilities and prior knowledge play a role in readers' cognitive load and reading strategies? Can system features as the number of links or the provision of navigation support be used to promote a pattern of user processing characteristics that subsequently enhance comprehension?

3. To investigate the relation between reading strategies and cognitive load and their effect on comprehension. Do the reading strategies that users follow determine their experienced cognitive load?

Next, the main results of the three studies conducted in this thesis are summarized.

Study 1: Cognitive factors and reading strategies involved in comprehension with hypertext systems (Madrid, Salmerón & Cañas, *Under review*)

Interactive graphical overviews are frequently used by hypertext designers and authors to give orientation and provide access to the main set of hypertext documents. However, the way in which readers use and benefit from this navigation tool seems to depend on their abilities and experience. In this study, we tested the relation between a set of cognitive abilities and the reading strategies that low prior knowledge hypertext readers follow when using an interactive graphical overview, and how reading strategies can predict comprehension. Results showed that readers' spatial abilities predicted a set of variables characterizing reading strategies: readers with higher spatial abilities accessed more different hypertext nodes, spent less time using the graphical overview and followed a reading order more related with the structure suggested by the graphical overview, which in turns leads to higher reading text coherence and better comprehension at both textbase and situation model level.

Study 2: Effect of number of links and navigation support on cognitive load and learning (Madrid, Van Oostendorp & Puerta Melguizo, 2009)

Does the number of links included in a hypertext system determine readers' cognitive load and comprehension? Is it possible to help readers to reduce cognitive load and to enhance learning by providing navigation support? These two questions were examined in an investigation in which low prior knowledge readers used an hypertext either with 3 or 8 links per page in which navigation support was provided or not. Navigation support was provided by signalling the two links that were more related with the text just read, which helped readers to develop a coherence strategy. Results showed that there was a benefit of using link suggestions for comprehension at situation model level, but no effect of the number of links per page was found. Moreover, the reading order that participants selected mediated the effects on cognitive load and comprehension: those readers that performed a more coherent reading order learned more and experienced less cognitive load than those who followed a less coherent one.

Study 3: The effect of prior knowledge and reading strategies on cognitive load and learning (Madrid & Cañas, 2009)

Following the results of Study 2, this study compared the effect of two different reading strategies (coherence vs. interest) on cognitive load and reading comprehension, both for low and high prior knowledge readers. Main results showed that the interest reading strategy causes higher levels of cognitive load during text reading than the coherence strategy both for low and high prior knowledge readers. Regarding comprehension and learning, the coherence strategy showed to be better for low prior knowledge readers, while both strategies lead to similar results for high prior knowledge readers. These results are interpreted as a greater investment of germane cognitive load for high prior knowledge readers in the interest condition.

The empirical evidence provided by the studies described above supports the hypertext comprehension model proposed. It stresses the importance of user processing characteristics. Furthermore, both the development of reading strategies and cognitive load seems to be influenced by user and system variables.

In conclusion, these user variables (such as spatial abilities) and system variables (such as the number of links or the navigation support) can determine the reading strategies that users follow (and thereby the selected reading order and other reading strategy variables) and/or the cognitive load level that they experience during hypertext reading, and subsequently the comprehension and learning outcomes. The coherence of the reading order is robustly shown to determine the comprehension level, at least for low prior knowledge readers. Results also support the approach adopted by the Cognitive Load Theory suggesting that, under some circumstances and for certain readers, increases in overall cognitive load could be beneficial if it is caused by a greater investment of germane cognitive load. From our point of view, the relation between cognitive load and hypertext comprehension is a matter of cognitive resources distribution between the different tasks that are involved in hypertext reading. To enhance comprehension in hypertext extraneous cognitive load has to be reduced while germane cognitive load has to be promoted (Zumbach, 2006). However, increasing germane cognitive load by activating prior knowledge can be only possible for high or moderate prior knowledge readers that are able to engage in active processing activities.



This work concludes with describing the theoretical implications (regarding the hypertext comprehension model proposed), methodological implications (about the measurement of both reading strategies and cognitive load) and practical implications (both for usability engineering and instruction).

# MAIN PUBLICATIONS

## **Publications integrated into this thesis**

- Madrid, R.I., Salmeron, L., & Cañas, J.J. (Submitted). The role of cognitive abilities as predictors of hypertext reading strategies and their effect on comprehension.
- Madrid, R.I., Cañas, J.J., & van Oostendorp, H. (In Press). Reading strategies and cognitive load: Implications for the design of hypertext documents. In Torrance, M. (Ed.). *Learning to write effectively: Current Trends in European Research*. Brussels: OPOCE.
- Madrid, R.I., & Cañas, J.J. (2009). The effect of reading strategies and prior knowledge on cognitive load during hypertext reading. *The Ergonomics Open Journal*, 2, 124-132.
- Madrid, R.I., van Oostendorp, H., & Puerta-Melguizo, M.C. (2009). The effects of the number of links and navigation support on cognitive load and learning with hypertext: The mediating role of reading order. *Computers in Human Behavior*, 25 (1), 66-75.
- Madrid, R.I., & Cañas, J.J. (2007). How reading strategies affect comprehension of texts in hypertext. In D. Alamargot, P. Terrier & J.-M. Cellier (Eds.). *Improving the production and understanding of written documents in the workplace*. Elsevier
- Madrid, R.I., Salmeron, L., Cañas, J.J. & Fajardo, I. (2005). Cognitive Factors related to text comprehension with hypertext overviews. In G. Chiazzese, M. Allegra, A. Chifari & S. Ottaviano (Eds.). *Methods and technologies for learning*. Southampton: WIT Press. (pp. 597-598).

## Other publications

- Galdón, P., Madrid, R.I., de la Rubia, E., Diaz, A., & González, L. (Under review). ConTactos: Improvement in a mobile device interface for the visually impaired through the design of haptic tones. *IEEE Transactions on Haptics*
- Madrid, R.I., Ávila, V., Fajardo, I., & Ferrer, A. (In Press). Writing easy-to-read documents for people with intellectual disabilities. In Torrance, M. (Ed.). *Learning to write effectively: Current Trends in European Research*. Brussels: OPOCE.
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# SOBRE LA ORGANIZACION DE LA TESIS

El presente trabajo presenta un conjunto de estudios dirigidos al desarrollo de un modelo de comprensión de hipertexto.

La tesis comienza, Capítulo I, con una introducción al estudio de la lectura de hipertexto. A continuación, en el Capítulo II, se revisan la evidencia existente sobre la relación entre las características de procesamiento de hipertexto (estrategias de lectura y carga cognitiva de los usuarios) y la comprensión. En el Capítulo III se analiza cómo las características tanto de los sistemas hipertexto como de los usuarios pueden predecir el procesamiento de hipertexto y de forma indirecta afectar a la comprensión.

En el Capítulo IV se exponen la justificación y objetivos de esta tesis. Aunque el objetivo general del desarrollo de este modelo es poder explicar y predecir los resultados de comprensión, queremos poner el foco en la relación entre las diferentes variables que forman parte del modelo, examinando el papel mediador de las estrategias de lectura y la carga cognitiva.

En el Capítulo V se ofrece un resumen de los principales resultados de los estudios que componen la tesis. En el momento de la presentación de este trabajo, los estudios están publicados o en proceso de publicación en revistas internacionales, por lo que se ha optado por incluir el manuscrito completo de estos artículos en inglés. Estos artículos se encuentran en forma de apéndices al final del documento (Appendix I,II y III).

Finalmente, el Capítulo VI (Chapter VI, redactado en inglés), presenta la discusión general de los resultados de la tesis, incluyendo un análisis de las implicaciones tanto teóricas como prácticas y una propuesta de investigación futura.



# **CAPITULO 1.**

**Introducción. La lectura de hipertexto**

---



### 1.1. Definición y breve historia del hipertexto

El hipertexto se considera teóricamente un sistema compuesto por bloques o fragmentos de textos que se comunican por medio de enlaces, de forma que ofrecen al lector numerosos senderos de lectura (Landow, 1994, 2006). Un concepto relacionado con el hipertexto es el de hipermedia, en el que además de texto se incluye otra información audiovisual como imágenes, sonido, animaciones, etc.

La historia del hipertexto comienza con Vannevar Bush, quien en 1945 predijo la revolución electrónica:

*“Consider a future device for individual use, which is a sort of mechanized private file and library. It needs a name, and to coin one at random, ‘memex’ will do. A memex is a device in which an individual stores all his books, records, and communications, and which is mechanized so that it may be consulted with exceeding speed and flexibility. It is an enlarged intimate supplement to his memory.”*

Vannevar Bush, The Atlantic Monday, 1945

Esta idea fue elaborada durante décadas por algunos discípulos de V. Bush, como Ted Nelson, quien en 1965 acuñó el término hipertexto. En 1985, surge *Intermedia*, un programa informático que permitía el enlace bidireccional entre documentos para ordenadores Apple Macintosh, y que fue seguido por otros programas más usados como *Guide* o *Hypercard*. Poco después, en 1987, tuvo lugar la primera conferencia dedica al hipertexto (*Hypertext’87*). El hipertexto se extendió rápidamente en la primera parte de los años 90 debido tanto a los CD-ROM, que permitían almacenar grandes cantidades de información, como al desarrollo de la World Wide Web (WWW) por el premio nobel Tim Berners-Lee (Nielsen, 1995).

En los últimos 15 años, la extensión del uso de Internet y la WWW ha convertido al hipertexto en uno de los sistemas de acceso a la información más populares. Tanto es así que el hipertexto está reemplazando el texto lineal tradicional en áreas tan importantes como son la educación, la comunicación o el comercio. Por tanto no es extraño que el análisis de la conducta y el procesamiento de la información de las personas en este medio se consideren un tema de investigación de primera magnitud.



El estudio del uso de hipertexto se ha enfocado desde un punto de vista teórico y también práctico (Czerwinski y Larson, 2002). Desde el punto de vista teórico de la psicología cognitiva, interesa saber cómo el sistema cognitivo humano accede y procesa la información en hipertexto, y si este difiere en alguna dimensión del modo en que lo hace con el texto lineal (McKnight, Dillon y Richardson, 1991; van Oostendorp, 2003; Rouet, Levonen, Dillon y Spiro, 1996). Desde el punto de vista práctico de la ingeniería de usabilidad, la industria de las nuevas tecnologías, los gobiernos y otras organizaciones están interesados en saber cómo pueden mejorar los sistemas basados en hipertexto (páginas web, enciclopedias, plataformas de teleformación, etc.) para que el usuario tenga una experiencia más satisfactoria y comprenda mejor la información que se quiere transmitir (Granollers, Lorés y Cañas, 2005; Nielsen, 1993; Tullis y Albert, 2008).

Un paso necesario en el estudio del hipertexto desde estas dos perspectivas es definir las tareas que se realizan en el hipertexto, como difieren de las que se realizan en el texto lineal, cómo las personas realizan estas tareas y cómo puede esto afectar a la comprensión y aprendizaje. Desarrollamos estos aspectos en el siguiente apartado.

## **1.2. Tareas cognitivas relacionadas con la lectura de hipertexto**

Entre las ventajas del hipertexto está el mejorar la velocidad de acceso y proporcionar un acceso ubicuo a la información sin utilizar una secuencia de lectura predefinida. Pero además, se ha propuesto que el hipertexto mejora los procesos de comprensión y aprendizaje en comparación con el texto lineal. Así, Jonassen (1988) señaló que el uso de hipertexto debería facilitar la comprensión debido a que existe una correspondencia entre su estructura y las estructuras de memoria asociativa humana.

Sin embargo, la comprensión de hipertexto se suele asociar con dos problemas que limitan su utilidad: (1) en relación al proceso de navegación, los usuarios sufren de desorientación y sobrecarga cognitiva (Conklin, 1987; Kim & Hirtle, 1995), (2) y en relación a la comprensión y el aprendizaje, no hay una evidencia experimental concluyente que pruebe que la experiencia de aprendizaje sea mejor con hipertexto que con texto lineal (Chen & Rada, 1996; Dillon & Gabbard, 1998; Shapiro & Niederhauser, 2004). Estos dos problemas parecen estar relacionados, ya que existe alguna evidencia que muestra que la desorientación lleva a una peor ejecución y aprendizaje (Ahuja & Webster, 2001; Puerta Melguizo, Lemmert & van Oostendorp,

2006) y que la sobrecarga cognitiva puede ser responsable de los problemas en la comprensión en los sistemas hipertexto (DeStefano & LeFevre, 2007).

Para obtener un conocimiento de los beneficios reales de usar el hipertexto para la comprensión y el aprendizaje, es importante entender mejor qué tareas cognitivas están implicadas y como comprenden los lectores la información presentada en formato hipertexto. ¿Implica la lectura de textos en formato hipertexto los mismos procesos y requiere de los lectores las mismas habilidades cognitivas que aquellos implicados en la lectura de texto lineal?

En el ámbito de la alfabetización y la enseñanza, se ha propuesto que el hipertexto presenta para los estudiantes una nueva serie de requisitos en cuanto a habilidades, estrategias y disposiciones implicadas en la lectura de hipertexto que no están presentes en lectura de texto lineal (Coiro, 2009).

Desde el punto de vista de la ergonomía cognitiva, existen diferencias en los procesos cognitivos implicados en ambos tipos de lectura, ya que esta no es independiente del contexto en que se realiza. Esto se explica por el **Principio de dependencia mutua** (Cañas, Salmerón & Fajardo, 2004; Cañas, 2008): en la interacción (en este caso la lectura) intervienen una persona (el lector) y un interfaz (sea este un libro impreso o un hipertexto), existiendo una dependencia mutua entre las funciones cognitivas humanas y las propiedades del interfaz donde se ofrece la información. Puesto que las propiedades del nuevo interfaz (hipertexto) son distintas al del interfaz tradicional (texto lineal en formato libro), las tareas y procesos implicados en la lectura y comprensión también se modifican.

Por tanto, es necesario realizar un análisis de las tareas que participan en este nuevo escenario. A diferencia del texto lineal, cuando se usa un hipertexto no solo hay que leer la información contenida en el texto, también hay que tomar decisiones sobre los contenidos a leer y se deben realizar acciones sobre el interfaz para desplazarse entre las unidades de información que lo componen (navegación), siguiendo una ruta guiada por la tarea específica que se está realizando. Parece claro que hay diferentes tareas implicadas en la lectura de hipertexto que deben ser analizadas independientemente. En este sentido, Salmerón (2006) señala que las principales tareas que diferencian la comprensión con hipertexto de la comprensión con texto lineal son la selección del

orden de lectura de las diferentes secciones, la elección de qué secciones leer y la adquisición de la estructura del hipertexto.

Las diferentes tareas no solo difieren en sus contenidos, sino también en la cantidad de recursos cognitivos requeridos para su ejecución. Una evidencia de esto podemos encontrarla en los resultados del estudio de Oulasvirta (2004), quien examinó dos tipos de tareas con hipertexto: tareas de contenidos y tareas de navegación-orientación. La conclusión fue que, desde un punto de vista de la memoria de trabajo, esas dos tareas son distintas en la profundidad del procesamiento que los lectores llevan a cabo, siendo más superficial en el caso de las tareas de navegación-orientación.

Para ofrecer una visión general de las tareas y procesos implicados en la comprensión con hipertexto adoptaremos la propuesta de Kim y Hirtle (1995), quienes clasificaron las tareas cognitivas relacionadas con el uso de hipertexto en tareas de lectura, tareas de navegación y tareas de gestión. Las tareas de lectura son realizadas por los usuarios para comprender el texto presentado en un sistema hipertexto, las tareas de navegación se llevan a cabo para acceder a las unidades de información distribuidas entre los diferentes nodos y por último las tareas de gestión se realizan para coordinar las actividades de navegación y lectura.

### *1.2.1. Tareas de lectura*

Leer y comprender la información incluida en los diferentes nodos de texto son tareas esenciales en el uso de hipertexto. A pesar del incremento de tareas de control que recaen en el lector y las limitaciones cognitivas que añade el uso del sistema hipertexto, se asume que la forma de percibir, procesar y almacenar la información textual está guiada por los mismos principios que la lectura de texto lineal (Wenger y Payne, 1996).

En el contexto de los procesos de comprensión, usaremos como marco teórico de esta tesis el *Modelo de Construcción - Integración* desarrollado por Walter Kintsch, el cual se ha mostrado muy eficaz para explicar no solo la comprensión de texto lineal, sino también de algunos efectos relacionados con el hipertexto como veremos en este trabajo.

### **Modelo de Construcción - Integración (C-I)**

El modelo C-I de comprensión de textos (Kintsch y van Dijk, 1978; Kintsch, 1988, 1998) concibe la comprensión como un proceso cuyo objetivo es formar una representación mental coherente del texto, el cual se realiza a través de un procedimiento cíclico compuesto de dos fases: construcción e integración. En la fase de construcción, una red de elementos inter-relacionados extraída del texto se añade a la memoria de trabajo y se combina con la información que ya estaba presente anteriormente. Durante la integración, un proceso de propagación de la activación selecciona los elementos de la red que presentan mayor activación. Al final del proceso, los nodos de mayor activación se almacenan en la memoria de trabajo para estar disponibles en el siguiente ciclo. Por lo tanto, la lectura de un texto se lleva a cabo en el contexto de los elementos del texto leídos anteriormente.

El modelo distingue tres niveles en la representación mental que el lector construye a partir del texto: el *nivel superficial*, una representación textual (palabra por palabra) del texto; el *texto base*, una representación jerárquica proposicional que se construye en la memoria a partir de la información que se encuentra dentro del texto; y el *modelo de la situación*, que integra la información del texto base con el conocimiento previo que el lector tiene almacenado en la memoria a largo plazo. En el contexto de la comprensión de textos, el texto base y el modelo de la situación son las dos representaciones más relevantes, y atenderemos solo a ellas en este trabajo.

En algunas partes de este trabajo se usan de manera intercambiable los conceptos de comprensión y aprendizaje. En este punto es útil incluir la aclaración terminológica aportada por Kintsch (1994): la comprensión puede producirse a varios niveles, de forma que podemos hablar de comprensión aunque simplemente se pueda recordar el contenido del texto a partir del texto base; por el contrario, para que haya aprendizaje a partir de un texto es necesario que se haya construido un buen modelo de la situación, de forma que esta nueva información pueda usarse en otros contextos.

Hay muchos factores que intervienen en la construcción del modelo de la situación, pero la coherencia textual y el conocimiento previo son los más importantes. Por **coherencia textual** entendemos el grado en que un lector es capaz de entender las relaciones entre ideas expresadas en un texto (Britton & Gülgoz, 1991). Existen características del texto que contribuyen a la coherencia textual, como el grado en que

los conceptos, ideas y relaciones aparecen de manera explícita dentro de un texto. Recientemente se ha empezado a utilizar el término cohesión para referirse a las características de coherencia de un texto, reservando el término coherencia para referirse a una propiedad de la representación mental que construye el lector (Louwerse, 2004). En este trabajo usaremos solamente el término coherencia para ser consistentes con la terminología usada en los artículos ya publicados en nuestra línea de investigación, aunque debe aclararse que hacemos referencia a características del texto.

El **conocimiento previo** de los lectores interacciona con la coherencia del texto, de forma que tiene un efecto diferencial en la construcción del modelo de la situación. (Graesser, McNamara & Louwerse, 2003; Louwerse, 2002; Louwerse & Graesser, 2004). Cuando lectores con bajo conocimiento del dominio leen un texto de alta coherencia construyen mejores modelos de la situación que cuando leen uno de baja coherencia. Si las proposiciones de dos fragmentos de texto no comparten argumentos, es necesario realizar inferencias que sirvan de puente accediendo al conocimiento previo para rellenar esa falta de información. Puesto que realizar inferencias consume recursos cognitivos, la dificultad se incrementa para los lectores de bajo conocimiento. En el caso de lectores de alto conocimiento previo, existen evidencias de que estos aprenden menos cuando leen un texto de alta coherencia textual que uno poco coherente. La razón es que en este último caso son menos propensos a usar su conocimiento previo en la construcción del modelo de la situación mientras que cuando existen saltos en la coherencia textual esto les permite activar su conocimiento previo para realizar inferencias, compensando la falta de información explícita con un procesamiento más profundo del texto (McNamara, E. Kintsch, Songer & W. Kintsch, 1996; McNamara & Kintsch, 1996).

El modelo de C-I ha sido usado extensivamente como marco para realizar investigación en el campo de la comprensión de hipertexto (Foltz, 1996; Hofman & van Oostendorp, 1999; Potelle & Rouet, 2003; Protopsaltis, 2008; Salmerón, Cañas, Kintsch & Fajardo, 2005; Salmerón, Kintsch & Cañas, 2006a). El interés especial en la aplicación de este modelo está relacionado con los efectos de la coherencia textual en la comprensión. En el contexto del hipertexto, la coherencia textual puede verse desde dos perspectivas. Desde una *perspectiva de producción del discurso*, la coherencia textual es una propiedad del texto que refleja la estructura de coherencia en la mente del autor.

En un texto lineal, el autor trata de diseñar un texto coherente creando continuidad de temas y argumentos, lo cual no tiene mucho sentido en el caso del hipertexto, ya que es el lector quien elige el orden de lectura y selecciona los textos a leer. Desde una *perspectiva de comprensión del discurso*, la coherencia puede verse también como una propiedad de la representación mental construida por el lector del texto (Storrer, 2002). Desde esta otra perspectiva, tiene sentido preguntarnos por la importancia de las actividades que realizan los usuarios durante la lectura para la comprensión de hipertexto, ya que el orden de lectura de los nodos afecta a la coherencia textual global y por tanto también a la comprensión.

Del argumento anterior se extrae una idea de especial importancia para este trabajo: la representación mental que construye el lector se ve afectada por ciertas características del texto que a su vez dependen de su propio comportamiento. Esto es lo que llamamos la **coherencia de la lectura del texto**, que puede ser definida como el grado en que el patrón o ruta de navegación – o dicho de otra forma, el orden de lectura - que un lector sigue a través del hipertexto da como resultado una línea coherente de argumentos o ideas. Apoyando la importancia de la coherencia de la lectura del texto, diversos estudios diseñados para explorar el papel de la coherencia textual en la comprensión con hipertexto han mostrado que la comprensión es mayor cuando los textos son leídos en un orden coherente (Foltz, 1996; Salmerón et. al.2005, Salmerón, Kintsch y Cañas, 2006a), lo cual podría ser especialmente relevante para lectores de bajo conocimiento previo. Así, el estudio de Salmerón et al. (2005) mostró que aquellos lectores de bajo conocimiento previo que seleccionaban un orden de lectura de alta coherencia construían un mejor modelo de la situación que aquellos que seleccionaban un orden de lectura de baja coherencia. Otros estudios han demostrado que los estudiantes de bajo conocimiento previo son más propicios a tener dificultades con la navegación y la comprensión de hipertexto (Amadiou, Tricot & Marine, 2009,2010; Chen, Fan & Macredie, 2004; Lawless, Schrader & Mayall, 2007; Muller-Kalthoff & Moller, 2006) lo cual podría explicarse en cierta medida por el efecto de la coherencia de lectura del texto.

### 1.2.2. *Tareas de navegación*

En cuanto a las tareas relacionadas con el acceso a los diferentes nodos de información en un hipertexto, existe una división clásica entre las tareas de búsqueda

(*searching*) y las tareas de navegación (*browsing*). Aunque ambas pueden emplearse para adquirir información en un hipertexto, en este trabajo nos centraremos en tareas de navegación. Se pueden consultar otros estudios (Rouet, 2003) que analizan las estrategias de búsqueda en hipertexto.

En el contexto de este trabajo entendemos las tareas de navegación en hipertexto como aquellas acciones que incluyen planificar y ejecutar rutas de lectura a través del hipertexto. A nivel de cada página, esto se realiza mediante la selección y accionamiento de enlaces. En la navegación, los usuarios empiezan en una determinada página o nodo de información y continúan leyendo el resto de páginas que están unidas a través de enlaces. Esto requiere la identificación previa de aquellos elementos del interfaz que representan un enlace (links) entre los diferentes nodos. La forma, localización y número de los enlaces dependen del diseño del sistema hipertexto, aunque existen ciertas convenciones (como por ejemplo, subrayar y/o cambiar de color aquellas palabras o etiquetas que representan un enlace) que son normalmente conocidas por los usuarios.

Una vez identificados los elementos que representan un enlace y que permiten la navegación, el lector de hipertexto debe realizar una toma de decisiones sobre qué enlace seguir basándose en sus metas de lectura. Algunas veces el usuario quiere encontrar una información muy específica que responda una pregunta de partida (por ejemplo, *¿Dónde está situada la arteria aorta?*). En este caso el enlace se seleccionará en tanto que el usuario entienda que este pueda llevarle a una respuesta a su pregunta (por ejemplo, el enlace *Arterias* será preferido al enlace *Venas*). Pero frecuentemente, los usuarios navegan con el objetivo más amplio de comprender la información contenida en el hipertexto y aprender de diferentes fuentes (por ejemplo, *Conocer el funcionamiento y estructura del sistema circulatorio*). En este caso el objetivo será maximizar la comprensión de los contenidos. Veremos más adelante las diferentes estrategias que usan los lectores para seleccionar enlaces con el objetivo de comprender hipertexto.

### **1.2.3. Tareas de gestión**

Las tareas de lectura y de navegación pueden influenciarse mutuamente. De hecho se ha señalado que los problemas relacionados con la navegación pueden afectar a la comprensión y viceversa. Por ejemplo, Nauman, Waniek y Krems (2001)

encontraron que a más problemas de navegación menor era el contenido que podía ser recordado. Esto puede explicarse por el hecho de que un lector de hipertexto no solo construye una representación del texto para la comprensión, sino también una representación de la estructura del texto para la navegación. Los problemas de orientación y navegación aparecen como resultados de un conflicto entre las dos representaciones en alguna de sus dimensiones (Naumann, 2009; Waniek, Brunstein, Naumann y Krems, 2003; Waniek, In Press).

Por ello, es necesario gestionar las tareas de lectura y de navegación, lo cual requiere recursos cognitivos. Estos recursos son necesarios para monitorizar que la navegación está permitiendo comprender la información de manera adecuada, y tomar las siguientes decisiones en base a ello.

### **1.3. Variables implicadas en la comprensión de hipertexto**

Tras este análisis de las tareas implicadas en el uso de de hipertexto, cabe preguntarse qué variables participan en las mismas y por tanto pueden predecir la comprensión de hipertexto. Siguiendo el principio de dependencia mutua que describimos al inicio de este trabajo, debemos analizar características tanto de los usuarios como del sistema hipertexto, así como el proceso de interacción entre ambos.

Las variables de usuarios y sistema son características pre-existentes a la sesión de lectura del hipertexto y son estables en gran medida durante el proceso de navegación. Las variables del sistema se refieren a las características del hipertexto relacionadas con su diseño, como la estructura de los contenidos y de los enlaces entre nodos, las herramientas de navegación ofrecidas, el uso de material multimedia, etc. Las variables de los usuarios son aquellas como el nivel de conocimiento previo, la experiencia con ordenadores e hipertextos, las habilidades de meta-comprensión, la capacidad de memoria de trabajo, las habilidades espaciales, los estilos cognitivos, etc.

Estas variables son determinantes en la comprensión de hipertexto, sin embargo, desde una perspectiva centrada en el usuario, el objeto principal de estudio es la interacción en sí misma y cómo las actividades de los usuarios durante la lectura determinan la comprensión (Unz & Hesse, 1999). Por ello, en el siguiente capítulo analizaremos en detalle aquellas variables que caracterizan la interacción entre usuario y sistema, y que llamaremos características del procesamiento de hipertexto.





## **CAPITULO 2.**

**Efecto de las características del procesamiento en la comprensión de hipertexto**

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En el contexto de este trabajo, asumimos que existen diferencias en las características del procesamiento que cada lector hace del hipertexto. Este procesamiento puede caracterizarse a través de dos componentes. Por una parte existe un componente comportamental, las *estrategias de lectura*, el cual determina la conducta de navegación de los usuarios. Por otra parte, existe un componente cognitivo relacionado con el procesamiento de la información en la memoria de trabajo, y que conceptualizaremos como *carga cognitiva*. En este capítulo analizamos la evidencia experimental que relaciona ambos componentes con la comprensión y aprendizaje de hipertexto.

### **2.1. Papel de las estrategias de lectura**

El papel de las actividades de los lectores no ha sido siempre tenido en cuenta, aunque su importancia es evidente para explicar la comprensión y el aprendizaje cuando se usa hipertexto. En general, las estrategias de procesamiento que un lector adopta ante un determinado material pueden definirse como conjuntos de procedimientos que se ponen en marcha para lograr una meta o llevar a cabo una tarea. Para poder hablar de la existencia de estrategias no necesario que los lectores sean conscientes de ellas (no tienen que ser explícitas), pero si que existan varias opciones de actuación para conseguir un mismo objetivo (Gerjets y Scheiter, 2003).

En el caso del hipertexto las estrategias tienen un papel muy relevante, ya que respecto a otros materiales de aprendizaje tiene la ventaja de incrementar el control del lector sobre el proceso de lectura. Este control se materializa a través de la secuenciación (el orden en el que el lector quiere acceder a las diferentes unidades de información) y a la selección o control de contenidos (qué contenidos quiere leer de un conjunto de documentos) (Scheiter y Gerjets, 2007). La regla específica que sigue un lector de hipertexto para la secuenciación y el control de contenidos es conocida como estrategia de lectura (Salmerón, Kintsch y Cañas, 2006a).

Las estrategias de lectura que siguen los usuarios de hipertexto se han examinado desde dos perspectivas. En primer lugar, algunos estudios han tratado de

determinar las diferentes **reglas de decisión** que usan los lectores para seleccionar su ruta de navegación, y como afectan estas a la comprensión. En segundo lugar, otra serie de estudios ha puesto el foco en la **conducta de navegación**, ya que es en esta donde se materializan las reglas de decisión que adoptan los lectores y el medio por el que se tratan de conseguir los objetivos de comprensión o aprendizaje. En este trabajo se presentan estudios que se han enfocado desde ambas perspectivas.

### *2.1.1. Estrategias de lectura entendidas como conducta de navegación*

Esta perspectiva es la más común en los estudios sobre hipertexto. Metodológicamente, se trata de identificar patrones diferentes de navegación, describirlos y analizar su efecto en la comprensión.

Un ejemplo ilustrativo es el estudio de Salmeron et al. (2005), en el que se realizaron dos experimentos analizando el efecto de las estrategias de lectura en la comprensión. Los usuarios fueron asignados a posteriori a diferentes grupos en función del patrón de navegación seguido durante la tarea. En el primer experimento, los resultados mostraron que un incremento en la cantidad de información leída en un hipertexto predecía la construcción del texto base en lectores de bajo conocimiento previo (no era relevante para lectores de alto conocimiento previo). Además, los lectores pertenecientes a diferentes grupos de navegación obtenían también diferentes resultados en la construcción del modelo de la situación. Un análisis de las características de estos grupos mostró que el efecto se debía tanto al número de nodos accedidos como a la coherencia textual, aunque cuando se leía un número mínimo de nodos la coherencia textual parecía ser la principal responsable de los efectos en la construcción del modelo de la situación.

En un segundo experimento, Salmerón et al. (2005) replicaron el efecto de conocimiento previo y coherencia textual (McNamara et al., 1996; McNamara y Kintsch, 1996) en hipertexto. Su hipótesis era que los lectores de bajo conocimiento previo se benefician más de un texto de alta coherencia que de uno poco coherente, mientras que por el contrario, los lectores de alto conocimiento previo aprenden más de un texto poco coherente. En el experimento, los participantes leyeron todos los nodos de texto con la ayuda de uno entre dos tipos de mapas de contenidos (en los que los nodos se organizaban en un orden de alta vs. de baja coherencia). Adicionalmente, se midió la coherencia del orden de lectura seguido por los lectores (alta y baja coherencia textual).

Los resultados mostraron que el efecto del conocimiento previo y la coherencia textual era replicado en el hipertexto pero que esto dependía del orden de lectura seguido efectivamente por los participantes y no por el tipo de mapa de contenidos usado. Es decir, el efecto de las variables de sistema (tipo de mapa de contenidos usado) parece estar mediado por el procesamiento que hacen los usuarios del texto a través de las estrategias de lectura.

### *2.1.2. Estrategias de lectura entendidas como regla de decisión*

Desde esta perspectiva se analizan estrategias de lectura describiendo el criterio seguido por los participantes en la selección de los enlaces. En algunos casos se instruye a los usuarios en seguir una regla de decisión determinada, mientras en otros esta regla se infiere mediante diferentes técnicas (análisis de pensamiento en voz alta, juicios de los lectores, análisis de grabaciones de audio, etc.). Por ejemplo, Lawless y Kulikowich (1998) sugirieron tres tipos de usuarios de hipertexto: los buscadores de conocimiento, los exploradores de características y los usuarios de hipertexto apáticos. Otras descripciones de posibles estrategias de lectura en hipertexto las ofreció Balcytiene (1999), quien identificó tres estrategias principales: lectura sistemática, exploración debida a preferencias individuales (interés) y lectura sistemática vs. exploratoria. Se encontró que los dos últimos patrones eran mejores para el aprendizaje que el primero.

Una estrategia de lectura especialmente interesante desde el punto de vista de la comprensión consiste en mantener la coherencia textual (Amadiou, Tricot y Mariné, 2010; Foltz, 1996; Salmeron et. al. 2005). En un experimento realizado por Foltz (1996), los sujetos recibieron instrucciones para leer los textos que componían un hipertexto describiendo en voz alta lo que pensaban cuando tenían que seleccionar algún enlace. El análisis de los protocolos verbales mostró que los sujetos usaban estrategias para mantener la coherencia global del texto, y que parecía que se basaban en el mapa de contenidos y los títulos de los nodos para guiar sus decisiones.

Investigaciones recientes han señalado que, junto a la búsqueda de coherencia textual, las principales estrategias parecen ser la estrategia de interés y la posición de los enlaces (Protopsaltis, 2008; Salmerón, Kintsch y Cañas, 2006a; Salmerón, W. Kintsch y E. Kintsch, 2010). A continuación describimos estas tres estrategias:

a) *Estrategia de coherencia*: como se ha señalado, consiste en seleccionar el enlace más relacionado con el texto que se acaba de leer, y por lo tanto promover un orden de lectura de mayor coherencia. La coherencia textual en hipertexto depende del control del aprendiz, ya que el orden de lectura seleccionado por los lectores determina la coherencia de la secuencia de lectura (Salmerón et al. 2005).

b) *Estrategia de interés*: está basada en seleccionar los enlaces más interesantes para el lector en primer lugar, retrasando la lectura de los menos interesantes. Por lo tanto la estrategia de interés suele producir una secuencia de lectura menos coherente que la estrategia de coherencia.

c) *Posición del enlace en la pantalla*: A diferencia de las dos estrategias anteriores, esta se considera una estrategia pasiva en la que no hay una selección razonada del orden de lectura, sino que la selección está determinada por la posición del enlace en la pantalla (por ejemplo, elegir siempre el primer enlace que aparece). En este sentido, la coherencia del orden de lectura dependerá de cómo haya situado los enlaces el autor del hipertexto.

En dos experimentos, Salmerón et al. (2006) examinaron los efectos en la comprensión de estas estrategias de lectura. Los resultados del primer experimento mostraron que, en términos de adquisición del modelo de situación, para los lectores de bajo conocimiento previo era mejor seguir una estrategia de coherencia que la estrategia de interés, mientras que a los lectores con mayor conocimiento les era indiferente seguir cualquiera de las estrategias. A diferencia de lo que cabría esperarse (ver pag. 28), los lectores de alto conocimiento previo no aprendieron más con una estrategia de interés. Esta diferencia podría explicarse por la existencia de mecanismos diferentes en la comprensión de hipertexto de los que actúan en el texto lineal. Analizamos estos mecanismos en detalle en el siguiente apartado.

### *2.1.3. Mecanismos de influencia de las estrategias de lectura en la comprensión*

El estudio de Salmerón, Kintsch y Cañas (2006a) partía de la hipótesis de que el efecto de las estrategias de lectura en la comprensión con hipertexto se producía a través de dos mecanismos diferentes.

El primero es inducido por el texto: de forma similar a la lectura de texto lineal, los lectores de bajo conocimiento previo adquieren un mejor modelo de la situación tras seguir un orden de lectura con alta coherencia que uno de baja coherencia. Por otra parte, los lectores con algo de conocimiento previo pueden no obtener buenos resultados si leen en un orden muy coherente, ya que esto les lleva a no activar su conocimiento previo y por tanto a un procesamiento superficial del texto, de forma que hacerlo en un orden de baja coherencia puede aportarles beneficios en la comprensión (E. Kintsch y W. Kintsch, 1995; McNamara, 2001).

El segundo mecanismo es el de influencia estratégica: Para seleccionar un enlace siguiendo una estrategia de coherencia o interés, los lectores tienen que procesar activamente la relevancia de los enlaces presentados para dicha estrategia, y consecuentemente implicarse en un procesamiento activo del texto. Esto es lo que permitiría a los lectores de alto conocimiento previo superar el procesamiento superficial que puede ser inducido por un orden de lectura de alta coherencia, y de esta forma comprender mejor un hipertexto en comparación con la lectura de un texto lineal de similar coherencia al anterior pero en el que no se han elegido los enlaces.

Para explorar estos mecanismos, un segundo experimento del mismo estudio exploró las diferencias entre leer un texto de alta o baja coherencia sin seleccionar activamente el orden de lectura o leer textos con un nivel de coherencia similar siguiendo una estrategia (de coherencia o interés) para seleccionar enlaces. Los resultados mostraron que los lectores de bajo conocimiento previo comprendían mejor un texto de alta coherencia que uno de baja coherencia, y no había diferencias entre hacerlo seleccionando el orden de lectura o leyendo un texto lineal con un nivel de coherencia similar. Parecía por tanto que los efectos de las estrategias de lectura para lectores de bajo conocimiento previo eran solo inducidos por el texto. Sin embargo, los lectores con conocimiento previo aprendían menos de un texto de alta coherencia que de uno de baja coherencia al leerlos de forma lineal, pero al leerlo seleccionando enlaces mejoraban al seguir una estrategia de coherencia (aunque no había diferencia al seguir una estrategia de interés) y aprendían igual de ambos. Por tanto, para los lectores de alto conocimiento previo el beneficio de las estrategias de lectura no se debe solo al orden de lectura seleccionado, sino también a un mecanismo de influencia estratégica relacionado con la regla de decisión adoptada (al menos en la estrategia de coherencia).



El hecho de que el mecanismo de influencia estratégica no apareciera cuando se seguía una estrategia de interés puede interpretarse entendiendo que el beneficio de seguir una estrategia se debe a que el texto se procesa activamente. En el caso de la estrategia de interés no hay diferencia con leer un texto de baja coherencia ya que este ya obliga al lector a leer el texto de forma activa. Posteriores estudios sobre texto lineal también han puntualizado que el efecto negativo de leer un texto de alta coherencia desaparece cuando los lectores de alto conocimiento previo tienen altas habilidades lectoras que les permiten procesar un texto coherente activamente (O'Reilly y McNamara, 2007; Ozuru, Dempsey y McNamara, 2009). Por tanto, podemos concluir que lo importante para los lectores de hipertexto con alto conocimiento previo es leer el texto de forma activa, independientemente de que esto se deba a la baja coherencia del texto, a sus altas habilidades lectoras o al empleo de una determinada estrategia.

En cualquier caso, los resultados de este estudio muestran también que reglas de decisión y conducta de navegación son dos aspectos de las estrategias de lectura que, aunque están relacionados, pueden tener efectos diferentes (estratégico vs. inducido por el texto) en la comprensión. Es importante también señalar que no existe una relación de causalidad directa entre ambos aspectos: **una misma regla de decisión adoptada por dos lectores para leer un determinado hipertexto puede llevar a conductas de navegación diferentes**. Como veremos más adelante, existen muchas variables tanto del sistema como de los usuarios que pueden determinar la conducta de navegación de un lector de hipertexto cuando adopta una determinada regla de decisión.

## 2.2. Papel de la carga cognitiva

### 2.2.1. Carga cognitiva y aprendizaje: La Teoría de la Carga Cognitiva

La carga cognitiva puede definirse como la cantidad de recursos cognitivos que una persona necesita para realizar una tarea determinada (O'Donnell y Eggemeier, 1986). La sobrecarga cognitiva se produce cuando el procesamiento cognitivo requerido en una tarea sobrepasa la capacidad cognitiva disponible (Mayer y Moreno, 2003). En estos casos se espera un deterioro en la ejecución en la tarea.

La **Teoría de la Carga Cognitiva** (Kirschner, 2002; Paas y van Merriënboer, 1994; Sweller, 1988; Sweller, van Merriënboer y Paas, 1998) surge en el ámbito de la

resolución de problemas y se ha desarrollado en el campo del diseño instruccional. Parte de premisas bien establecidas sobre el funcionamiento del sistema cognitivo humano, como puede ser la distinción entre un almacén de memoria a corto plazo de recursos limitados y otro de memoria a largo plazo con recursos potencialmente ilimitados (Baddeley, 2007; Baddeley y Hitch, 1974; Baddeley y Logie, 1994). Se asume que la información almacenada en la memoria a largo plazo lo hace en forma de esquemas, en los cuales la información está categorizada y organizada. Los esquemas varían en su grado de automaticidad, es decir, en la cantidad de esfuerzo consciente que debe de realizar un aprendiz para aplicarlos. En la resolución de problemas se piensa que los dos principales pre-requisitos son la construcción y la automatización de esquemas. Un esquema requiere recursos de memoria a corto plazo para ser construido, pero una vez que existe, permite aumentar la cantidad de información que puede estar activa en la memoria de trabajo por el mecanismo de *chunking* (Sweller, 1994).

Para esta teoría, la carga cognitiva es un constructo multidimensional que representa los requerimientos que la realización de una tarea impone en el sistema cognitivo de un aprendiz (Paas y van Merriënboer, 1994). Se distinguen varios componentes de la carga cognitiva de una tarea: carga cognitiva intrínseca (*intrinsic CL*), inefectiva (*extraneous CL*) y efectiva (*germane CL*):

- **Carga intrínseca:** La carga cognitiva intrínseca depende de la interactividad entre los elementos a aprender (complejidad) y del conocimiento / experiencia previos de los aprendices. Si la interactividad entre elementos es baja, estos pueden aprenderse de uno en uno de forma simple, mientras que si la interactividad es alta el aprendizaje se vuelve más complejo (ej. aprendizaje de vocabulario vs. gramática en una lengua extranjera). Este tipo de carga cognitiva no puede reducirse, ya que esto afectaría a la calidad del aprendizaje y a sus contenidos.

- **Carga inefectiva:** Es la cantidad de recursos cognitivos que se invierten en la tarea pero que no benefician o incluso interfieren con el aprendizaje. Es dependiente del diseño de la tarea o de los materiales a utilizar, y debe reducirse, ya que es inefectiva para el aprendizaje.

- **Carga efectiva:** Es la cantidad de recursos dedicados a la construcción y automatización de esquemas, llevando a actividades de aprendizaje en profundidad. Está influenciada por las características individuales de los aprendices (conocimiento previo,

habilidades cognitivas y metacognitivas, etc.). Para mejorar el aprendizaje debe aumentarse este tipo de carga, ya que implica la liberación de recursos cognitivos adicionales para el aprendizaje, más allá de los estrictamente necesarios para una comprensión superficial.

Para la comprensión y el aprendizaje, la suma de estos tres componentes de carga cognitiva debe permanecer entre los límites de la capacidad de la memoria de trabajo, ya que si es excedida por los requerimientos cognitivos de la tarea, la adquisición de conocimiento puede dañarse.

### *2.2.2. La carga cognitiva en la comprensión y aprendizaje con hipertexto*

La importancia de la carga cognitiva en el uso de hipertexto está ya presente en los primeros estudios sobre estos sistemas. En la mayor parte de los trabajos, se ha considerado que las características especiales del hipertexto incrementan la carga cognitiva afectando negativamente a la comprensión. Así Conklin (1987) se refiere a la cantidad de recursos cognitivos que son necesarios para realizar correctamente una tarea de hipertexto y que pueden llevar a una sobrecarga del sistema cognitivo. Esta misma inquietud se mantiene 20 años después, y diferentes autores advierten que la carga cognitiva tiene que ser analizada para estudiar su relación con la comprensión de hipertexto (DeStefano y LeFevre, 2007; Zumbach y Mohraz, 2008). DeStefano y LeFevre (2007) señalaron que la lectura de hipertexto requiere recursos de memoria de trabajo adicionales en comparación con la lectura de texto lineal, y que este incremento podría llevar a problemas de comprensión, principalmente para los lectores de bajo conocimiento previo. Desde el punto de vista de las características del sistema cognitivo humano, el usuario del hipertexto tiene que emplear recursos para la tarea de navegación que por tanto no estarán disponibles para la tarea de lectura, lo cual puede dañar la realización de procesos de inferencia y afectar a la comprensión (Foltz, 1996; Niederhauser, Reynolds, Salmen y Skolmoski, 2000; Shapiro, 1999; Shapiro y Niederhauser, 2004). Similar razonamiento puede extraerse del hecho de que una tarea secundaria tiene un efecto negativo en la comprensión de textos lineales (Inhoff & Fleming, 1989).

Por otra parte, un incremento en la carga cognitiva de una tarea no tiene por qué tener un efecto negativo si los requerimientos de carga cognitiva se mantienen entre los límites de la memoria de trabajo (Xie y Salvendy, 2000). De hecho, si la carga cognitiva

no excede estos límites, una mayor inversión de esfuerzo mental en la tarea puede también llevar a una mejor comprensión si los recursos adicionales se usan para el procesamiento activo (carga efectiva). Habría por tanto que reducir en lo posible la carga cognitiva inefectiva y aumentar la carga cognitiva efectiva (Zumbach, 2006).

Uno de los objetivos de esta tesis es determinar qué variables del usuario y del sistema afectan a la carga cognitiva, y si el uso de diferentes estrategias de lectura puede actuar modificando el balance entre carga cognitiva efectiva e inefectiva, afectando por tanto a la comprensión.



# **CAPITULO 3.**

**Variables predictoras de las características del  
procesamiento de los usuarios**

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En el apartado anterior se ha mostrado cómo las características del procesamiento que llevan a cabo los usuarios de hipertexto (estrategias de lectura y carga cognitiva) determinan la comprensión y el aprendizaje de los contenidos. Para ir más allá en la explicación de los procesos de comprensión de hipertexto, es necesario preguntarse por qué los usuarios siguen una estrategia de lectura y no otra, y qué variables determinan la carga cognitiva en la lectura de hipertexto. Desde el punto de vista de la Teoría de la Carga Cognitiva (Sweller, van Merriënboer y Paas, 1998; Sweller, 1999), las variables del sistema y del usuario interactúan para conformar el nivel de carga cognitiva de la tarea. Igualmente, el desarrollo de estrategias de lectura en hipertexto se ve influido por variables relativas tanto al lector como a las características del sistema hipertexto (Salmerón, 2006; Cañas, 2008).

En la siguiente sección examinamos las variables de usuario y sistema que están relacionadas con las características del procesamiento de los usuarios durante la lectura de hipertexto.

### **3.1. Efectos del diseño del sistema hipertexto**

Existen numerosas variables relacionadas con el diseño del sistema que pueden afectar al uso y comprensión con hipertexto. Algunas de las variables que han sido consideradas en la literatura son el número de enlaces por página (Waniek, In Press; Zhu, 1999), la profundidad y anchura de los menus (Larson y Czerwinski, 1998), el uso de mapas de contenidos (Nilsson y Mayer, 2002; Shapiro, 2000) y la provisión de vistas previas de contenidos (Antonenko y Niederhauser, 2010; Cress y Knabel, 2003; Maes, van Geel y Cozijn, 2006).

En nuestros estudios, hemos tenido en cuenta variables relacionadas con los sistemas de ayuda a la navegación (la sugerencia de enlaces y el uso de mapa de contenidos) y con el número de enlaces por página.



### 3.1.1. *Sistemas de ayuda y soporte a la navegación*

Uno de los problemas más documentados en cuanto a la navegación y comprensión de hipertexto se refiere a la **desorientación** (estar perdido en el hipertexto). Los usuarios que sufren este problema tienen dificultades en encontrar la información, saber donde se encuentra exactamente dentro de la estructura del hipertexto o cómo llegar a una determinada página (Ahuja y Webster, 2001; Kim y Hirtle, 1995; Ransom, Wu y Schmidt, 1997).

Para reducir la desorientación así como el incremento de carga cognitiva asociada, algunos sistemas hipertexto y sitios web ofrecen ayudas y sistemas de soporte a la navegación (Brusilovsky, 2004; Puerta Melguizo, Van Oostendorp y Juvina, 2007). La mayoría de estas ayudas tienen como elemento principal el señalar las relaciones entre los diferentes nodos. Señalar estas relaciones parece tener efectos beneficiosos (Naumann, Richter, Flender, Christmann y Groeben 2007; Salmerón, Gil, Bråten y Strømsø, 2010). Por ejemplo, Salmerón et. al. (2010) realizaron un experimento comparando el uso de un interfaz de tipo listado con otro del tipo mapa de contenidos gráfico, en el cual se mostraban las relaciones retóricas causa-efecto entre documentos. Los resultados mostraron que aquellos usuarios que habían usado el interfaz en el que se señalaban las relaciones entre documentos realizaban una navegación más eficiente y tenían una mejor comprensión.

A continuación describimos dos ayudas a la navegación (sugerencias de enlaces y mapas de contenidos) que han sido empleadas en este trabajo y que, aunque pueden diferir en el tipo y cantidad de información que ofrecen, se basan en señalar las relaciones entre los nodos.

#### **Sugerencias de enlaces**

Parte de los problemas de navegación se deben a la dificultad de juzgar la relevancia de las etiquetas de los enlaces para una determinada meta o estrategia de lectura. Diferentes modelos cognitivos como COLIDES (Kitajima, Blackmon y Polson, 2000) o SNIF-ACT (Fu y Pirolli, 2007; Pirolli, 2007) dan un papel central a los aspectos semánticos de los enlaces. Para estos modelos, la conducta de navegación en las tareas de búsqueda estaría guiada por los juicios que realizan los usuarios sobre la similitud semántica entre las etiquetas de los enlaces y sus metas (*information scent*). La dificultad de seleccionar el enlace más relevante para nuestra meta o estrategia de

lectura puede deberse a varias causas, como a la presencia de varios enlaces que compiten en relevancia, a que la relevancia de las etiquetas sea muy baja o a que los usuarios no tengan suficiente conocimiento previo para juzgar dicha relevancia (Kitajima, Polson & Blackmon, 2007).

Una forma de superar este tipo de problemas es ofrecer sugerencias de enlaces basadas en las relaciones entre los nodos. Estas sugerencias, además de señalar las relaciones que existen entre dos textos, proponen a los usuarios una serie de opciones destacadas que les ayuden a decidir la relevancia de los enlaces para su estrategia.

Las sugerencias de enlaces han demostrado que ayudan a los usuarios en las tareas de navegación. Van Oostendorp y Juvina (2007) destacaron los enlaces relevantes basándose para ello en un modelo cognitivo similar a COLIDES (Kitajima, Blackmon y Polson, 2000) en el que usaron Análisis Semántico Latente (*Latent Semantic Analysis*, LSA) para calcular la similaridad semántica entre etiquetas de enlaces y metas de los usuarios. Los enlaces que tenían un grado de similaridad semántica más alto en relación a la meta fueron seleccionados. Cuando la ruta adecuada para la tarea incluía un enlace que estaba presente en la pantalla, este era destacado. Encontraron que estas sugerencias mediante enlaces destacados eran recibidas positivamente y mejoraban la ejecución de los usuarios.

Salmerón, Kintsch y Cañas (2006b) realizaron una propuesta para ofrecer sugerencias de enlaces con el objetivo de mejorar la comprensión. El método se basaba en usar LSA para evaluar la similaridad semántica entre el texto que se acaba de leer y las etiquetas de los enlaces, de forma que se pudiesen sugerir aquellos enlaces que promuevan un orden de lectura de alta coherencia.

Una crítica que podría hacerse a las sugerencias de enlaces es que estas eliminan la libre navegación propia del hipertexto. En realidad no se trata de eliminar las opciones de navegación, sino solo de limitarlas a aquellas opciones más relevantes para la tarea. De hecho la mayoría de los sistemas hipertexto ofrecen un número limitado de opciones (no enlazan la totalidad de páginas que componen el hipertexto). La pregunta es, ¿cuál es el beneficio de ofrecer este tipo de sugerencias respecto a no hacerlo? Las sugerencias de enlaces basadas en mostrar las relaciones semánticas podrían tener efectos positivos tanto en las estrategias de lectura como en la carga cognitiva de los usuarios de bajo conocimiento previo. En primer lugar, la sugerencia de enlaces permite

a los usuarios realizar una estrategia de lectura de mayor coherencia, al permitir a los lectores seleccionar un orden de lectura coherente sin tener que basarse en su conocimiento previo (McNamara y Shapiro, 2005). En segundo lugar, la toma de decisiones en hipertexto puede conllevar un incremento de la carga cognitiva que afecte a la comprensión (DeStefano y LeFevre, 2007) y la sugerencia de enlaces puede limitar este incremento al ofrecer información adicional sobre la relevancia de las diferentes opciones.

### **Uso de mapas de contenidos**

Los mapas de contenidos son representaciones (gráficas o textuales) que muestran la estructura del hipertexto. Aquellos mapas que además son interactivos, sirven de herramientas para seleccionar el próximo documento a leer, de forma que pueden ser utilizados como herramienta de apoyo a la navegación. Los investigadores en comprensión de hipertexto han propuesto que la visualización de la estructura ofrecida por estos mapas de contenidos interactivos puede también mejorar la representación mental de la estructura (Dee-Lucas y Larkin, 1995; Shapiro, 2000; Waniek et al., 2003).

Sin embargo, otros estudios han mostrado resultados nulos o contradictorios (Brinkerhoff, Klein y Koroghlanian, 2001; Naumann, Waniek y Krems, 2001; Shapiro, 1998; Waniek et al., 2003). Por ejemplo, algunos resultados apuntan a que los mapas de contenidos no benefician la comprensión en absoluto, al distraer la atención de la tarea principal (Hofman y van Oostendorp, 1999; Nilsson y Mayer, 2002). Otros han sugerido que pueden crear carga cognitiva inefectiva, por lo que es más útil emplear otros sistemas de navegación que aporten señales menos explícitas que guíen la lectura pero no sobrecarguen el sistema cognitivo (Shapiro, 1999; Waniek y Ewald, 2008).

Estos resultados contradictorios pueden ser solo aparentes, ya que existen muchas variables que pueden estar interfiriendo en los beneficios de usar los mapas de contenidos para comunicar la estructura del sistema. Shapiro y Niederhauser (2004) realizaron una revisión en la que concluyeron que la efectividad de un cierto tipo de estructura o mapa de contenido depende de la interacción entre variables como el conocimiento previo de los lectores, sus metas, aspectos metacognitivos o la conducta de navegación desarrollada. Las estructuras bien definidas pueden ser de ayuda para alcanzar un buen texto base y guiar a los lectores de bajo conocimiento previo, pero los

sistemas poco estructurados promueven un aprendizaje más profundo y la búsqueda de coherencia dentro del sistema, especialmente para los lectores de alto conocimiento previo. Otros estudios han confirmado este análisis, encontrando un beneficio para los lectores de bajo conocimiento previo de los mapas de contenidos jerárquicos frente a otras representaciones de la estructura como los mapas en red (Amadieu, Tricot y Marinee, 2009, 2010; Potelle y Rouet, 2003).

En cualquier caso, el beneficio de los mapas de contenidos dependerá de que permita a los lectores desarrollar una estrategia de lectura adecuada sin aumentar la carga cognitiva inefectiva (Wanick y Ewald, 2008).

### *3.1.2. Número de enlaces en la página*

El número de enlaces por página ha sido un aspecto cuestionado en la literatura sobre usabilidad (Larson y Czerwinski, 1998; Nielsen, 2001). Si bien no hay un consenso sobre cuál es el número óptimo de enlaces, sí que parece mostrarse que la ejecución baja a medida que se van incrementando el número de opciones.

Aparte del efecto que el número de enlaces pueda tener en la eficacia del uso de hipertexto, otros estudios han mostrado que el número de enlaces presentes en una página puede influir la comprensión y aprendizaje. Zhu (1999) realizó un experimento comparando dos hipertextos con diferente número de enlaces (3-7 vs. 8-12). Los resultados mostraron que aquellos lectores que había usado un hipertexto con más enlaces por página obtenían una peor comprensión, lo que puede ser debido a una mayor desorientación y a la sobrecarga cognitiva en esa condición. Destefano y LeFevre (2007), tomaron esta evidencia junto a otras para hipotetizar que este efecto negativo era debido a dos mecanismos. Por una parte, un incremento en el número de enlaces aumenta la carga cognitiva relacionada con la toma de decisiones, lo cual puede dañar la comprensión. Por otra parte, un mayor número de enlaces incrementa la posibilidad de seguir un orden de lectura de baja coherencia, y por tanto las interrupciones que afectan al desarrollo del modelo de la situación.

## **3.2. Efectos de las características de los usuarios**

En este trabajo nos centraremos en dos aspectos que consideramos de especial importancia y desarrollaremos a continuación: el conocimiento previo de los lectores y

las habilidades cognitivas. Sin embargo queremos dejar constancia de que el número de características de los usuarios relacionados con las estrategias de lectura y la carga cognitiva en hipertexto es bastante más amplio e incluye aspectos como los estilos cognitivos (Calcaterra, Antonietti y Underwood, 2005; Chen y Macredie, 2002), las habilidades metacognitivas (Moos y Marroquin, 2010; Salmerón, W. Kintsch y E. Kintsch, 2010), el género (Protopsaltis y Bouki, 2009) o la edad (Graff, 2005; Lin, 2003).

### *3.2.1. Conocimiento previo*

El conocimiento previo es una variable de primera magnitud para explicar los procesos de comprensión en hipertexto (McDonald y Stevenson, 1998; Müller-Khaltoff y Möller, 2006). El conocimiento previo puede ejercer su influencia en la comprensión de hipertexto tanto de forma directa como indirecta. Como se ha señalado anteriormente, el conocimiento previo tiene un efecto directo en la comprensión que se ve mediado por la coherencia textual. Pero por otra parte, el conocimiento previo puede tener también un efecto indirecto en la comprensión a través de las estrategias de lectura y la carga cognitiva.

Existen bastantes evidencias que muestran que los lectores de bajo conocimiento previo tienen problemas en la comprensión de hipertexto cuando se compara con el texto lineal, y que el uso de hipertexto puede ser más apropiado para los lectores de mayor conocimiento (ver Chen, Fan y Macredie, 2006 para una revisión). Una explicación de estas diferencias puede ser que los lectores novatos en una materia carecen de conocimiento para elegir un orden de lectura coherente, sobre todo en aquellos hipertextos poco estructurados. Amadiou, Tricot y Mariné (2009) encontraron que los lectores de alto conocimiento previo seguía un orden de lectura más coherente que los de bajo conocimiento previo cuando usaban un mapa de contenidos en red, pero no cuando usaban un mapa de contenidos jerárquico. Esto muestra que los lectores más expertos en un tema pueden usar su conocimiento para compensar la falta de señales explícitas en el hipertexto. En otro estudio (Amadiou, Tricot y Mariné, 2010) los autores encontraron resultados similares, concluyendo que los lectores de alto conocimiento previo navegan activamente con el objetivo de establecer y mantener la coherencia (esto es, siguiendo una estrategia de coherencia).

### 3.2.2. *Habilidades cognitivas*

Las habilidades cognitivas son un amplio número de variables que se ha demostrado que afectan a un gran número de tareas diferentes, y que pueden definirse de manera genérica como “*aquellas habilidades necesarias para el correcto procesamiento de la información de manera que resulte una ejecución exitosa*” (Carroll, 1993). La Teoría de las habilidades cognitivas de Cattell-Horn-Carroll (CHC) (McGrew, 2005; 2009), ofrece una taxonomía que trata de poner orden en la gran cantidad de datos psicométricos recogidos en las últimas décadas (p.ej. Carroll, 1993; Ekstrom, French y Harman, 1979; Horn, 1998). Para ello, ofrece tres niveles o estratos, el primero incluye la inteligencia general (*factor g*), el segundo habilidades como el razonamiento fluido, la memoria a corto plazo o el procesamiento visual, y el tercero habilidades más específicas que actuarían como subcomponentes de aquellas presentes en el segundo estrato. Así por ejemplo, la habilidad de segundo nivel relacionada con el procesamiento visuo-espacial incluiría un conjunto de sub-habilidades visuo-espaciales en el tercer nivel como son la *flexibilidad de cierre*, la *exploración espacial* o la *velocidad de cierre*.

¿Por qué se piensa que las habilidades cognitivas pueden tener un papel especial en la comprensión de hipertexto? DeStefano y LeFevre (2007) examinaron gran cantidad de estudios sobre la lectura de hipertexto, concluyendo que este incluye nuevos requerimientos que incrementan las demandas cognitivas si lo comparamos con el texto lineal. Este incremento en los requerimientos cognitivos para el procesamiento de la información se ha señalado como responsable de algunos problemas y desventajas del hipertexto (como la desorientación y la sobrecarga cognitiva) (Boechler, 2001; Dias y Sousa, 1997; McDonald y Stevenson, 1996; Ransom, Wu y Schmidt, 1997). Puesto que las tareas con altos requerimientos cognitivos son más perjudiciales para individuos con menores habilidades cognitivas (Gonzalez, 2005), se puede predecir que el nivel de los lectores en aquellas habilidades cognitivas relevantes para las tareas de hipertexto afectarán a su ejecución y comprensión.

En cualquier caso, no todas las habilidades cognitivas son igualmente importantes para la lectura de hipertexto. La teoría CHC contempla más de 80 habilidades cognitivas diferentes en el nivel de habilidades más específicas. Por tanto,

un paso necesario será determinar qué habilidades concretas determinan qué aspectos del procesamiento de los usuarios.

En este punto ya partimos de estudios previos donde se ha mostrado la implicación de algunas habilidades en el uso de hipertexto, como son la capacidad de memoria de trabajo (Juvina & Oostendorp, 2004; Lee & Tedder, 2003; Naumann, Richter, Christmann y Groeben, 2008; Tardieu & Gyselinck, 2002), las habilidades espaciales (Dahlbäck & Lönnqvist, 2000; Downing, Moore y Brown, 2005; Juvina & Van Oostendorp, 2004; Juvina & Van Oostendorp, 2008) o el razonamiento lógico (Coiro y Dobler, 2007; Westerman, Davies, Glendon, Stammers & Matthews, 1995). Sin embargo, aunque estos estudios señalan la implicación de determinadas habilidades en la lectura de hipertexto, aun no está claro cuál es su papel concreto en el procesamiento que hacen los usuarios del hipertexto. En nuestro trabajo desarrollamos un estudio exploratorio para indagar qué habilidades cognitivas pueden predecir determinados aspectos de las estrategias de lectura.

### **3.3. Relación entre estrategias de lectura y carga cognitiva**

En este capítulo hemos revisado algunas características, tanto del sistema como de los usuarios, que pueden afectar a las estrategias de lectura y la carga cognitiva de los lectores. Sin embargo es evidente que estrategias de lectura y carga cognitiva no son dos elementos independientes sino interrelacionados. En este apartado revisaremos evidencias que apuntan a que las estrategias de lectura pueden ser un elemento importante para determinar la carga cognitiva de una tarea y, por otra parte, que el nivel de carga cognitiva que un usuario soporta también pueden afectar a las estrategias de lectura que siguen los usuarios de hipertexto.

#### ***3.3.1. La estrategia de lectura puede afectar a la carga mental de la tarea.***

Uno de los supuestos principales de la Teoría de la Carga Cognitiva es que el diseño instruccional (en nuestro caso el diseño del sistema hipertexto) determina la carga cognitiva de la tarea, y esta a su vez determina los resultados de comprensión y aprendizaje. Como ya se ha señalado anteriormente, este esquema puede parecer un poco simplista, ya que no tiene en cuenta las actividades que realizan los usuarios

durante la lectura, es decir, ignora que estos pueden decidir en cualquier momento qué secciones leer y en qué secuencia hacerlo (Gerjets y Scheiter, 2003; Scheiter y Gerjets, 2007).

El desarrollo de estrategias de lectura es una actividad que consume recursos cognitivos (Scheiter y Gerjets, 2007). DeStefano y LeFevre (2007) señalaron que, en comparación con la lectura de un texto lineal, la carga cognitiva puede ser influenciada por las estrategias de lectura en hipertexto tanto de forma directa como indirecta.

- La influencia directa se produce durante el proceso de selección de enlaces, cuando los lectores encuentran un enlace y deben usar una regla de decisión para determinar si seguirlo o no, lo cual requiere recursos cognitivos. Los requerimientos cognitivos de cada una de estas reglas de decisión puede variar dependiendo de características tanto del sistema (p.ej. tipo de ayuda de navegación usada) como de los usuarios (p.ej. capacidad de memoria de trabajo). En cualquier caso puede esperarse que una estrategia basada en la posición del enlace en la pantalla requerirá menos recursos cognitivos que la estrategia de coherencia, ya que esta última requiere juzgar la similaridad semántica de los enlaces con el texto que hemos leído.
- La influencia indirecta se produce a causa de la conducta de navegación de los usuarios, cuando el enlace que se sigue lleva a un texto poco relacionado con el anterior (reduce la coherencia textual) y, como consecuencia, a una interrupción en el proceso de comprensión que requiere recursos cognitivos adicionales para la creación de una representación mental coherente.

Pero las estrategias de lectura pueden tener un efecto no solo en la cantidad, sino también en el tipo de carga cognitiva que se emplea en una tarea. Como ya se ha señalado, la comprensión y el aprendizaje con los sistemas hipertexto será mejor si se reduce la carga cognitiva inefectiva y se aumenta la carga cognitiva efectiva. Pero, ¿cómo pueden afectar las estrategias de lectura a los diferentes tipos de carga cognitiva?

Aunque por el momento no hay estudios que aborden directamente la relación entre estrategias de lectura y carga cognitiva en cuanto a sus diferentes componentes, existen estudios que pueden aportar algunos datos. Por ejemplo, se piensa que el desarrollo de estrategias de lectura puede aumentar la carga cognitiva efectiva respecto a la lectura de un texto lineal, ya que al ser necesario seleccionar los enlaces se



promueve el procesamiento activo (Landow, 1992; Patterson, 2000), aunque esto puede ser solo beneficioso para lectores con algo de conocimiento previo (Salmerón, Kintsch y Cañas, 2006a). De hecho, para aquellos lectores de bajo conocimiento previo, los incrementos en carga cognitiva debidos al desarrollo de las estrategias de lectura suelen ser de tipo inefectivo y se relacionan con problemas en la comprensión (DeStefano y LeFevre, 2007).

### *3.3.2. La carga cognitiva de la tarea puede afectar a las estrategias de lectura*

Aunque esta hipótesis no se evalúa de manera directa en este trabajo, es necesario señalar que la carga cognitiva experimentada por un lector de hipertexto también puede influir el desarrollo de las estrategias de lectura. Desde un punto de vista de las estrategias de procesamiento seleccionadas por los lectores, estas dependen de factores como la configuración de metas del lector, de su conocimiento previo pero también de la disponibilidad de recursos cognitivos o de la valoración del coste/beneficio de las diferentes estrategias en un contexto determinado (Gerjets y Scheiter, 2003).

En relación a este argumento existe evidencia de que la sobrecarga cognitiva puede llevar a la desorientación y a una navegación desestructurada y poco eficiente (Conklin, 1987; Dias y Sousa, 1997; Kim y Hirtle, 1995; Ransom, Wu y Schmidt, 1999). Por tanto, una sobrecarga del sistema cognitivo causada por la complejidad de los materiales podría llevar a los lectores a ejecutar una estrategia de lectura pasiva que consuma menos recursos cognitivos en la toma de decisiones, siguiendo los enlaces según su posición en la pantalla. Por otra parte, en el caso de una tarea menos compleja, los lectores pueden utilizar los recursos cognitivos disponibles para llevar a cabo una estrategia de lectura más activa, explorando diferentes vías de navegación (Zumbach, 2006). Apoyando esta idea, Naumann (2009) demostró recientemente que solo cuando hay suficientes recursos cognitivos disponibles los lectores pueden tratar de desarrollar activamente una estrategia de coherencia.

# **CAPITULO 4.**

## **Justificación y objetivos de la tesis**

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Existe abundante información sobre la implicación de diversas características tanto del usuario como del sistema en la comprensión y aprendizaje con hipertexto. Esto es debido a que tradicionalmente se ha considerado que los resultados de comprensión en hipertexto son una función de las habilidades de los usuarios y de las características del sistema hipertexto. Estos aspectos son importantes pero, como se ha discutido en los anteriores capítulos, no es posible realizar predicciones sobre la comprensión de hipertexto si no tenemos en cuenta las acciones de los lectores de hipertexto durante la navegación y procesamiento del texto (Salmerón et al., 2005; Unz y Hesse, 1999). Una conclusión similar puede extraerse de tareas cognitivas muy diferentes a la lectura de hipertexto, ya que la ejecución de una persona en una determinada tarea es una función de sus habilidades, los recursos cognitivos empleados y la estrategia usada (Botella, Peña, Contreras, Shih y Santacreu, 2009).

La presente tesis se enmarca en el contexto de dos proyectos de investigación consecutivos en el tiempo (RAYUELA I y II) que profundizan en este argumento.

En primer lugar, el proyecto **RAYUELA I: Papel de las estrategias de lectura en la comprensión de textos en sistemas hipertexto (SEJ2004-05430)** exploró en una primera fase varias cuestiones:

- ¿Cuáles son las estrategias de lectura seguidas por los lectores de hipertexto?
- ¿Cómo afectan estas estrategias al orden de lectura de las secciones y a la selección de secciones a leer?
- ¿Cuáles son los mecanismos a través de los cuales las estrategias de lectura afectan a la comprensión de hipertexto?

Estos estudios permitieron determinar la importancia de las estrategias de lectura en la comprensión de hipertexto e identificar una serie de variables clave, como es el caso de la coherencia del orden de lectura (Salmerón et al., 2005; Salmerón, Kintsch y Cañas, 2006a).

La siguiente fase de este proyecto se centró en investigar qué factores determinaban la elección y ejecución de una estrategia de lectura determinada y no otra. Aunque tanto variables del sistema hipertexto como de las características de los usuarios

podrían estar influyendo estas estrategias, se decidió en un primer momento analizar la influencia de las habilidades cognitivas y meta-cognitivas de los lectores. Un estudio preliminar en este sentido fue realizado por Salmerón (2006, Apéndice III) analizando el papel de las habilidades de meta-comprensión de los lectores en la selección de las estrategias de lectura. En cuanto a las habilidades cognitivas se realizaron igualmente algunos estudios exploratorios previos (Madrid, Salmerón, Cañas y Fajardo, 2005; Madrid, Salmerón y Cañas, 2006a; Madrid, Salmerón y Cañas, 2006b) que mostraron la importancia de las habilidades cognitivas como predictores del comportamiento de navegación de los lectores de hipertexto.

Junto a los resultados obtenidos en RAYUELA I, los resultados de estos estudios exploratorios permitieron proponer un marco explicativo que describía la relación entre diferentes tipos de variables en la comprensión con hipertexto, incluyendo la relación entre las características de los lectores, las variables del sistema y las estrategias de lectura seguidas por los usuarios de hipertexto (Madrid y Cañas, 2007).

Es en ese punto donde se inicia la investigación descrita en la presente tesis. En concreto, el *Estudio I* se concibe con el objetivo de analizar el papel de diferentes habilidades cognitivas de los lectores como predictores de la ejecución de estrategias de lectura, en términos de comportamiento de navegación. Desde un enfoque del diseño de sistemas hipertexto, el foco suele ponerse en diseñar sistemas que den soporte y orientación a los lectores en el proceso de navegación, como es el caso de los mapas de contenidos. Sin embargo, la forma en que los lectores usan o se benefician de estos sistemas puede depender de sus habilidades o experiencia. Así, el Estudio I se centra en determinar qué aspectos de las estrategias de lectura que los usuarios desarrollan (a través de su conducta de navegación) se relacionan con una buena comprensión, y qué características de los usuarios (en el caso de este estudio, diferentes habilidades cognitivas) pueden predecir la ejecución de dichas estrategias.

Como continuación al proyecto RAYUELA I, se desarrolla el proyecto **RAYUELA II: Estrategias cognitivas de navegación y búsqueda en los sistemas hipermedia: El papel de la carga cognitiva (SEJ2007-63850/PSIC)**. En este proyecto se trata de continuar con la investigación ya iniciada encaminada a identificar los factores que determinan que un lector siga una estrategia de lectura determinada. Los resultados hasta el momento habían indicado que las características del sistema

hipertexto interactúan con las características del sistema cognitivo humano en la ejecución de una estrategia de lectura y, por tanto, en el nivel de comprensión alcanzado por los lectores. La hipótesis principal de este proyecto es que la carga cognitiva que los lectores soportan asociada a la ejecución de una estrategia - y que depende tanto de las diferencias cognitivas individuales como de las funcionalidades y estructura del sistema hipertexto - es un factor determinante para la comprensión y por tanto debe integrarse dentro de un modelo explicativo de comprensión de hipertexto.

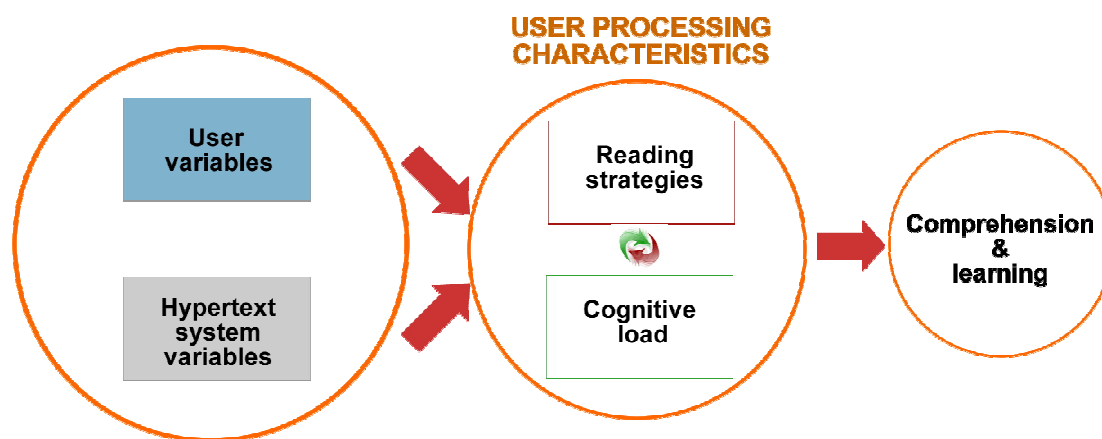
Es en el contexto de RAYUELA II donde se realizan los estudios II y III de esta tesis. En el *Estudio II* se analiza el efecto de características del sistema - como son el número de enlaces por página y la provisión de un sistema de apoyo a la navegación - en la carga cognitiva y la comprensión con hipertexto. El análisis de los resultados de este estudio también muestra la importancia de las estrategias de lectura como variable mediadora y su relación con la carga cognitiva y la comprensión.

Siguiendo al estudio II, en el *Estudio III* se explora cómo el adoptar diferentes estrategias para seleccionar el orden de lectura (estrategia de coherencia vs. interés) afecta a la carga cognitiva y la comprensión de lectores de diferente nivel de conocimiento previo (bajo vs. alto conocimiento previo).

Los estudios incluidos en esta tesis tienen como objetivo común avanzar en el desarrollo de un modelo de la comprensión con hipertexto que ponga un **mayor énfasis en las variables relacionadas con el procesamiento de los usuarios durante la lectura de hipertexto**. Este modelo que proponemos trata de servir de marco para analizar la relación entre variables. Para ello asume que, durante la lectura de un hipertexto, los usuarios realizan una serie de acciones a nivel comportamental y llevan a cabo una serie de procesos cognitivos que determinan en última instancia la comprensión. Por acciones comportamentales nos referimos a la ejecución de estrategias de lectura que determinan la forma en que se accede al hipertexto (p.ej. orden de lectura, nodos accedidos, uso de ayudas de navegación, etc.). En cuanto a los procesos cognitivos, estos se reflejan en el nivel y tipo de carga cognitiva experimentada por el usuario durante la lectura del hipertexto.

Una representación esquemática del modelo que muestra la relación entre variables puede verse en la Figura 2. Las características del usuario interactúan con características del sistema hipertexto para dar lugar a una estrategia de lectura concreta

y un determinado nivel de carga cognitiva (ambas características de procesamiento de los usuarios). La carga mental y las estrategias de lectura se estarían influyendo mutuamente (el nivel de carga cognitiva puede hacer que se adopte una estrategia u otra, o que se tengan dificultades para ejecutar correctamente una estrategia; igualmente, el adoptar una determinada estrategia puede incrementar el nivel de carga cognitiva o reducirlo). Tanto las estrategias de lectura como la carga cognitiva serían características de procesamiento de los usuarios que finalmente determinarían los resultados de comprensión y aprendizaje.



**Figura 2. Modelo de comprensión de hipertexto**

Aunque el objetivo de este modelo es predecir la comprensión y el aprendizaje cuando se usan sistemas hipertexto, la principal aportación de esta tesis está en analizar el papel mediador de las variables relacionadas con el procesamiento de los usuarios.

Teniendo como marco de investigación el esquema que refleja la figura anterior, se han realizado tres estudios cuyos objetivos se exponen a continuación.

### **Estudio I. Habilidades cognitivas predictoras de las estrategias de lectura y el papel de estas en la comprensión de hipertexto**

Este primer estudio está especialmente interesado en el papel de las variables de usuario, y se plantea dos preguntas de investigación principales:

- ¿Cuáles son las variables relacionadas con las estrategias de lectura que pueden predecir unos buenos resultados de comprensión?
- ¿Qué habilidades cognitivas son importantes y cuál es su papel como predictoras de las estrategias de lectura?

### **Estudio II: El efecto del diseño del hipertexto en la carga cognitiva y la comprensión. El efecto mediador de las estrategias de lectura**

Este segundo estudio presenta un experimento más centrado en el efecto de las variables del sistema, así como en el papel de la carga cognitiva. Presenta varios objetivos:

- Comprobar si el incremento en el número de enlaces por página incrementa la carga cognitiva y lleva a una peor comprensión
- Evaluar el efecto de un sistema de apoyo a la navegación basado en la sugerencia de enlaces para reducir la carga mental y mejorar la comprensión.
- Determinar si las estrategias de lectura de los usuarios actúan como mediadores entre las variables del sistema y la carga cognitiva y comprensión.

### **Estudio III: Efecto del conocimiento previo de los lectores y las estrategias de lectura en la carga cognitiva**

En este último estudio el objetivo es obtener información sobre la relación entre estrategias de lectura, carga cognitiva y comprensión. Por ello las preguntas de investigación eran:

- ¿Qué efecto tienen dos estrategias de lectura distintas (coherencia e interés) en la carga cognitiva y el comprensión?
- ¿Es este efecto distinto para lectores de bajo y alto conocimiento previo?
- ¿Qué papel juegan los diferentes componentes de la carga cognitiva en la relación entre estrategias de lectura y comprensión?





## **CAPITULO 5.**

### **Resumen de resultados**

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A continuación se ofrece un resumen de los principales resultados de los estudios que conforman esta tesis, y que se describen de forma detallada en forma de apéndices (Appendix I, II y III).

### **5.1. Estudio I: Habilidades cognitivas predictoras de las estrategias de lectura y el papel de estas en la comprensión de hipertexto**

La principal meta del *Estudio I* era examinar el papel de diferentes habilidades cognitivas en las estrategias de lectura desarrolladas por lectores de bajo conocimiento previo, así como la relación entre estas estrategias de lectura y la comprensión. El sistema hipertexto utilizado era accedido a través de un mapa de contenidos gráfico interactivo, una ayuda a la navegación muy común en estos sistemas.

#### *5.1.1. ¿Cuáles son las variables relacionadas con las estrategias de lectura que pueden predecir unos buenos resultados de comprensión?*

Las estrategias de lectura son factores principales que afectan a la comprensión y el aprendizaje con sistemas hipertexto. Estas estrategias pueden ser analizarse a través de una serie de variables que caracterizan la conducta de navegación de los lectores. Específicamente, la adquisición del texto base se ha relacionado previamente con la cantidad de información leída (número de nodos de información accedidos), mientras que la construcción del modelo de la situación se relaciona con la coherencia de la lectura del texto (Salmerón et al. 2005; Salmerón, Kintsch y Cañas, 2006a). Junto a confirmar estas relaciones, el estudio pretendía explorar el papel de otras variables relacionadas con el uso de los mapas de contenidos. Este es el caso del tiempo de uso del mapa de contenidos, una variable que parece ser importante cuando se usan estas ayudas de navegación (Salmerón, Baccino, Cañas, Madrid y Fajardo, 2009).

Para medir la comprensión de los lectores, estos realizaron una serie de pruebas relacionadas tanto con la adquisición del texto base (preguntas basadas en el texto) como con la adquisición del modelo de la situación (preguntas de inferencia y tarea de juicios de relación).

Los análisis de regresión mostraron que, como era esperado y en línea con estudios anteriores, un mayor número de nodos accedidos se relacionaba con una mejor adquisición del texto base, mientras que seguir un orden de lectura de mayor coherencia textual se relacionaba con una mejor adquisición del modelo de la situación. Por otra parte, también se encontró una relación inversa entre el tiempo de uso del mapa de contenidos y la adquisición del modelo de la situación: a más tiempo dedicado a inspeccionar el mapa para seleccionar enlaces peor era la adquisición del modelo de la situación.

En conjunto podemos señalar que, en el contexto de un sistema hipertexto que incluye un mapa de contenidos gráfico, una estrategia de lectura beneficiosa para la comprensión de lectores de bajo conocimiento previo se caracteriza por un alto número de nodos accedidos, un orden de lectura de alta coherencia textual y un tiempo corto de uso del mapa de contenidos.

Puesto que todos los lectores usaron el mismo sistema hipertexto, las diferencias en estrategias de lectura deben atribuirse a las diferencias individuales en alguna habilidad de los lectores participantes. Es por ello que el estudio planteaba la siguiente pregunta de investigación.

**5.1.2. *¿Qué habilidades cognitivas son importantes y cuál es su papel como predictoras de las estrategias de lectura?***

En cuanto a esta pregunta se trataba de analizar cuál era la relación entre una serie de habilidades cognitivas seleccionadas (varias habilidades espaciales, capacidad de memoria de trabajo y razonamiento lógico) y las variables que caracterizaban las estrategias de lectura seguida por los participantes. Para ello, los lectores completaron una selección de test cognitivos previamente a la sesión de lectura de hipertexto.

Los resultados mostraron resultados significativos solo para las habilidades espaciales. Dos de estas habilidades (*Velocidad de Cierre* y *Exploración Espacial*), predecían varias de las variables de las estrategias de lectura implicadas en la comprensión. Concretamente, a mayor *Velocidad de Cierre* menor era el tiempo que dedicaban a usar el mapa de contenidos y mayor era la similitud del orden de lectura seguido con aquel sugerido por el mapa de contenidos (lo cual equivalía a un orden de

lectura de alta coherencia). Por otra parte, una alta habilidad de *Exploración Espacial* predijo el acceso a un número mayor de nodos diferentes.

### *5.1.3. Relación entre habilidades espaciales, estrategias de lectura y comprensión*

Los resultados del Estudio I ofrecen más datos sobre los componentes implicados en la comprensión de hipertexto y las relaciones entre ellos. Pueden extraerse dos conclusiones principales:

**1) Las estrategias de lectura que siguen los usuarios predicen la comprensión.** Los resultados de este estudio apoyan la necesidad ya expresada en la introducción de este trabajo de tener en cuenta las variables relacionadas con las estrategias de lectura como un factor principal y no solo como un subproducto de la tarea de comprensión de hipertexto. La comprensión de los lectores puede por tanto mejorarse mediante el uso de estrategias de lectura adecuadas, lo cual puede promoverse mediante el empleo de ayudas a la navegación o por el entrenamiento de dichas estrategias, tal y como han sugerido algunos autores (McNamara y Shapiro, 2005).

**2) Las habilidades espaciales de los lectores afectan a las estrategias de lectura que estos desarrollan.** Si bien la estructura del hipertexto o la presencia de ayudas a la navegación (como el mapa de contenidos interactivo usado en nuestro estudio) podrían determinar en gran medida la estrategia de lectura usada, este estudio muestra que las características de los usuarios como las habilidades espaciales pueden tener también una influencia en la navegación. Ya que la eficiencia de las ayudas a la navegación como los mapas de contenidos de hipertexto puede depender de las habilidades espaciales de los lectores, su diseño debe acomodar las diferencias individuales en estas habilidades y ofrecer una menor complejidad espacial.

## **5.2. Estudio II: El efecto del diseño del hipertexto en la carga cognitiva y la comprensión. El efecto mediador de las estrategias de lectura**

### *5.2.1. Estudio Ila: Efecto de número de enlaces y apoyo a la navegación en la carga cognitiva y la comprensión*

El propósito principal del estudio II era el análisis de los efectos de dos variables relacionadas con el sistema hipertexto, como son el número de enlaces y la provisión de un sistema de apoyo a la navegación, en la carga cognitiva y la comprensión de lectores de bajo conocimiento previo.

Parte de las hipótesis empleadas en este estudio se derivan de las predicciones de DeStefano y LeFevre (2007). En primer lugar, estos autores proponen que realizar elecciones de navegación en hipertexto impone más carga cognitiva cuando el número de enlaces en la página es mayor. La influencia de este efecto puede venir por dos mecanismos: directamente - cuando al existir más enlaces hay mayores requerimientos cognitivos para su selección - o indirectamente - cuando al existir más enlaces se incrementa la probabilidad de acceder a los documentos en un orden de lectura de baja coherencia. En segundo lugar, y como consecuencia de lo anterior, un alto número de enlaces puede dañar la comprensión con hipertexto. Por ello en nuestro estudio realizamos una comparación entre dos sistemas hipertexto que ofrece bien 3 o bien 8 enlaces.

La otra entrada para nuestras hipótesis estaba relacionada con una preocupación práctica: ¿cómo es posible ayudar a los aprendices a enfrentarse con los problemas que DeStefano y LeFevre asocian con el uso de hipertexto, esto es, un incremento de la carga cognitiva y una lectura desorganizada que llevan a una menor comprensión? Más en concreto, se quería comprobar la utilidad de ofrecer ayuda a la navegación en forma de sugerencias de enlaces que se basen en la similaridad semántica entre el texto que se acaba de leer y las etiquetas de los enlaces. Este sistema de ayuda a la navegación se basa en una técnica descrita por Salmerón, Kintsch y Cañas (2006b) que propusieron un método automatizado para sugerir enlaces basado en medidas de coherencia obtenidas con LSA. Este sistema no solo podría ayudar a los lectores a seleccionar un orden de lectura coherente, sino que en el contexto de este estudio también podría reducir la carga cognitiva en las situaciones predichas por DeStefano y LeFevre. En primer lugar, al sugerir algunos enlaces se focaliza la atención de los lectores en menos enlaces, por

lo que la carga cognitiva relacionada con la toma de decisiones será menor. Adicionalmente, al promover un orden de lectura más coherente, esto también llevaría a una reducción de la carga cognitiva asociada a la lectura. Como consecuencia, este sistema también permitiría una mejor comprensión y aprendizaje. Por tanto en este estudio la mitad de los participantes usaron un hipertexto que ofrecía sugerencias de enlaces (señalando los dos enlaces con mayor similaridad con el texto que se acababa de leer) mientras que la otra mitad leyó un hipertexto sin sugerencias de enlaces.

En el estudio participaron lectores de bajo conocimiento previo (se utilizó un texto sobre neuropsicología y los participantes eran alumnos de disciplinas no relacionadas con el tema), y fueron instruidos para utilizar la coherencia como regla de decisión (debían tratar de seleccionar el enlace más relacionado con lo que acababan de leer). De esta forma se trataba de controlar el efecto de diferentes niveles de conocimiento previo y diferentes tipos de estrategias de lectura.

Como era de esperar, el que todos los participantes usarán la misma regla de decisión no garantiza que todos siguieran el mismo orden de lectura. Los resultados mostraron que la coherencia del orden de lectura era mayor para aquellos que había usado el hipertexto con apoyo a la navegación frente a los que no, y para aquellos que usaron el hipertexto de 3 enlaces frente a los que usaron el hipertexto de 8 enlaces. Sin embargo, el número de enlaces y el apoyo a la navegación no tuvieron ningún efecto en la carga cognitiva experimentada durante la selección de enlaces o la lectura de textos.

En cuanto a los resultados de comprensión, los análisis mostraron que ni el número de enlaces ni el apoyo a la navegación tenían efecto en la adquisición del texto base. Por otra parte, si bien el número de enlaces no mostró un efecto a nivel del modelo de la situación, sí que lo hizo el apoyo a la navegación. Así, aquellos lectores que usaron el hipertexto que ofrecía sugerencias de enlaces obtuvieron un mejor modelo de la situación que aquellos que usaron el hipertexto sin apoyo a la navegación.

La falta de resultados en cuanto a carga cognitiva podría explicarse por la forma en que se relacionan la carga cognitiva y la coherencia del orden de lectura. Puesto que esta última no depende directamente de las características del sistema hipertexto sino que es dependiente de las acciones de los lectores, esto sugirió realizar nuevos análisis para explorar el papel mediador del orden de lectura en la carga cognitiva y la comprensión.



### *5.2.2. Estudio IIb: El papel mediador del orden de lectura en la carga cognitiva y la comprensión*

En primer lugar se agruparon los participantes en dos grupos (baja vs. alta coherencia) en función de la coherencia del orden de lectura seguido. Esto mostró que, si bien usar un hipertexto de 3 vs. 8 links o con sugerencias de enlaces vs. sin sugerencias incrementaba la posibilidad de seguir un orden de lectura de alta coherencia, alrededor de 1/3 de los participantes de estos grupos seguía realizando un orden de lectura de baja coherencia. Por tanto, era posible que esta distribución de participantes en las diferentes condiciones hubiese difuminado el resultado.

Una nueva serie de análisis se realizaron para determinar el efecto del orden de lectura. Para ellos se usaron el número de enlaces y el orden de lectura como variables independientes, y las medidas de carga cognitiva y de comprensión como variables dependientes.

En este caso sí que se mostró un efecto del orden de lectura en la carga cognitiva. Los lectores que siguieron un orden de lectura de mayor coherencia tuvieron menor carga cognitiva durante la lectura y parecían haber sufrido también menos carga cognitiva durante la selección de enlaces. En cuanto a los resultados en comprensión, si bien no se encontró ningún efecto en las medidas de texto base, sí que se reveló un efecto del orden de lectura en las medidas del modelo de la situación: aquellos participantes que siguieron un orden de lectura más coherente obtuvieron mejores puntuaciones en la tarea de juicios de relación y la misma tendencia se mostró en las preguntas de inferencia (aunque en este caso los resultados no fueron significativos).

Los resultados de este estudio refuerzan la importancia de las acciones de los usuarios de hipertexto en la comprensión, ya que se muestra que aquellos lectores de bajo conocimiento previo que son capaces de seguir un orden de lectura coherente alcanzan una mejor comprensión de los contenidos, independientemente de la características del sistema hipertexto que hayan usado.

### **5.3. Estudio III: Efecto del conocimiento previo de los lectores y las estrategias de lectura en la carga cognitiva**

El estudio III trata de ampliar los resultados del estudio II, el cual tenía dos limitaciones que prevenían de extraer conclusiones generales, principalmente aquellas relacionadas con el efecto de las estrategias de lectura en la carga cognitiva.

En primer lugar, en el Estudio II solo participaron lectores de bajo conocimiento previo. Estos no recibirían influencias de mecanismos estratégicos de las estrategias de lectura (Salmerón, Kintsch y Cañas, 2006a) y por lo tanto su carga cognitiva y comprensión estarían afectados solo por los mecanismos inducidos por el texto. Ya que los lectores que siguieron un orden de lectura menos coherente obtuvieron una carga cognitiva mayor y una menor comprensión, podemos concluir que ese incremento en la carga cognitiva se debe sobre todo a carga cognitiva inefectiva (*extraneous*) y no efectiva (*germane*). Sin embargo, basándonos en resultados previos los lectores con algo de conocimiento previo podrían obtener resultados diferentes debido a los mecanismos de influencia estratégica de las estrategias de lectura. En resumen, el mecanismo de influencia estratégica podría producir carga cognitiva efectiva para los lectores con conocimiento previo que no están disponibles en el caso de los lectores de bajo conocimiento previo. Por lo tanto, para probar los efectos hipotéticos de los mecanismos estratégicos de las estrategias de lectura en la carga cognitiva, se requería un nuevo experimento en el que se incluyesen participantes con un nivel más alto de conocimiento previo.

En segundo lugar, todos los participantes del Estudio II recibieron instrucciones para seguir la estrategia de coherencia con el objetivo de controlar los efectos que pudiesen producir diferentes estrategias de lectura. Sin embargo, ya sabemos que la estrategia de coherencia no es la única estrategia de lectura que los lectores pueden realizar, y seguir diferentes estrategias de lectura puede tener un efecto distinto en la carga cognitiva de la misma forma que lo tiene en la comprensión (Salmeron, Kintsch y Cañas, 2006a). Este efecto podría ser relevante principalmente durante las tareas de navegación (esto es, durante la selección de enlaces), ya que diferentes estrategias podrían necesitar diferente cantidad de recursos para evaluar la relevancia de los enlaces para sus objetivos, pero también durante las tareas de lectura, ya que diferentes estrategias de lectura hacen a los lectores focalizarse en diferentes aspectos del texto.

Apoyando estas ideas, la evidencia procedente del campo de la ergonomía cognitiva muestra que las personas que usan estrategias alternativas para realizar una misma tarea difieren en la cantidad de esfuerzo mental necesario para ejecutar la tarea (Brainbridge, 1974, 1998).

Para resolver estas limitaciones, en este estudio se realizó un experimento en el cual se prueba el efecto de diferentes estrategias de lectura, en lectores con y sin conocimiento previo, en la carga cognitiva y la comprensión. El estudio ahonda en dos cuestiones:

**1) El efecto de las estrategias de lectura en la carga cognitiva:**

Nuestra hipótesis era que los lectores tanto de bajo como de alto conocimiento previo obtendrían mayor carga cognitiva con la estrategia de coherencia durante la selección de enlaces, debido a una mayor carga en toma de decisiones en comparación con la estrategia de interés. También preveíamos que los lectores de bajo y alto conocimiento previo tendrían una mayor carga cognitiva durante la lectura con la estrategia de interés que con la de coherencia, debido a la mayor carga cognitiva que requiere un orden de lectura de baja coherencia.

Los análisis mostraron resultados que a priori podrían parecer contradictorios. En primer lugar, la intensidad de carga cognitiva en la selección de enlaces requerida por la estrategia de interés se mostró mayor que la requerida por la estrategia de coherencia. En segundo lugar, la intensidad de la carga cognitiva en la lectura se mostró igual para ambos tipos de estrategia a pesar de que aquellos que habían seguido la estrategia de interés realizaron un orden de lectura considerablemente menos coherente.

Para explicar esto, fue necesario tener en cuenta no solo la intensidad, sino también la duración de la carga cognitiva en línea con lo que se conoce como *Hipótesis del volumen de la atención* (Hidi, 1995; Reynolds, 1992). Esta idea puede resumirse de forma intuitiva señalando que aunque dos tareas requieran la misma intensidad de carga cognitiva para realizarse, una puede ser más demandante que otra si su duración es mayor. Usando este argumento puede concluirse que la estrategia de interés conlleva una mayor carga cognitiva durante la lectura, puesto que el análisis mostró que requería más tiempo que la de coherencia tanto para lectores de bajo como de alto conocimiento previo siendo la intensidad de la carga cognitiva la misma para ambos tipos de estrategia. En el caso de la carga cognitiva durante la selección de enlaces, se encontró

que se requería más tiempo para la estrategia de coherencia que para la de interés, una relación inversa a la que se encontró en cuanto a la intensidad de la carga cognitiva. Esto no permite pronunciarse sobre cuál de las estrategias demanda más recursos cognitivos, aunque sí se puede señalar que ambas requieren un balance diferente en cuanto a intensidad y duración de la carga cognitiva.

## **2) La relación entre estrategias de lectura, carga cognitiva y comprensión:**

Tras analizar los resultados en carga cognitiva, se evaluó el efecto de las estrategias de lectura y el conocimiento previo en la comprensión, y se usó el patrón conjunto de resultados para analizar la relación entre carga cognitiva y comprensión.

Teniendo en cuenta los mecanismos inducidos por el texto y de influencia estratégica propuestos por Salmerón, Kintsch y Cañas (2006a) y la división entre diferentes componentes de carga cognitiva (intrínseca, efectiva, inefectiva) que establece la Teoría de Carga Cognitiva (p.ej. Paas, Renkl y Sweller, 2004) se habían establecido una serie de hipótesis:

1º Para lectores de bajo conocimiento previo, la mayor carga cognitiva obtenida al realizar una estrategia de interés respecto a la estrategia de coherencia, estaría compuesta de carga cognitiva inefectiva y por tanto daría lugar a una menor comprensión.

2º Para lectores de alto conocimiento previo, ambas estrategias les permiten crear carga cognitiva efectiva y procesar el texto de manera más activa, obteniendo de esta forma una buena comprensión tanto con la estrategia de coherencia como con la de interés.

En línea con nuestra hipótesis, el análisis de los resultados de las preguntas de inferencia mostró que aquellos lectores de bajo conocimiento previo que siguieron una estrategia de coherencia construyeron un mejor modelo de la situación que los lectores que usaron la estrategia de interés. Por su parte, los lectores de alto conocimiento previo obtuvieron similares resultados con ambas estrategias.

En cuanto a la carga cognitiva, es difícil determinar qué componentes concretos de la carga cognitiva (efectiva, inefectiva) están implicados en una determinada tarea, ya que las medidas usadas (tiempos de reacción a tarea secundaria, tiempo de lectura y de selección de enlaces) solo permiten obtener una medida de carga cognitiva global.

Sin embargo, sí que es posible inferir de manera indirecta esta relación observando su efecto en la comprensión. Así por ejemplo, y teniendo en cuenta la carga cognitiva experimentada durante la lectura, podemos asumir que para los lectores de bajo conocimiento previo la mayor carga cognitiva de la estrategia de interés tiene un componente de carga cognitiva inefectiva derivada del orden de lectura incoherente. En el caso de los lectores de alto conocimiento previo, la mayor carga cognitiva en la lectura debe tener un componente de carga cognitiva efectiva, ya que esta no lleva a una peor comprensión respecto a la estrategia de coherencia.

# **CAPITULO 6.**

## **General discussion and conclusion**

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Most hypertext comprehension studies have focused on the effect of user and / or system variables on hypertext comprehension. However, previous studies in this line of research have demonstrated the importance of reading strategies as a mediating factor in hypertext comprehension (Salmerón et al., 2005; Salmerón, Kintsch & Cañas, 2006). These results focused our research on determining which user and system variables could predict the selection or development of a certain reading strategy. In addition, the readers' cognitive load experienced during hypertext reading has been proposed to be an important characteristic of user processing affecting comprehension with hypertext systems (DeStefano & LeFevre, 2007).

The general objective of this thesis was to progress towards a model of hypertext comprehension by analyzing the role of user processing characteristics as mediators between user and system variables and comprehension outcomes (see Figure 1). To that end, three studies have been conducted in which reading strategies and cognitive load have been considered as main variables to explain hypertext comprehension outcomes (see Table 1, which shows a summary of the variables under consideration in the three studies presented).

In the following sections we will discuss the contribution of this work to this objective by clarifying

- 1) the effect of user processing characteristics on comprehension,
- 2) the relation between user processing characteristics: reading strategies and cognitive load and
- 3) the role of user and system variables as predictors of user processing characteristics.



	Variables	Study I	Study II	Study III
<b>User and system variables</b>	<i>User variables</i>	Prior knowledge (Low)	Prior knowledge (Low)	Prior knowledge (Low vs. High)
		Flexibility of closure		
		Speed of closure		
		Spatial scanning		
		Memory span		
		Logical reasoning		
	<i>System variables</i>	[Graphical overview]	Number of links(3vs8)	[Menu with 8 links]
			Navigation support (with vs. without)	
<b>Reading strategies</b>	<i>Decision rule</i>	[Free navigation]	[Coherence strategy]	Coherence vs. interest strategy
	<i>Navigation behavior</i>	Reading text coherence	Reading text coherence	Reading text coherence
		Number of nodes accessed		
		Reading order similarity overview		
		Overview usage time		
<b>Cognitive load</b>	Intensity	-	RTs Link selection	RTs Link selection
			RTs Reading	RTs Reading
	Duration	-	Link selection Times	Link selection Times
			Reading times	Reading times
<b>Comprehension</b>	Textbase	Textbase questions	Textbase questions	Textbase questions
	Situation model	<b>Inference questions</b>	<b>Inference questions</b>	<b>Inference questions</b>
		<b>Relatedness judgment task</b>	<b>Relatedness judgment task</b>	<b>Relatedness judgment task</b>

Table 1: Summary of variables considered in the three studies presented. [ ] indicated that this variable was controlled

## 6.1. The effect of user processing characteristics on comprehension

User processing characteristics (reading strategies and cognitive load) are variables that can be used to define the behaviour and cognitive processing that a certain user carries out during hypertext reading.

### 6.1.1. *Reading strategies: decision rules and navigation behavior*

Reading strategies have been previously examined from two complementary approaches. Firstly, some studies focused on determining the different **decision rules** that readers adopt to select which links to follow and in which order (Protopsaltis, 2008; Salmerón, Kintsch & Cañas, 2006a). Secondly, another series of studies have analyzed reading strategies focusing on the readers' **navigation behaviour** which, as a consequence of the decision rule adopted by the reader, affects aspects such as reading order, number of links accessed, use of navigation tools, etc.

It has been argued that decision rules and navigation behaviour are two aspects of reading strategies that conjointly determine comprehension outcomes in hypertext. For example, Salmerón, Kintsch & Cañas (2006a) stated that reading strategies have an effect on hypertext comprehension in two different ways, by text-induced and strategic influences. On the one hand, if the comprehension outcomes of a particular hypertext reading strategy for a certain group of readers is not different from the results obtained reading the text linearly with a similar low or high text coherence level, it can be said that its influence is text induced. That is, the text-induced influence (related with navigation behaviour) is the indirect effect of a certain reading strategy due to changes in text coherence associated with the reading order followed by the reader. Apart from the fact that in hypertext the reader selects his/her own reading order, this influence is similar to the effect that can be expected from a coherent/incoherent linear text. On the other hand, if the comprehension outcomes of that reading strategy differ from the results obtained by reading the text in a linear manner, it can be said that its influence is due to a strategic influence. The strategic influence (related with decision making) is caused directly through the active processing induced by the strategy used.

But how can we distinguish the text-induced and the strategic influence effects of a certain reading strategy? In our research we have used a mixed approach by

measuring users' navigation behaviour in all the studies, but examining the role of decision rules in different ways (see Table 1): whereas in Study I decision rules were not controlled by allowing free navigation, in Study II they were controlled by instructing users in following a coherence strategy (reading the hypertext node most related with the previously read one in order to maintain text coherence) and in Study III they were manipulated by instructing readers to use either a coherence or an interest strategy (reading first the most interesting nodes for the user, delaying the less interesting ones).

It is important to make this distinction since readers following the same decision rule (e.g. using the same decision rule for selecting the next link to read) could actually perform very different navigation behaviours (e.g. different reading orders). This can be applied both to the coherence and the interest strategy. For example, all the participants in Study II received the instruction to follow the same decision rule (coherence strategy) but they vary in their achieved reading text coherence in a sensitive way. Different factors (such as prior knowledge, design features, reading skills, etc.) could have deviated readers from the optimal path of that strategy. In the case of those following the interest reading strategy in Study III, their decision rule was less related with text features but with motivational factors (reading interesting contents regarding the readers' opinion), and therefore the navigation behaviour obtained with this strategy could have high variability between individuals.

Previous studies determined that reading strategies affect comprehension both at textbase and situation model level (Salmerón et. al. 2005; Salmerón, Kintsch & Cañas, 2006a). A relation of reading strategies with textbase acquisition was found in Study I. It was shown that, similar to previous studies, the amount of information accessed was the best predictor of textbase acquisition for low prior knowledge readers. It can be seen as an obvious statement, but in the case of hypertext it is important to make clear that readers select what content to read and this can affect comprehension (Salmerón et al. 2005). In contrast, textbase acquisition was not affected by reading strategies in Studies II & III since all participants read the same amount of information.

Regarding the effects of reading strategies at situation model level, the three studies presented in this thesis robustly support that low prior knowledge readers benefit from a reading order that maximizes reading text coherence. For high prior knowledge

readers, Study III showed that using a coherence strategy for selecting links leads to the same comprehension results as using the interest strategy, even when both strategies lead to reading sequences with very different level of reading text coherence. Linear text studies have suggested that reading a coherent text can be detrimental for high prior knowledge readers, so results of Study III can be interpreted as a strategic influence for using the coherence strategy for selecting links actively (McNamara & Shapiro, 2005; Salmerón, Kintsch & Cañas, 2006a).

These findings are also consistent with recent studies showing that prior knowledge supports comprehension when readers use a hypertext structure that leads them to follow a less coherent reading order (Amadiou, Tricot & Marinee, 2009; 2010). Moreover, studies I & II also suggest that reading strategies seem to mediate influences of user and system variables on comprehension, that is, these variables affect directly reading strategies that subsequently affect comprehension.

An additional variable characterizing reading strategies (overview use time) predicted comprehension at situation model level in Study I. Its effect on comprehension can be interpreted in terms disorientation problems (Müller-Kalthoff & Möller, 2006) or reading interruption (DeeLucas & Larkin, 1996; DeStefano & LeFevre, 2007). Moreover, recent research has also claimed for the importance of the timing of graphical overview use in hypertext comprehension (Salmerón, Baccino, Cañas, Madrid and Fajardo, 2009).

From a methodological point of view, these results points to the importance of reading strategies as a mediating variable in hypertext comprehension. A similar conclusion can be extracted from results on research topics not related with hypertext reading. For example, Botella et. al. (2009) conducted an experiment assessing participants' ability with dynamic spatial tasks, showing that the strategies they used affect their performance. They suggested that for a comprehensive analysis of performance, researcher must pay attention to the strategy that participants use to complete a certain task. In a similar way, our own results recommends that research on hypertext comprehension must consider the specific reading strategies performed by readers in order to avoid confounding results caused by these mediating variables on comprehension.

### *6.1.2. Cognitive load*

Cognitive load in hypertext reading can be seen as the amount of cognitive resources required by the hypertext task. Traditionally, there are two different approaches for considering the role of cognitive load in hypertext reading. From the first approach, hypertext features increase overall cognitive load in comparison with linear text, which could lead to disorientation and hinder comprehension (Conklin, 1987; DeStefano & LeFevre, 2007). From the second approach, that of the Cognitive Load Theory (Sweller, 1988; Sweller, van Merriënboer & Paas, 1998; Zumbach, 2006), hypertext features can increase overall cognitive load but their effect on comprehension and learning depends on its composition (tradeoff between different types of load: intrinsic, extraneous and germane cognitive load).

Cognitive load in our experiment was measured as a dependent variable, and therefore we can only discuss their relation with comprehension indirectly. However, we can say that for low prior knowledge readers higher cognitive load during hypertext reading were accompanied by lower comprehension at situation model level both in Studies II and III. Contrarily, for high prior knowledge readers an increase in cognitive load caused by the type of reading strategy use was related with a better situation model acquisition in Study III. One of the aims of this thesis was to test if reading strategies could both affect overall cognitive load and modify the tradeoff between extraneous and germane cognitive load, subsequently affecting learning. This issue is discussed in the next section.

## **6.2. Relation between user processing characteristics: Reading strategies and cognitive load**

Previous research have suggested that reading strategies adopted by hypertext readers to actively select the links to be followed could affect cognitive load through two different mechanisms: directly, by increasing the amount of cognitive resources needed for decision making during link selection, and indirectly, by guiding users to read contents in an unrelated order that need extra cognitive resources to be comprehended (DeStefano & LeFevre, 2007). To explore both mechanisms we analyzed readers' cognitive load separately during link selection and during reading.

The effect of reading strategies on cognitive load during link selection

Cognitive load during link selection reflects variations on the mental effort required by decision making processes. This seemed to be related with the reading strategies adopted by the reader (both in terms of decision rules and navigation behaviour). For example, in Study II the intensity of cognitive load during link selection was higher for those who followed a low coherence reading order using a coherence strategy as decision rule. This can also be interpreted as the other way around, that is, those participants who encountered difficulties (higher cognitive load) in selecting the optimal link for the coherence strategy achieved a lower coherence reading order. Study III showed that following either the coherence or the interest strategy as decision rules had different requirements of cognitive resources to be performed. However, differences in Study III were observed as a tradeoff between intensity (higher for the interest strategy) and duration (higher for the coherence strategy), which makes it difficult to determine which reading strategy consumes more resources (in terms of volume).

In summary, the evidence provided by our studies suggests that changes on cognitive load are related with variations in reading strategies. However, there are methodological issues that prevent us to interpret this relation that will be discussed at the end of this section.

The effect of reading strategies on cognitive load during reading

Cognitive load during reading was higher for both low and high knowledge readers when they followed a reading order with lower reading text coherence. This was true when we compared different reading orders achieved using the same decision rule (coherence) (Study II) and when we compare different reading orders achieved using two alternative decision rules (coherence vs. interest) (Study III). These results confirm DeStefano & LeFevre's prediction that when hypertext is processed in a low coherence reading order cognitive load increases. Although both studies show similar findings regarding cognitive load, there are differences in the specific dimensions of cognitive load affected by reading strategies. Whereas in Study II different reading orders achieved using the coherence strategy affected the intensity of cognitive load, in Study III different reading orders achieved using different decision rules (coherence vs. interest) affected the duration of cognitive load. These suggest additional methodological issues to be analysed below.

Methodological issues and analysis of contributions of structural cognitive load

Findings described in this section prompt two methodological issues regarding the measurement and interpretation of cognitive load in hypertext reading. First, there is the issue of the multidimensionality of the cognitive load construct (Xie & Salvendy, 2000). Different measures can be taken reflecting different aspects of cognitive load (intensity, duration, average or overall cognitive load, etc.), which can lead to different results. We adopted the approach known as the volume of attention hypothesis (Hidi, 1995; Reynolds, 1992) that states that both intensity and duration of cognitive load are relevant. When variations between conditions appear only in one dimension (higher intensity or duration), or in different dimensions in the same direction (higher intensity and duration), results are easy to interpret as an increase in cognitive load. However, when variations appear in two dimensions but in different directions (e.g. higher intensity but lower duration), the meaning of such results become hard to unveil. This question leads to the other methodological issue detected, that of the structural cognitive load: how to determine the specific contribution of each of the components (intrinsic, extraneous and germane) to the overall cognitive load measured? Are there different measures that can be associated to changes in each of the specific components?

These two issues have been acknowledged by other authors (Antonenko & Niederhauser, 2010; DeLeeuw & Mayer, 2008). DeLeeuw and Mayer (2008) suggested that different measures should not be assumed to measure overall cognitive load, but different structural types. Antonenko and Niederhauser (2010) recently claimed that one of the shortcomings of the Cognitive Theory is that, to the date, it was unable to use measurement techniques to differentiate between different types of load. They proposed that the specific contribution of extraneous and germane cognitive load can be deduced analyzing the result of cognitive level relative to comprehension performance.

In addition to this last claim, we propose that to get insight into the contribution of each load type during hypertext reading it is useful to add reading strategies to that analysis. The distinction made by Salmerón, Kintsch and Cañas (2006a) between text-induced and strategic influences of reading strategies can be useful. For low knowledge readers, the effect of reading strategies is mainly due to text coherence (text-induced). When readers follow a low coherence reading order they find coherence breaks that consume cognitive resources and lead to extraneous cognitive load (see McCrudden,

Schraw, Hartley & Kiewra, 2004 for a similar argument in linear text). For high knowledge readers there is a mixed influence of text-induced and strategic effects caused by active processing, which creates germane cognitive load either with a coherence or an interest strategy. With a coherence strategy readers are forced to use their prior knowledge to select links and subsequently they can overcome the shallow processing that they suffer when they read high coherent texts linearly. With an interest strategy the same text-induced coherence breaks that are harmful for low knowledge readers, lead to germane cognitive load by forcing them to use their prior knowledge to make bridging inferences.

Taken into account the evidence described above, we can deduce that increases in cognitive load for low prior knowledge readers in Studies II and III were mainly composed of extraneous cognitive load, whereas increases in cognitive load for high prior knowledge readers in Study III were mainly composed of germane cognitive load.

### **6.3. The role of user and system variables as predictors of user processing characteristics**

As user processing characteristics are the main variables affecting comprehension outcomes with hypertext, a principal objective of this thesis was to determine which user and system variables are related with those variables. In the following section we will discuss the evidence obtained on this issue.

#### ***6.3.1. The effect of user variables***

Our model proposes that reader' abilities and skills could predict reading strategies and cognitive load in hypertext. We assume that there are many different variables that can affect user processing characteristics, but we selected only a subset of them to test previous predictions and validate the model. Future research should continue examining the role of additional variables.

#### ***The role of prior knowledge***

Prior knowledge is a main factor determining comprehension, both with linear text (e.g. Ozuru, Dempsey & McNamara, 2009) and hypertext systems (e.g. Chen, Fan & Macredie, 2006; Mitchell, Chen & Macredie, 2005). It was hypothesized that prior knowledge could also determine reading strategies, since novice readers couldn't be



able to select an appropriate reading order, especially when using ill-structured hypertexts (Amadiou, Tricot & Marinee, 2010).

In Studies I and II prior knowledge was controlled by recruiting only novice participants, since the focus was set on analyzing the effect of other user (cognitive abilities) or system (number of links vs. navigation support) variables on the user processing characteristics and comprehension outcomes of low prior knowledge readers. Therefore, the direct effects of prior knowledge on reading strategies were not analyzed in these two studies.

In Study III the level of prior knowledge was manipulated by selecting participants with different backgrounds in order to obtain two groups of readers with noticeable differences between them. However, this manipulation affected comprehension outcomes but not their reading strategies. Difference with other studies that did find such effect of prior knowledge (e.g. Amadiou, Tricot & Mariné, 2009; 2010) may be due to the type of navigation system used (menu of links vs. interactive conceptual map). For example, Amadiou, Tricot and Mariné (2010) found that when using a hierarchical hypertext structure low prior knowledge readers followed a more coherent reading order than high prior knowledge readers, while the reverse relation was found when using a network hypertext structure.

An alternative explanation for this lack of results is that in our study participants received instructions to follow specific decision rules (i.e. coherence or interest strategies) and therefore this manipulation may have limited the effect of prior knowledge to their navigation behavior. It is still possible that the effect of prior knowledge in reading strategies arise in terms of the selection of the decision rules to follow and not in terms of the navigation behaviour to be performed. However, a recent study analyzing predictors of the selection of decision rules did not find any effect of prior knowledge level (Salmerón, W. Kintsch & E. Kintsch, 2010).

### **The role of cognitive abilities**

Several studies have demonstrated that some cognitive abilities (e.g. spatial abilities or working memory capacity) predict comprehension with hypertext (e.g. Chen & Rada, 1996; Lee & Tedder, 2004). Our model proposes that cognitive abilities not only affect comprehension, but also the user processing characteristics that mediate readers' comprehension.

The role of cognitive abilities was tested in Study I. Our aim was to investigate which specific cognitive abilities could predict specific reading strategy variables. From the set of cognitive abilities selected in that study, only spatial abilities showed to be significant as predictors. The importance of spatial abilities in navigation tasks has been shown by a number of studies (Blustein et al., 2009; Boechler, 2001; Fajardo, Salmeron, Cañas & Abascal, 2005; Mozorov, 2009). Their role in hypertext reading can be related with the visual processing of spatial representations as the interactive graphical overview showed in our study, but also with the construction of a hypertext structure mental representation for orientation and navigation (Naumann, 2009; Waniek, In Press).

Our study did not find a relation with other cognitive abilities as working memory span or logical reasoning. Differences with other studies can be caused by the specific hypertext system employed which stressed the importance of spatial factors through the use of the interactive graphical overview. Since reading strategies result from an interaction between user and system variables, it can be expected that other cognitive abilities can play a role in determining reading strategies with different hypertext systems.

The relation between cognitive abilities and cognitive load was not directly measured in Study I. However, since it has been suggested that the complexity of graphical overviews can increase the visual-spatial demands (DeStefano & LeFevre, 2007), it can be argued that the impairment in performance that was shown in Study I for participants with lower spatial abilities could be reflecting higher extraneous cognitive load in that experimental setting.

In this work we have focused on the role of user variables such as prior knowledge and some cognitive abilities. Moreover, the studies tested the effect of these variables in reading strategies in terms of navigation behaviour and not in terms of decision rules. It can be concluded that user variables play a role in hypertext reading. However, there are many other user variables that must be taken into account, like readers' self-regulation or motivation (Moos & Marroquin, 2010; Salmerón, W. Kintsch & E. Kintsch, 2010), which also may play a role in the adoption of decision rules for reading strategies. For example, Salmerón, W. Kintsch and E. Kintsch (2010) found that low prior knowledge readers used the coherence strategy for link selection more if they

set a high learning goal, use appropriate learning strategies or have an accurate calibration of comprehension

### ***6.3.2. The effect of system variables***

From the practical point of view of usability engineering, the objective is to determine the effect of different system variables on navigation and comprehension in order to design better hypertext systems (e.g. educational hypertexts) (Nielsen, 1993; Tullis & Albert, 2008). This topic is especially important since even the use of navigation aids originally conceived to facilitate navigation tasks could impose a cognitive burden on comprehension (Waniek & Ewald, 2008).

Three system features were considered in our studies: the number of links in the navigation system, the use of an interactive overview to access hypertext contents and the provision of link suggestions to offer navigation support. This section analyzes the role of each feature on reading strategies.

#### ***The role of number of links***

Does increasing the number of links affect reading strategies and cognitive load during hypertext reading? That is the prediction that could be extracted from the review from DeStefano and LeFevre (2007), and that was tested in Study II. On the one hand, increasing the number of links means to increase the probability of selecting a link unrelated with the previously read text (i.e. lower coherence reading order). On the other hand, the number of links can affect cognitive load directly by increasing the decision making requirements or indirectly through the reading order followed.

An effect of number of links on reading text coherence was found. Even when all participants were instructed to follow a coherence strategy, low prior knowledge readers who used a 8-links hypertext seem to follow a less coherent reading order than those who used a 3-links hypertext. This result is an example of the distinction between reading strategy as decision rule and reading strategy as navigation behaviour: even when all participants received instructions to follow the same decision rule (i.e. to select the link more related with the previous read content) their success in fulfilling it depended on system variables such as the number of links.

Regarding cognitive load, it was argued that it could be affected by a higher number of links both directly (by increasing decision making requirements) and

indirectly (by leading to a low coherent reading order that subsequently produces higher cognitive load). Here we focus on the direct effect of this variable, since the indirect effect through reading strategies was analyzed in the previous section.

Contrary to our expectations, Study II did not show a direct effect of number of links on cognitive load during link selection, but it was related with the ability of readers to select the proper link. That is, as already discussed, readers that were less successful in following a coherence strategy experienced higher cognitive load during link selection either with 3 or 8 links per page. This result suggests that there are other non-controlled variables that may influence the difficulty of link selection and therefore the experienced cognitive load. For example, in the context of the MESA model on information architecture, Miller and Remington (2004) proposed that the quality of link labels is a key element in the assessment of links' relevance for users' goals.

### **The role of link suggestions**

To find the most relevant link for user goals within a set is not an easy task. Even if readers were able to select the appropriate decision rule for selecting links, factors as labels relevance, readers' prior knowledge or the number of competing links can affect their success in selecting the right link (Fu & Pirolli, 2007; Kitajima, Polson & Blackmon, 2007; Miller & Remington, 2004).

Some authors suggested that providing readers with a navigation tool based on semantic similarities could improve the development of coherence strategies for less skilled users, and therefore enhance their comprehension (McNamara & Shapiro, 2005; Salmerón, Kintsch & Cañas, 2006b). Confirming this prediction, Study II showed that when link suggestions based on semantic similarities were offered, low prior knowledge readers followed a reading order with higher reading text coherence and subsequently achieved a better situation model.

We further proposed that link suggestions based on semantic similarities could also benefit readers by reducing cognitive load. However, even when link suggestions enhanced reading text coherence and learning they did not show an influence on the overall cognitive load experienced. Therefore, link suggestions affected cognitive load indirectly through reading strategies but there was not a direct effect of providing

support on cognitive load. The role of link suggestions can also be seen in terms of efficiency of the cognitive resources invested. Using link suggestions can guide readers attention to a sub-set of items for which the available cognitive resources can be used to make a decision, whereas without such navigation support the same amount of resources have to be distributed between more options. Ozcelik, Arslan-Ari and Cagiltay (2010) recently found support for a similar argument. In a study using eye-tracking methodology with multimedia materials, they signalled the most relevant parts of the materials by changing the colour of the items. They found that signalling guided learners' attention which allows them to use more of their processing resources for high order cognitive processes.

Summarizing, we argue that link suggestions do not reduce overall cognitive load directly, but allow readers to perform a better reading strategy for comprehension by focussing processing resources to a reduced set of relevant options.

### **The role of interactive graphical overviews**

There is some evidence pointing out that hierarchical graphical overviews can be useful to reduce disorientation and cognitive load and to support the development of highly coherent reading paths (Amadiou, Tricot & Marinee, 2009; 2010; McNamara & Shapiro, 2005). In Study I readers used a hierarchical interactive graphical overview to access hypertext contents. However in that study this system variable was not manipulated but rather we measured the reading strategies that participants followed when using it. But even so, some ideas can be extracted from the use that readers made with that system. For example, as already discussed, its effectiveness for comprehension depends on readers' spatial abilities so it can be hypothesized that graphical overviews with less spatial cognitive demands will cause less cognitive load to readers, who will perform a reading order more similar to hypertext structure and therefore will comprehend the text better. However, this last prediction has to be confirmed in future experiments comparing different types of interactive overviews varying in their level of visuo-spatial demands.

As a summary of this section, the results showed that reducing the complexity of navigation systems allow readers to follow an appropriate reading strategy to reduce extraneous cognitive load and to comprehend the information from the hypertext.

## 6.4. Conclusions

The extensiveness of hypertext use, mainly due to the popularization of Internet, has revealed the importance of conducting research on hypertext comprehension. Since hypertext is replacing linear text in important areas as education, important topics are how readers comprehend information in hypertext systems and which new skills or abilities are involved in their use for comprehension and learning. Research effort comes from the fields of cognitive psychology, human computer interaction or literacy research (Amadiou, Tricot & Marinee, 2009; Coiro, 2009; Potelle & Rouet, 2003; Salmerón, Kintsch & Cañas, 2006a).

In this context, the aim of this work was to progress towards a hypertext comprehension model by focusing on the role of user processing characteristics. User processing characteristics, as reading strategies and cognitive load, are very important variables to explain comprehension and learning with hypertext systems. The model described can be used as a framework for conducting research on hypertext comprehension. In this framework, the three main ideas are:

(1) Hypertext comprehension has to be analyzed in relation with user processing characteristics: a) the reading strategy followed by the reader and b) the cognitive load associated with hypertext reading.

(2) A mutual influence mechanism between reading strategies and cognitive load has to be supposed.

(3) Cognitive load and reading strategies, as user processing characteristics, have to be explained by an interaction between user variables (such as spatial abilities) and system variables (such as the number of links per page or the provision of navigation support).

Next, the main implications of using this model are summarized at theoretical, methodological and practical level.

### 6.4.1. *Theoretical implications*

From a theoretical point of view, the results show that, in order to explain comprehension outcomes, the most important variables are those that characterize the

behaviour (reading strategies) and cognitive processing (cognitive load) of readers during hypertext reading. In replication of previous studies on hypertext comprehension, low prior knowledge readers achieved better comprehension when they read all hypertext contents and followed a higher coherence reading order (by using a coherence strategy and following it as much as possible). When using a graphical overview to access contents it is also important to devote time to the text contents and not to the navigation tool. Definitively, following a high coherence reading order also decreased (extraneous) cognitive load. For high prior knowledge readers, our research supports the idea that they can adapt to different reading strategies and cognitive load levels in hypertext without affecting their comprehension.

Which variables can predict the development of these user processing characteristics? For low prior knowledge readers, it was shown that spatial abilities are key user variables to predict reading strategies when using a graphical overview. Users with higher spatial abilities showed a pattern of user processing characteristics related to better comprehension, that is, a coherent reading order that follows the structure of the hypertext, shorter times of overview use and a higher amount of different pages accessed. System design variables are also relevant, and using hypertext with less number of links and/or providing link suggestions has shown to promote the selection of a reading order with higher coherence.

Regarding cognitive load, this work demonstrates that the most relevant variables are those related with reading strategies. Both low and high prior knowledge readers who read a hypertext in a low coherence reading order experienced higher cognitive load during reading. It seems that the increase of cognitive load was composed of extraneous cognitive load for low knowledge readers, whereas for high knowledge readers it is composed of germane cognitive load. Following different decision rules also affected cognitive load related with decision making in link selection, although this effect can be better interpreted as a change in the tradeoff between intensity and duration of cognitive load and not as an increase or decrease in the overall amount of cognitive resources needed.

#### *6.4.2. Methodological implications*

In the process of conducting the three studies presented some methodological issues arrived. Some of them have been fixed, both there are others that still remain and should be a matter of future research.

##### Reading strategies: decision rules and navigation behaviour

Reading strategies in hypertext have been defined as decision rules for selecting which contents to read and in which order. Their importance has been showed in this thesis, replicating previous studies, which suggests that they have to be controlled in hypertext comprehension research. However, the relation between the decision rule and the navigation behaviour performed is not straightforward. Very similar navigation behaviour can be achieved by two readers using very different reading strategies and, conversely, completely different navigation behaviour can result from using the same decision rule. There is not an easy procedure to explore the effect of both aspects of reading strategies. We choose to use a combination of approaches to control and manipulate decision rules (free navigation, coherence strategy, coherence vs. interest strategy) while measuring navigation behaviour. In this measurement, it was very useful to apply the LSA technique for obtaining a reading text coherence measure.

Future research should find new procedures to measure separately the antecedents and consequences of both aspects of reading strategies. In this sense, Salmerón, W.Kintsch and E. Kintsch (2010) have proposed an interesting procedure to analyze predictors of the selection of different decision rules for link selection in hypertext.

##### Cognitive load: measures and interpretation of structural cognitive load

An important methodological improvement in two of the studies presented is the direct measurement of cognitive load associated with hypertext reading (Brunken, Plaas & Leutner, 2003). This has been done by using the dual-task paradigm, measuring RTs to secondary task while performing different hypertext tasks (reading vs. selecting links). This measure of the intensity of cognitive load was complemented with measure of duration of cognitive load (reading and link selection times). Although the information obtained was useful (particularly when coupled with comprehension results) there are still two methodological issues that have to be resolved for the advance



of the Cognitive Load Theory (Antonenko & Niederhauser, 2010; DeLeeuw & Mayer, 2008). First, different cognitive measures seem to tap different dimensions of cognitive load (intensity, duration, overall cognitive load, accumulated cognitive load, etc.) (Xie & Salvendy, 2000). Second, at this moment there is no evidence indicating that any of these measures is able to evaluate different structural components of cognitive load (i.e. intrinsic, extraneous and germane cognitive load). We propose that the contribution of each specific type of cognitive load can be deduced from the pattern of reading strategies, cognitive load measures and comprehension outcomes.

#### *6.4.3. Practical implications*

At the beginning of this thesis we argued for the importance of hypertext comprehension research, referring to the increasing use of hypertext as a learning and communication medium. Findings from this thesis can be used to inform the practice in two different applied disciplines: instruction and usability engineering.

##### Implications for usability engineering

There are several applications of the studies described in this thesis to the field of Web usability engineering:

**1. Measures of usability.** One of the main goals of usability engineering is to determine the easiness of use of a certain Website (e.g. Tullis & Albert, 2008). One of the most used techniques is to record user logs during Internet use, in order to analyze and interpret user behavior. However, performance measures as time of use, number of mouse clicks, navigation pattern, etc. are useless without a proper theoretical model that allow for data interpretation. The specific contribution of this thesis is to provide a set of online measures of reading strategies use that, together with a theoretical background, can be used to predict the comprehensiveness or learnability of a certain Website. For example, the reading text coherence achieved by a set of users and the number of information nodes accessed can be used to compare two different hypertext designs in terms of their appropriateness for readers with low prior knowledge.

**2. Usability guidelines for the comprehensibility of websites.** Beyond usability evaluation, it is possible to provide some design guidelines to be used by hypertext designers:

- Graphical overviews are useful to access the different pages, but limit their visuo-spatial complexity.
- On a certain page, include links only to those other pages sharing arguments or ideas with it.
- If the number of links on a page is high, provide design signals to be used as suggestions or cues about their relatedness with the current page. Some techniques are highlighting, grouping, signaling, etc.
- For those pages aimed at high prior knowledge users, a navigation system emphasizing free exploration based on personal interest is appropriate. For those pages aimed a user with less prior knowledge of the topic, a more linear navigation system emphasizing a coherent line of ideas is preferred

**3. Adaptive navigation support.** The aim of adaptive hypermedia is to adapt the presentation and functioning of Web systems to the goals, preferences or prior knowledge of each specific user (Brusilovsky, 2001; 2007). Adaptive navigation support techniques alter the appearance of links, using such methods as direct guidance, link hiding and removal, or link annotation. Evidence from this thesis suggests that, starting from a user model, it is possible to adaptively offer navigation support. Some examples:

a) For low prior knowledge readers, it is possible to offer link suggestions based on semantic similarity indexes obtained with LSA. These link suggestions can be disabled when a high prior knowledge reader accesses the system (or in consecutive learning sessions of the same reader).

b) The hypertext system can adapt to spatial abilities (or other cognitive abilities previously tested). For example, for high spatial ability readers a graphical overview can be offered, whereas a textual menu can be shown to readers with lower spatial ability.

#### Implications for instruction

It has been claimed that there is a need of new online digital literacy at school, since some students lacks the ability to comprehend online information properly (Coiro, 2009). Reading or learning strategy training seems to be a feasible method to improve the reading skills of hypertext readers (Azevedo & Cromley, 2004; McNamara & Shapiro, 2005). Based on the information obtained in this thesis, it is recommended to improve the ability of low prior knowledge readers of monitoring inter-documents

coherence in order to follow coherence strategies. For high prior knowledge readers, it is less important which specific strategy to follow but it is recommended to adopt an active processing approach for link selection.

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## **APPENDIX I.**

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*The following manuscript has been submitted to a journal:*

Madrid, R.I., Salmerón, L. & Cañas, J.J. (*Submitted*). The role of cognitive abilities as predictors of hypertext reading strategies and their effect on comprehension.



### **Abstract**

*This research investigated the relation of cognitive abilities to students' hypertext reading strategies and their effect on readers' comprehension. In an experiment, readers used an interactive overview to read and to comprehend the information contained in a set of hypertext pages. Results revealed that two spatial ability factors (Speed of closure and Spatial scanning) predicted reading strategy variables such as Reading order similarity to overview, Number of nodes accessed and Overview usage time. Additionally, reading strategy variables were related to readers' hypertext comprehension. These results are discussed and some practical implications for hypertext and instructional design are drawn.*

**Keywords:** hypertext comprehension; reading strategies; cognitive abilities



## 1. INTRODUCTION

One of the main advantages of hypertext over linear text is that it allows readers to easily access different sources of information on a particular topic. A number of studies claim that the use of hypertext speeds up information search and engages readers in deep information processing. However, literature reviews over the last two decades did not find a general benefit of hypertext use on comprehension or learning when compared with linear text use (Chen & Rada, 1996; DeStefano & LeFevre, 2007; Dillon & Gabbard, 1998; Shapiro & Niederhauser, 2004).

To explain that lack of general advantages we should examine those processes that take part in hypertext use, and exceed in complexity those of linear text reading. When readers use hypertext they also have to read text pages as in linear text reading, but in this case they have to navigate between the different information units that compose it, following a path guided by the specific goal for which they are using the hypertext. Kim and Hirtle (1995) classified cognitive tasks related to hypertext use into three groups: informational tasks, navigation tasks, and tasks management. Informational tasks are needed to comprehend the text presented in the hypertext system. Navigation and management tasks are performed to access the information units distributed among the different nodes and to coordinate information accessing and reading tasks. Informational tasks in hypertext are very similar to reading linear text, but, by contrast, readers are continuously interrupted to carry out navigational tasks such as searching, locating, selecting and clicking the desired links, which requires readers to perform complex cognitive actions (de Jong & van der Hulst, 2002).

In this context, the research referred to in the present paper starts from a general question: what are the variables that could predict comprehension when using

hypertext? Reviewing hypertext comprehension studies shows that the number of factors related to hypertext use tends to be higher and also to interact with each other, making it difficult for any single variable to have strong effects on comprehension (Shapiro & Niederhauser, 2004). These factors can be grouped into two sets of variables: system variables and user variables. System variables refer to hypertext features related to system design, such as text structure, hypertext structure, navigation tools, use of multimedia material, and so on. User variables include prior knowledge, experience with computers and hypertext, metacomprehension abilities, spatial abilities, memory span, cognitive styles, and so on.

Additionally, recent research suggest that the relation between user and system variables and comprehension outcomes have to be examined in the context of the specific reading strategy that readers develop to move through the hypertext system, since it determines the way in which a hypertext is comprehended (Salmeron, Cañas, Kintsch & Fajardo, 2005; Salmeron, Kintsch & Cañas, 2006).

However, little is known about which user and system characteristics determine hypertext reading strategies. In this study we will examine user characteristics, analyzing in the experiment reported the relations between a set of cognitive abilities, reading strategies and hypertext comprehension.

### **1.1. The role of cognitive abilities in hypertext reading**

DeStefano & LeFevre (2007) reviewed studies on cognitive load in hypertext reading, concluding that hypertext introduces new requirements that increase working memory demands when compared with traditional linear texts. The cognitive requirements of the interaction with hypertext systems are claimed to be responsible for certain problems and disadvantages of hypertext reading, such as disorientation and

cognitive overload (Boechler, 2001; Dias & Sousa, 1997; McDonald & Stevenson, 1996; Ransom, Wu & Schmidt, 1997).

From the point of view of the Cognitive Load Theory (Sweller, van Merriënboer & Paas, 1998), system and user variables interact to determine the cognitive load level of the task. For adequate comprehension and learning, cognitive load has to remain within the limits of the working memory capacity, since if it is exceeded by the task's cognitive requirements, knowledge acquisition could be impaired. Regarding user variables, cognitive load has been proposed to be dependent on the users' cognitive abilities: a task with high cognitive requirements is more demanding for individuals with low cognitive abilities than for those with high cognitive abilities (Gonzalez, 2005). Therefore, comprehension difficulties would appear if task requirements in hypertext reading are high or users' cognitive abilities are low (DeStefano & LeFevre, 2007).

Cognitive abilities that have been cited in the literature as having a role in hypertext use are spatial abilities (Dahlbäck & Lönnqvist, 2000; Juvina & Van Oostendorp, 2004; Juvina & Van Oostendorp, 2008), working memory (Juvina & Van Oostendorp, 2004; Lee, Tedder & Xie, 2006; Tardieu & Gyselinck, 2002) and logical reasoning (Kim & Allen, 2002; Westerman, et. al., 1995).

*Spatial abilities.* Several studies have suggested the implication of spatial cognition on hypertext navigation. Spatial cognition refers to an ability that comprises the knowledge and the mental representation of spatial structure (Liben, 1981). In the context of hypertext research, the spatial cognitive component of navigation can be defined as an ability that covers the knowledge and mental representation of the hypertext structure, together with knowledge about how to use this information for task

performance, and the capability of thinking on the mental representation of the hypertext. According to Juvina and van Oostendorp (2008), “the ability to mentally represent and manipulate information spaces is critical for Web navigation tasks”. Dahlbäck, Höök and Sjölander (1996) found a strong correlation between the performance on image rotation tests and the timing of navigation tasks. Juvina and van Oostendorp (2004) also found that users’ spatial abilities predicted performance with hypertext: the higher the spatial abilities, the fewer the page revisits, less use of back button and the better the task outcomes. These results are consistent with the data of the meta-analysis performed by Chen and Rada (1996) that showed an effect of spatial abilities on hypertext efficiency measures. Evidences also exist supporting the claim that people with high spatial abilities can visualize better the way in which hypertext information is organized than people with low spatial ability (Höök & Dahlbäck, 1997), and that they can learn the hypertext structure in a better way (Nilsson & Mayer, 2002).

*Logical reasoning.* In the context of Web searching behavior, Kim and Allen (2002) proposed that information seeking in hypertext is a task that requires problem solving, and therefore logical reasoning abilities could be involved on search tasks. Westerman et al. (1995) also found a relation between the performance on a logical reasoning test and the performance on information retrieval tasks.

*Working memory.* The requirements of working memory resources seem to be greater in hypertext than in linear text (Conklin, 1987; Tardieu & Gyselinck, 2002). Naumann, Waniek, Brunstein and Krems (2003) proposed that high working memory load in hypertext reading would lead to more navigation problems and less acquired knowledge, since navigation in hypertext uses up working memory resources and working memory capacity is limited. Furthermore, when graphics, images and other

media are embedded in hypertext (i.e. hypermedia or multimedia) the cognitive requirements of the task increase. For example, Tardieu and Gyselink (2002) have demonstrated that when using multimedia materials users are subject to additional constraints to working memory when integrating and comprehending information.

Taking into account the evidence shown above, it could be hypothesized that hypertext users with higher cognitive abilities (e.g. higher spatial abilities, logical reasoning or working memory span) will have a better performance and comprehension with hypertext systems than those with lower cognitive abilities. However, at this moment is not clear what adequate hypertext performance is and how it can lead to good comprehension outcomes. One of the main hypertext characteristics is that readers have to choose their own reading strategy to access fragments or pages contained in the hypertext, which could subsequently affect comprehension. Indeed, we assumed that readers' reading strategies are a main factor that could determine comprehension and learning outcomes. In the next section, we will describe the relations between readers' reading strategies and text comprehension processes when using hypertext.

## **1.2. The role of reading strategies on hypertext comprehension**

### ***1.2.1. Text comprehension and hypertext***

Navigation is the main activity that users perform for information retrieval with hypertexts. During navigation a person starts on a certain information unit (or page) and continues through the links that lead from that page to other information units. Very frequently, people navigate with the goal of comprehending the information they find and acquiring knowledge from it, and in that case we are talking about hypertext comprehension or learning. This is the case of hypertext systems used on hypermedia learning environments (Dias & Sousa, 1997).

State-of-the art discourse comprehension theories (Graesser, Millis & Zwaan, 1997; Kintsch & van Dijk, 1978; Van Dijk & Kintsch, 1983; Kintsch 1998) state that text comprehension implies the construction of several types of mental representations. Regarding comprehension and learning, the main representations are the textbase (a representation of the propositions included in the text) and the situation model (in which the textbase is elaborated with prior knowledge to build a rich representation of the situation described in the text).

There are several factors involved in text comprehension, but prior knowledge and text coherence are the main ones. It can be said that text coherence exists when two propositions of a document share arguments and are therefore semantically related. Research results have shown that the degree of coherence of a text has different effects on comprehension depending on the prior knowledge level of the reader. If the reader has not an adequate level of prior knowledge, the constructive processes that are needed for comprehension can be impaired or limited when low coherence texts are used. When readers with low prior knowledge read a highly coherent text they construct better situation models than when they read a low coherence one. If two text propositions do not share arguments, bridging inferences must be carried out by accessing background knowledge in order to fill the lack of information, which uses up cognitive resources. Regarding high knowledge readers, they are able to construct better situation models when they read a low coherent text. This can be explained by assuming that for readers with higher prior knowledge, coherence gaps instigate them to make inferences. As a result they are able to build rich elaborations and compensate the lack of explicit information with a deeper processing at situation model level (McNamara, E. Kintsch, Songer & W. Kintsch, 1996; McNamara & Kintsch, 1996).

But does hypertext comprehension and learning involve the same cognitive processes as linear text? It has been argued that basically the same text comprehension processes involved in linear text are involved in hypertext reading. However, nonlinearity - the main feature of hypertext - affects text coherence through the selection of the reading order. If novice readers' lack of knowledge, their inexperience with computers or disorientation makes them perform a reading strategy that leads them to a low coherence reading order, comprehension will be impaired. For that reason, reading strategies have to be examined in order to explain comprehension outcomes when readers use hypertext systems. We will discuss this issue in the next section.

### ***1.2.2. Reading strategies in hypertext***

Readers faced with an expository text in hypertext have to develop a particular strategy in order to decide what information will be read and in which order. Reading strategies determine the navigation pattern of the reader and has been shown to be a major variable affecting comprehension on hypertext systems (Foltz, 1996; Salmerón et al. 2005; Salmerón, Kintsch & Cañas, 2006).

For example, Salmerón et al. (2005) examined readers' navigation behavior and comprehension when using an interactive overview to access an expository hypertext. They showed that people using different reading strategies performed different reading orders and, as a consequence, the situation model acquisition was affected. Additionally, readers that followed a given strategy did choose nodes to read that were based on their interests, goals or time constraints, affecting the amount of information read which determined textbase construction (Lawless & Kulikowich, 1996; Salmerón et al., 2005) but not situation model construction (Salmerón et al., 2005).

Therefore, different reading strategies may lead to different reading orders, varying the global coherence and amount of text read and, subsequently, affecting knowledge acquisition (Naumann & Krems, 2005; Salmerón et al, 2005). The effect of reading order on hypertext comprehension seems to depend on the level of prior knowledge of the reader, a reading order with higher text coherence being better for low knowledge readers.

However, little is known about why hypertext readers perform one particular reading strategy over another. We assume that reading strategies are influenced both by system and user variables.

Hypertext system features, such as the availability of navigation support tools, could assist readers by suggesting certain reading strategies. One way of giving such navigation support in hypertext is through interactive overviews that convey text structure and serve as tools to select the next document to read. Hypertext comprehension researchers have also proposed that the visualization of the hypertext structure provided by these interactive overviews could enhance their mental representation (Dee-Lucas & Larkin, 1995; Shapiro, 2000; Waniek, Brunstein, Naumann & Krems, 2003). Regarding user variables, the present study proposes that the development of a specific reading strategy may also rely on individual differences in certain cognitive abilities that could determine the way in which readers use hypertext features (e.g. interactive overviews) and therefore their specific navigation behavior. To support this hypothesis, the experiment described below examines which cognitive abilities could predict reading strategy variables, and how they can subsequently affect hypertext comprehension.



## 2. METHOD

The main goal of this research is to examine the relation between cognitive abilities and the reading strategies of low prior knowledge readers when using an interactive graphical overview, and their effect on comprehension. To know which specific cognitive abilities are involved in hypertext use could help to develop better navigation systems that accommodate human cognitive constraints and enhance comprehension.

Our research questions are as follow:

*What is the role of cognitive abilities as predictors of reading strategies?*

As a summary of the literature reviewed in the introduction, it can be predicted that cognitive abilities will be related with hypertext performance and learning, and that readers with better cognitive abilities (high spatial abilities, working memory span and logical reasoning) will follow a better reading strategy than those with less cognitive abilities. But, how can a “good” reading strategy in this context be characterized? Being the goal of the reader to comprehend the information conveyed in the hypertext system, a good reading strategy will be one that leads to high comprehension and learning. This argument brings us to the next question.

*What are the reading strategy variables that can predict comprehension outcomes?*

As stated in the introduction, reading strategies can be considered main factors affecting comprehension and learning with hypertext systems. Specifically, the amount of information read (number of hypertext nodes accessed) is related with textbase acquisition while reading focused on the construction of text coherence is related with situation model construction.

Next to confirming the relation between these variables, the experiment will explore the role of interactive overviews use on hypertext comprehension through two additional variables: the *Reading order similarity with overview* (the degree in which the reading order followed by the reader maps the interactive overview structure) and the *Overview usage time* (the time spent looking at the interactive overview and selecting the next link to follow). These two variables may play an important role when using interactive overviews since both reflect cognitive processes related to orientation and navigation.

## **2.1. Method**

### **2.1.1. Participants**

In this experiment, we recruited fifty two undergraduate Psychology students from the University of Granada who received extra class credits for their participation. Data from one participant were excluded from the analyses because of his inability to follow the experimental instructions.

The mean age of the participants was 21.35 (SD = 1.93), there was 37 female and 14 male students.

### **2.1.2. Materials**

#### *2.1.2.1. Prior Knowledge*

The topic of the text (*Atmospheric pollution*) was mainly unfamiliar for Psychology students; however some differences in their prior knowledge could be relevant. Therefore, participants filled in a prior knowledge questionnaire with ten general multiple choice questions about atmospheric pollution. An example of these questions is:

*The increase of the greenhouse effect is responsible of ...*

*a) the ozone layer hole*

*b) the climate change*

*c) the air pollution*

### 2.1.2.2. Hypertext

We used an expository text on “Atmospheric pollution” in Spanish, with 4.792 words (section titles included), organized into 27 nodes. Text nodes were accessed through an interactive overview which showed the hierarchical relations between the different sections (See Figure 1). After participants read each node, they had to return again to the interactive overview in order to choose the next hypertext node to read.

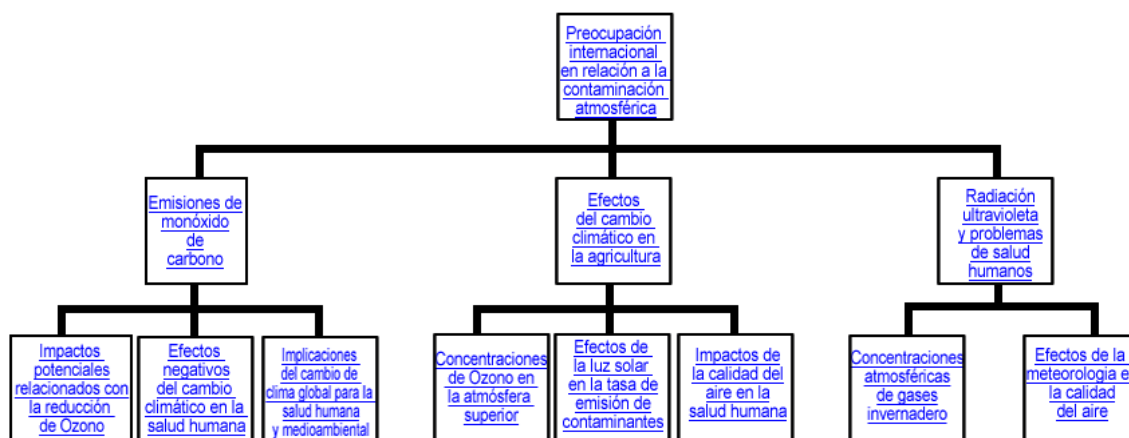


Figure 1. Fragment of the interactive overview used in the experiment

### 2.1.2.3. Cognitive tests battery

Participants filled in a set of tests from the *ETS – Kit of Factor Referenced Cognitive Tests* (Ekstrom, French, Harman, & Derman, 1976). Five cognitive tests were selected: Hidden figures test, Maze tracing speed test, Gestalt completion test, Visual number span test and the Nonsense syllogisms test. These tests assess those cognitive

abilities selected for analysing their relation to hypertext use (working memory capacity, logical reasoning and spatial abilities).

*Hidden figures test (CF-2)* measures a spatial ability factor called *Flexibility of closure*, which is defined as “the ability to detect figural stimuli within a similar figural context”. It has been also used to measure the cognitive style called field dependence / independence (Rittschof, In press).

*Maze tracing speed test (SS-1)* assesses *Spatial scanning* ability, needed to perform speeded visual exploration of a complicated visual array. Participants have to trace a path from the start to the end of a set of moderately complex labyrinths. It is considered a spatial ability test.

*Gestalt completion test (CS-1)* is used to assess *Speed of closure*, a subcomponent of spatial ability needed to integrate related parts of figural stimuli into an identifiable whole.

*Visual number span test (MS-2)* is a *Memory span* test, which uses numbers as visual stimuli. In the context of this test, the memory span is defined as the ability to recall a number of distinct elements for immediate reproduction. For the presentation of the stimuli it was used a computerized version instead of the classic paper cards presentation.

*Nonsense syllogisms test (RL-1)* assesses a factor called *Logical reasoning*, the ability for reasoning from a premise to its conclusion. The test includes a set of formal syllogisms without meaning which correctness can be assessed without prior knowledge.

#### 2.1.2.4. Reading strategies: User navigation metrics

Data extracted from user behaviour during hypertext reading can be analyzed taking into account various levels of meaning. We take the approach proposed by Juvina and van Oostendorp (2004) who suggested a distinction between syntactic, semantic and pragmatic information. Syntactic information includes how users move through the hypertext, which links they follow, in which order, etc. Semantic information refers to the meaning of the information that users read and process. Pragmatic information is related to user goals, interests, preferences, etc. In our data analyses we use both syntactic and semantic information, which can be used to characterize participants' reading strategies.

We extracted three syntactic measures from user navigation logs: *Number of different nodes accessed*, *Overview usage time* and *Reading order similarity with overview*. We include one semantic measure: *Reading text coherence*.

*Number of different nodes accessed.* It is the amount of different text nodes that the participant read.

*Overview usage time.* It is the percentage of total time that the reader was examining the overview in order to select links during the overall session.

*Reading order similarity with overview.* To test the degree in which the readers' reading order fit the spatial organization of the interactive overview, we used a measure obtained by dividing the number of user's node transitions that were suggested in the interactive overview by the number of total transitions made by the user. A transition was considered to be suggested by the interactive overview when a first order hierarchical relation between two nodes was shown by a link in the overview's spatial layout.

*Reading text coherence.* To obtain semantic information from navigation raw data we also used a computational method called LSA (Latent Semantic Analysis) (Landauer, Foltz, Laham, 1998; see <http://lsa.colorado.edu>). LSA have been used to test semantic similarity between two documents. In the field of web navigation it has been used to characterize semantically user navigation behaviour (Kitajima, Blackmon & Polson, 2000; Juvina & Van Oostendorp, 2008). In our experiment, we used LSA to extract a measure representing the coherence of the participant's reading order: in every node transition we computed the LSA cosine between the new text node and the previously read one. At the end of the session we combined the data of all transitions to obtain the mean LSA cosine from the readers' reading order. This measure (*Reading text coherence*) has been used successfully to predict comprehension outcomes with hypertext in previous research (Salmerón et al. 2005; Salmerón, Kintsch & Cañas, 2006).

#### 2.1.2.5. Comprehension outcomes

*Text-based questions score.* After the hypertext reading task finished, participants took a test with 22 multiple choice questions, for which the answer and the question were located in the same node and therefore making inferences was not required. Each question was related to the contents of a different node. An example of textbase questions:

*The vertical layers of the atmosphere affects ...*

- a) *ozone reduction*
- b) *air quality*
- c) *climate change*

Relatedness judgment task score. Participants had to judge the relation between 91 pairs of concepts (as a result of the combination of the 14 most relevant concepts in the text), using a scale from 1 to 6, in which 1 means “Low related” and 6 means “High Related”. A Ph. D in atmospheric science performed this task as an expert, and his score was used as reference, applying Pathfinder algorithm to the rating matrix of every participant, and comparing the resulting Pathfinder network with the one from the expert. Pathfinder is a technique that can provide a measure of the similarity of two conceptual networks (see Dearholt & Schvaneveldt, 1990) and that has been shown useful to measure comprehension at situation model level (Britton & Gülgöz, 1991).

An example:

*What is the relation between the following pair of concepts?*

*Stratosphere – CFC's*

*Low related    1 – 2 – 3 – 4 – 5 – 6    High related*

Inference questions score. Participants had to complete a ten multiple choice questions questionnaire. To answer this type of questions it is required to relate information contained in at least two nodes. Therefore this task was also intended to assess comprehension at situation model level. An example:

*The wind could negatively influence ...*

- a) air quality and ozone reduction*
- b) air quality and greenhouse effect*
- c) air quality and climate change*

### **2.1.3. Procedure**

The experiment was run in two sessions. The first session was devoted to fill in the set of cognitive tests. Four of them were paper and pencil tests, and the other one (Visual number span test) was administered using a computer presentation.

In the second session, participants had to perform the hypertext reading task and the comprehension testing tasks. First, participants filled in a questionnaire with 10 multiple choice questions to measure their prior knowledge. After that, they were instructed on how to use the hypertext and asked to read the hypertext content for 20 minutes. In the instructions it was made clear that they had to read the text for comprehension, since after the reading phase they had to answer some questions to measure their grade of learning.

At the beginning of the hypertext reading task the interactive overview representing the relations between nodes was presented to choose the node to read first. After clicking on the desired link, the corresponding node content was showed. At the bottom of the screen a button appeared to return to the interactive overview and then to choose a link corresponding to another node to read. After 20 minutes, a pop up window informed the participants that the reading time was ended, and they got instructions to perform the relatedness judgment task. Finally, participants had to fill in a 22 multiple-choice questionnaire aimed to measure knowledge acquisition at textbase level, and a 10 multiple choice questionnaire aimed to measure situation model construction.

## **2.2. Results**

### **2.2.1. Prior Knowledge Analysis**

Preliminary data analysis revealed that, according to the prior knowledge questionnaire, the sample had a low prior knowledge level ( $M = 3.63$ ,  $SD = 1.53$ , only 11.54 % of the participants answered correctly more than half of the questions). Even



so, we included the score on the questionnaire as predictor in the following analysis for control purposes.

### 2.2.2. Cognitive Abilities as Predictors of Reading Strategies

We analyzed the relation between the score on the five cognitive tests (i.e. those selected from the ETS-Kit) obtained in the first session of the experiment and the participants' reading strategies performed during the second session. We used SS-1, CF-2, MS-2, RL-1 and CS-1 tests and *Prior knowledge score* as predictors and reading strategy variables as dependent variables (i.e. *Number of different nodes accessed, Overview usage time, Reading order similarity with overview and Reading text coherence*).

Table 1 shows the correlations of all test's scores. Statistically significant correlations were found between SS-1 (Maze tracing speed test, *Spatial scanning*) and two other tests: CS-1 (Gestalt completion test, *Speed of closure*) and CF-2 (Hidden figures test, *Flexibility of closure*). This is an expected result since these tests measure different subcomponents of spatial abilities. Other significant relation was found between CF-2 and MS-2. In this case, evidence exist that flexibility of closure involves also working memory processes (Gwizdka & Chignell, 2004).

**Table 1. Correlations between cognitive abilities tests (n=51)**

	CF-2	CS-1	RL-1	SS-1	MS-2
CF-2	1.00	0.25	-0.12	0.37*	0.32*
CS-1	0.25	1.00	0.10	0.43*	0.03
RL-1	-0.12	0.10	1.00	0.26	-0.17
SS-1	0.37*	0.43*	0.26	1.00	0.02
MS-2	0.32*	0.03	-0.17	0.02	1.00

Note: \* p < .05

*Reading strategy variables: Syntactic measures*

*Number of nodes accessed.* Regression analyses were performed using cognitive tests scores and prior knowledge as predictors and *Number of different nodes accessed* as dependent variable. As can be seen in Table 2, stepwise regression analysis showed that the only significant predictor was the score on the Maze tracing speed test (SS-1, *Spatial scanning*) ( $R^2 = .12$ ; with a *Beta* of 0.373,  $p < .05$ ), the higher SS-1 score, the more different nodes were accessed.

**Table 2. Summary of the regression analysis for cognitive abilities predicting Number of nodes accessed (n=51)**

Variable	B	SE B	Beta	t
Step 1				
Spatial Scanning (SS-1)	0.386	0.139	0.241	1.736
Step 2				
Spatial Scanning (SS-1)	0.453	0.229	0.282	1.974
Logical Reasoning (RL-1)	-0.268	0.236	-0.162	-1.134
Step 3				
Spatial Scanning (SS-1)	0.598	0.250	0.373	2.398 *
Logical Reasoning (RL-1)	-0.349	0.146	-0.212	-1.450
Flexibility of Closure (CF-2)	-0.055	0.152	-0.213	-1.407

**Note.**  $R^2 = .058$  for Step 1;  $\Delta R^2 = .024$  for Step 2;  $\Delta R^2 = .037$  for Step 3; \*  $p < .05$ ; Predictors: PK, CS-1, CF-2, SS-1, RL-1, MS-2

*Reading order similarity with overview.* The score on the Gestalt completion test (CS-1, *Speed of closure*) was found to be the only predictor of *Reading order similarity with overview* as a result of the stepwise regression analysis ( $R^2 = .195$ ; with a *Beta* of 0.310,  $p < .05$ ) (see Table 3). When CS-1 score increased, *Reading order similarity with overview* did.

**Table 3. Summary of the regression analysis for cognitive abilities predicting Reading order similarity with overview (n=51)**

Variable	B	SE B	Beta	t
Step 1				
Speed of Closure (CS-1)	0.040	0.015	0.349	2.609 *
Step 2				
Speed of Closure (CS-1)	0.038	0.015	0.328	2.485 *
Logical Reasoning (RL-1)	0.011	0.007	0.221	1.676
Step 3				
Speed of Closure (CS-1)	0.036	0.015	0.310	2.341 *
Logical Reasoning (RL-1)	0.010	0.007	0.194	1.454
Prior Knowledge (PK)	0.014	0.012	0.159	0.187

**Note.**  $R^2 = .122$  for Step 1;  $\Delta R^2 = .048$  for Step 2;  $\Delta R^2 = .025$  for Step 3; \*  $p < .05$ ; Predictors: PK, CS-1, CF-2, SS-1, RL-1, MS-2

*Overview usage time.* Step regression analysis performed showed that the score on the Gestalt completion test (CS-1, *Speed of closure*) was the only significant predictor of *Overview usage time*. It accounted for near 10 % of the variance ( $R^2 = .095$ , with a *Beta* of -0.308,  $p < .05$ ; see Table 4), but there was an inverse relation: as higher was the reader's CS-1 score the lower was their *Overview usage time*.

**Table 4. Summary of the regression analysis for cognitive abilities predicting Overview usage time (n=51)**

Variable	B	SE B	Beta	t
Step 1				
Speed of Closure (CS-1)	- 12.75	5.63	- 0.308	-2.265 *

Note.  $R^2 = .095$  for Step 1; \*  $p < .05$ ; Predictors: PK, CS-1, CF-2, SS-1, RL-1, MS-2

Reading strategy variables: Semantic measure

*Reading text coherence.* No significant predictors were found for this reading strategy variable.

**2.2.3. Effect of Reading Strategies on Comprehension Outcomes**

We took into account the effect of *Overview usage time*, *Reading order similarity with overview*, *Number of different nodes accessed*, *Prior knowledge* and *Reading text coherence* on the knowledge acquisition measures (*Textbase questions score*, *Judgment related task score* and *Inference questions score*). However, preliminary analyses showed that *Reading order similarity with overview* and *Reading text coherence* variables were highly correlated ( $r = .84$ ) and that there was not a direct relation between *Reading order similarity with overview* and comprehension outcomes (all  $F$ 's  $< 1$ ). Therefore, we decided to remove *Reading order similarity with overview* from further analyses and focus on *Reading text coherence*. It is argued that, as predicted by discourse comprehension theories, the possible effects of reading order on hypertext comprehension are mostly related with the semantic aspects of reading strategies (i.e. the coherence of the reading order) and not with the syntactic ones (i.e. the similarity between the reading order followed by the reader and that suggested by the overview).

*Effects on textbase acquisition.* Regression analysis results showed that *Number of different nodes accessed* accounted just near 10 % of the variance in textbase question scores ( $R^2 = .092$ , with a Beta of 0.376,  $p < .05$ ). Table 5 shows the results of this analysis, only the *Number of different nodes accessed* was related with *Textbase questions scores*. The score on textbase questions increased when the amount of information accessed did.

**Table 5. Summary of the regression analysis for reading strategy variables predicting Textbase question scores (n=51)**

Variable	B	SE B	Beta	t
Step 1				
Number of Different Nodes Accessed	0.152	0.068	0.304	2.230 *
Step 2				
Number of Different Nodes Accessed	0.188	0.075	0.376	2.520 *
Overview Usage Time	-9.538	8.179	-0.174	-1.166

Note.  $R^2 = .092$ ;  $\Delta R^2 = .026$  for Step 2; Predictors: PK, Number of Different Nodes Accessed, Overview Usage Time and Reading Text Coherence

*Effect on situation model measures.* Table 6 shows the results of the stepwise regression analysis between reading strategy variables and *Relatedness judgment task scores*. The regression equation accounted for 13 % of the variance ( $R^2 = 0.132$ ;  $p < .05$ ). *Overview usage time* was the best predictor of situation model acquisition, the more time users spent browsing the overview, the worse was their score on the relatedness judgment task (*Beta* of -0.265, near significant  $p < .055$ ).

**Table 6. Summary of the regression analysis for reading strategy variables predicting Relatedness judgment task scores (n=51)**

Variable	B	SE B	Beta	t
Step 1				
Overview Usage Time	-0.000362	0.000175	-0.283	-2.062 *
Step 2				
Overview Usage Time	-0.000340	0.000173	- 0.265	-1.969 +
Reading Text Coherence	0.492	0.289	0.229	1.701 +

**Note.**  $R^2 = .080$  for Step 1;  $\Delta R^2 = .052$  for Step 2; \*  $p < .05$ ; +  $p < .10$   
Predictors: PK, Number of Different Nodes Accessed, Overview Usage Time and Reading Order Coherence

*Reading text coherence* also appeared as predictor in the regression equation, but it was only marginally significant (*Beta* of 0.229,  $p < .095$ ). However, a closer look at data distribution suggested that it could be found a clearer difference between readers performing a high reading text coherence order and readers performing a low reading text coherence order. To test this idea two participants' groups were distinguished based on the extreme values of coherence, that is, the lower boundary under the 40<sup>th</sup> percentile (*cosine* = .489;  $n = 21$ ;  $M = .459$ ,  $SD = .021$ ), and the higher boundary above the 60<sup>th</sup> percentile (*cosine* = .507;  $n = 20$ ;  $M = .522$ ,  $SD = .011$ ). An ANOVA was performed with coherence group (low and high) as independent variable and *Relatedness judgment task score* (Pathfinder similarities) as dependent variable. There was a near significant effect of level of *Reading text coherence* ( $F(1,39) = 3.94$ ;  $MSE = 0.0046$ ;  $p < .055$ ): the high coherence group obtained better scores ( $M = .262$ ;  $SD = 0.081$ ) than the low coherence group ( $M = .219$ ;  $SD = 0.051$ ) on this situation model measure.

No effect was found for inference questions as dependent variable  $F < 1$ .

### **2.3. Discussion**

The experiment analyzed the role of cognitive abilities as predictors of reading strategies, and the relation of these strategies with comprehension. The results of this experiment allow us to partially answer the questions that originated the study.

#### **2.3.1. What are the reading strategy variables that can predict comprehension outcomes?**

Comprehension results replicate those of Salmerón et. al. (2005) concerning low prior knowledge readers. As expected, low knowledge readers that followed a reading strategy leading them to read the texts in a high coherent order constructed a better situation model than those who read the contents in a low coherent way. Moreover,

textbase acquisition was not affected by reading order, but by the amount of information read. Because of the interactive overview design used in this experiment, following a reading order similar to that suggested by the overview structure were related to higher levels of *Reading text coherence*. Nauman and Krems (2005) also stated that a reading strategy strictly following the reading order suggested by the hypertext system should result in a better mental representation of the structure, less orientation problems and more efficient information retrieval by overcoming cognitive overload.

Interestingly, the *Overview usage time* variable showed an inverse relation to situation model construction. The processing of graphical overviews has been traditionally related with an enhancement in the comprehension of printed texts. However, their role in hypertext comprehension is still controversial since there is experimental evidence showing that graphical overviews could both facilitate and hinder comprehension (Chen & Rada, 1996; Hofman & Van Oostendorp, 1999; Shapiro & Niederhauser, 2004). In contrast with most of the previous research, the present study did not focus on the effect of the provision or not of interactive overviews but on their use. The results showed that when an interactive overview is provided, increasing the time devoted to their use is related with worse comprehension.

An increase in *Overview usage time* could reflect disorientation problems that make it difficult to concentrate on text and inhibit deep processing (Müller-Kalthoff & Möller, 2006). Furthermore, using the overview can be considered as an interruption in the reading processes that could hinder comprehension (DeeLucas & Larkin, 1996; DeStefano & LeFevre, 2007). The effects of that interruption may be worse if its duration is longer, since active text propositions in working memory fade away over

time and therefore the probability of being active when reading the next text node is lower.

In a recent study, Salmerón, Baccino, Cañas, Madrid and Fajardo (2009) have gone deeper into the role of *Overview usage time* on hypertext comprehension. They conducted two experiments using non-interactive overviews exploring the possibility that text comprehension depends on when the graphical overview is read (at the beginning or at the end of the session) and on hypertext difficulty. Results showed that readers of difficult hypertexts who devoted time to overview processing at the beginning of the text found the overview useful and achieved a better comprehension. On the other hand, using overviews with easy hypertext were linked to lower comprehension if read at the end of the session. Direct comparisons with this study are difficult since the variable of the moment at which the overview was read was not controlled in the present investigation. Therefore it is not possible to know if the hindering of situation model acquisition as shown in the present experiment was related to reading the overview at the beginning or at the end of the session. This issue will be explored more deeply in future experiments.

### **2.3.2. What is the role of cognitive abilities as predictors of reading strategies?**

The experiment tested the relation between three cognitive abilities (spatial abilities, working memory and logical reasoning), reading strategies and hypertext comprehension. Contrary to our predictions, the analyses did not show a significant relation between the score on the cognitive tests selected to assess working memory or logical reasoning and reading strategies variables. This result may be related with the use of interactive overviews in our experiment: hypertext reading could have been



affected by users' logical reasoning ability or working memory capacity when no navigation support is offered but *not* when an interactive overview is used to support link selections. It might also have been the case that the tests used did not tap the specific subcomponents of cognitive abilities involved in this task. For instance, the working memory test used (Visual number span test) may have tapped the subcomponent ability related with storing and processing visual information, but not textual information. Indeed, several studies considering the role of working memory on hypertext processing used a reading span test to assess working memory ability that could have been more appropriate to measure the working memory components involved in hypertext comprehension (e.g. Lee, Tedder & Xie, 2006; Naumann, Richter, Christmann, & Groeben, 2008).

On the other hand, two spatial abilities (*Speed of closure* and *Spatial scanning*) significantly predicted reading strategy variables. Speed of closure factor was related both to *Overview usage time* and to *Reading order similarity with overview*. *Overview usage time* decreased and *Reading order similarity with overview* increased (and subsequently the *Reading text coherence* was higher) as a function of the score on *Speed of closure*. Additionally, participants with higher *Spatial scanning* ability accessed more different nodes than participants with lower *Spatial scanning* ability. Considering the hypertext system design used in this experiment, it can be argued that the role of spatial abilities on reading strategies is related with overview processing, orientation and navigation, since the overview is not only used to preview hypertext structure but also to select the next node to read.

As a summary, readers with higher spatial abilities selected a reading strategy the characteristics of which were demonstrated to predict better comprehension: less time spent using the overview, higher amount of information read, and higher similarity

between the reading order followed and the spatial organization of the overview (which in turn, leads to higher *Reading text coherence*).

### **3. CONCLUSIONS**

#### **3.1. Relations between spatial abilities, reading strategies and hypertext comprehension**

This study reported an experiment on the relation between cognitive abilities, users' reading strategies and comprehension when using hypertext systems. Its results add knowledge to our understanding of the variables involved in hypertext comprehension and the relations between them. Two main conclusions can be drawn:

*1. Reading strategies that users follow predict comprehension.* Traditionally, researchers have tried to predict hypertext comprehension based on user characteristics and system design. However, the results of this study support the need expressed by some authors of taking into account reading strategy variables as a main factor and not as a by-product of the hypertext comprehension task. The practical implication of this finding is that readers' comprehension can be enhanced by fostering the development of suitable reading strategies. This can be done through the use of navigational aids or by strategy training, as some authors have suggested (McNamara & Shapiro, 2005).

*2. Readers' spatial abilities affect reading strategies.* Freedom of navigation is one of the main characteristics of hypertext, and the way in which users navigate and process the hypertext depends on several aspects. Hypertext structure or the provision of navigational aids (such as the interactive overview used in our study) might strongly determine the reading strategy used. However, this study shows that user characteristics, such as spatial abilities, also have an influence, and especially hypertext readers with

weaker abilities might have navigation problems (e.g. disorientation and cognitive overload) that subsequently could hinder comprehension. These results also have practical implications for hypertext design: since the efficiency of navigational aids as hypertext overviews rely on reader's ability to use them properly, design has to accommodate individual differences in cognitive abilities. In the case of spatial abilities this could be done by reducing the spatial complexity of hypertext overviews for less skilled readers.

### **3.2. Limitations and future work**

The limitations of this study are mainly related to the specific hypertext and experimental design used. The most widespread hypertext type is the network hypertext, which allows readers to navigate from one hypertext node to a set of connected nodes. Frequently network hypertexts include some interactive overview in the form of sitemaps or contents lists, but they are not the only mean of navigation. In our study, we demonstrated that there is a relation between spatial abilities and reading strategies when using a hypertext in which the navigation options were restricted and text nodes could only be accessed through the interactive overview. It is possible that interactive overviews are a more cognitive demanding tool than other navigation facilities in terms of spatial abilities and this relation might not be replicated with different hypertext systems. Indeed, it has been argued that interactive overviews could create more cognitive load and its usefulness may depend on readers individual differences (Scott & Schwartz, 2007). Moreover, some others have suggested that other system variables, such as the number of links, affect cognitive load (DeStefano & LeFevre, 2007). Therefore, further studies should analyze the cognitive requirements of other kinds of

hypertext structures and navigation systems and their relation to reading strategies and comprehension.

This study also supports the idea that reading strategies act as a mediator between cognitive abilities and hypertext comprehension. However, reading strategy variables are commonly measured as the result of readers' navigation behavior and there is a lack of knowledge about the cognitive processes that are carried out during hypertext tasks (Naumann & Krems, 2005; Salmerón et al. 2005; Salmerón, Kintsch & Cañas, 2006). Future research should measure and analyze more directly these cognitive processes.

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## APPENDIX II.

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The effects of the number of links and navigation support on cognitive load and learning with hypertext: The mediating role of reading order. *Computers in Human Behavior*, 25, 66–75.



**Abstract.** Problems in learning with hypertext systems have been claimed to be caused by high levels of disorientation and cognitive load. This was recognized by DeStefano and LeFevre (2007) who predicted an increase of cognitive load and impairment of learning for hypertexts with a higher number of links per page. From a practical perspective, several navigation support techniques, such as providing link suggestions, have been proposed for guiding learners and reducing cognitive overload. In an experiment, we tested DeStefano and LeFevre's predictions as well as the usefulness of link suggestions. Participants used different versions of a hypertext, either with 3-links or 8-links per page, presenting link suggestions or not. We tested their cognitive load and learning outcomes. Results showed that there was a benefit of using link suggestions for learning, but no effect of number of links on learning was found. Moreover, the effects of our manipulations on cognitive load were mediated by the reading order that participants selected. Implications for research and the design of navigation support systems are discussed.

**Keywords:** Hypertext comprehension; Cognitive load; Navigation support; Learning.

## 1. INTRODUCTION

Hypertext is becoming one of the most important tools for acquiring information, not only because it is used extensively on the Internet, but also in many learning environments such as CD's or DVD's in the form of Encyclopaedias, Educational Hypermedia or Games.

Searching and navigating (also called browsing or surfing) are the main activities that users perform to find information in hypertext systems. By navigating, users select a reading order, starting on a particular information unit (page) and continuing through the links that lead them from that page to other information units. Navigation can be directed by different goals. Sometimes, the user may want to find some specific information, but very frequently people navigate with the more open goal of comprehending the information and learning from different sources. This is often the case of the hypertext systems used in learning environments as educational hypertexts. By navigating, users select their own reading order, which may influence its cognitive load and learning results. We will explore these issues more deeply in the current study.

Learning with hypertexts has two problems that limit its usefulness: (1) regarding the navigation process, people suffer disorientation and cognitive overload (Conklin, 1987; Kim & Hirtle, 1995), (2) regarding comprehension and learning, there is no conclusive experimental evidence that probes that the learning experience is better with hypertexts than with traditional systems such as books (Chen & Rada, 1996; Dillon & Gabbard, 1998; Shapiro & Niederhauser, 2004). These two problems seem to be related, since some evidence exists that shows that disorientation leads to worse learning and performance (Ahuja & Webster, 2001; Puerta Melguizo, Lemmert & van

Oostendorp, 2006) and high cognitive load in hypertext systems may be responsible for comprehension problems (DeStefano & LeFevre, 2007).

In this study we focus on this latter aspect: the relation between cognitive load imposed by hypertext design features and learning results. With this purpose we analyze the effect of the number of links presented on the navigation menu on cognitive load, reading order and learning outcomes. At the same time, we will test the usefulness of navigation support in form of link suggestions for reducing cognitive load and enhancing learning.

## **2. LEARNING WITH HYPERTEXT**

In this section we will present research findings about comprehension and learning with hypertext systems. Firstly, we start describing the Cognitive Load Theory and its predictions on hypertext comprehension and learning. We continue describing the Construction – Integration model of text comprehension and showing some evidence obtained in hypertext comprehension within this framework. Finally, we will show some proposals to enhance readers' performance with these systems mainly through navigational support.

### ***2.1. Cognitive Load and Learning with Hypertext***

Cognitive load is a multidimensional construct that refers to how much load is imposed to a learner's cognitive system by a certain task. Cognitive Load Theory (Sweller, 1988; Kirschner, 2002; Paas & van Merriënboer, 1994) assumes a working memory architecture (Baddeley & Hitch, 1974; Baddeley & Logie, 1994) that can be viewed as a system of limited capacity that can only handle a limited number of elements at the same time. If the cognitive load of a task (or various tasks) exceeds the

limits of working memory then performance gets seriously affected (DeStefano & LeFevre, 2007; Xie & Salvendy, 2000). Working memory plays a very important role in comprehension processes since it has to keep active the partial products of reading while providing a link with long term memory (Van Dijk & Kintsch, 1983; Kintsch, Patel & Ericsson, 1999).

There is some evidence showing that the role of cognitive load is important for hypertext comprehension. Lee and Tedder (2003) found that readers with high working memory capacity had a better recall of content when using hypertext compared with those of low working memory capacity. Correspondingly, there is a claim that cognitive requirements of hypertext exceed those of linear text (Conklin, 1987; Tardieu & Gyselinck, 2002; DeStefano & LeFevre, 2007). However, there is no agreement about this, and some authors think that there is not a greater need of cognitive resources with hypertext, but merely a different balance of resources (Wenger & Payne, 1996).

Cognitive Load Theory explains how instructional design can affect learning. It makes a distinction between intrinsic, extraneous and germane cognitive load. Intrinsic cognitive load is related with the inherent nature of the materials to be learnt (interactivity between elements) and prior knowledge (PK). Extraneous load (ineffective for learning) is the effort required by poorly designed tasks, while germane cognitive load (effective for learning) concerns activities related with the construction of schemas and automation leading to higher levels of comprehension. Extraneous and germane cognitive load depend on instructional design and through the design, these can be reduced or enhanced. Since the total amount of cognitive load imposed by a hypertext task has to stay within the limits of working memory capacity, a bad design can increase

extraneous cognitive load too highly, leading to navigation and comprehension problems and to impairment in reading performance.

DeStefano and LeFevre (2007) have claimed recently that problems on hypertext reading can be caused by the cognitive load that users suffer while following links. In their revision of the literature, DeStefano and LeFevre found better performance when the number of link's options is reduced (Jacko & Salvendy, 1996; Landauer & Nachbar, 1985; Parush, Shwartz, Shtub & Chandra, 2005). They hypothesized that cognitive load may be influenced either directly or indirectly. The direct influence occurs during the link selection process, when readers encounter a link and have to make a decision on whether to follow it or not; this decision requires extra cognitive resources in comparison to linear reading where no decision need to be made. The indirect influence occurs during reading, when the link followed leads to semantically un- or less related text and subsequently to an interruption of the comprehension process that requires extra cognitive resources. In the next section, we will describe how hypertext comprehension processes occur in the light of one of the most accepted theories, the Construction – Integration model of Kintsch (1988, 1998).

## ***2.2. Comprehension and learning with hypertext***

To contextualize hypertext effects on comprehension and learning we will start by considering the Construction-Integration (C-I) model of text comprehension (Kintsch 1988, 1998). This model conceives comprehension as a process of forming a coherent mental representation from the text. This is performed via a cyclic procedure composed of two phases: construction and integration. In the construction phase, a network of interrelated elements extracted from text is added to working memory and combined with the information that was present there before. During integration a spreading



activation process selects the most activated elements of the network. At the end of the process, the most activated nodes are stored in working memory to be available in the next cycle. Therefore reading is carried out in the context of the previously read text elements.

According to the C-I model, various mental representations are constructed during reading, being the textbase and situation model the most important for learning. The textbase is a mental representation of the propositions contained in the text. The situation model is considered the deepest mental representation, and it is formed when the textbase is integrated with prior knowledge. There are several factors that are important for situation model construction; text coherence and prior knowledge are the most important ones. By text coherence we mean the extent to which a reader is able to understand the relations between ideas expressed in a text (Britton & Gülgöz, 1991). There are text characteristics that contribute to text coherence, like the explicitness to which the concepts, ideas, and relations appear within a text. When readers with low domain knowledge read a highly coherent text they construct better situation models than when they read low coherent ones. On the other hand, if the propositions of two text fragments do not share arguments, bridging inferences must be made by accessing background knowledge in order to fill in the lack of information. Since making inferences consumes cognitive resources, the difficulty is even higher for low knowledge readers (Graesser, McNamara & Louwerse, 2003; Louwerse, 2002; Louwerse & Graesser, 2004; McNamara, E. Kintsch, Songer & W. Kintsch, 1996; McNamara & Kintsch, 1996).

At this point it may be useful to distinguish between text memory and learning from text and the way in which they are related with different comprehension levels.

Even though a text can be recalled only from textbase, this does not imply a deep level of understanding. For learning from text it is necessary to elaborate the text content from prior knowledge and to integrate it, achieving a good situation model (Kintsch, 1994).

Comprehension and learning with hypertext seem to follow the same rules as linear texts, except for the fact that readers can select their own reading order by deciding what links to follow. Reading order is an important characteristic of hypertext reading and has a consistent result on learning. By reading order, the coherence between chosen text sections is modifiable, so if learners decide to read the content in a low coherent way their learning is impaired (Salmerón, Cañas, Kintsch & Fajardo, 2005; Salmerón, Kintsch & Cañas, 2006a). This effect on learning is caused by what we call the coherence of the reading order, which can be defined as the degree in which the reader's navigation path (or reading order) follows a coherent line of arguments or ideas. Salmerón et al. (2005) gave support to this idea when they showed that low prior knowledge readers who selected a reading order with high text coherence between their visited information nodes constructed a better situation model than those who selected a low coherent reading order. No effect of text coherence was found on textbase.

In general, low prior knowledge students are more prone to have difficulties with navigation and comprehension of hypertext (Amadiou, Tricot & Marine, 2006; Chen, Fan & Macredie, 2004; Lawless, Schrader & Mayall, 2007; Muller-Kalthoff & Moller, 2006). Since promoting coherent hypertext reading helps low prior knowledge readers with learning, several navigation support systems have been proposed to assist readers with selecting a coherent reading order (McNamara & Shapiro, 2005; Salmerón,

Kintsch & Cañas, 2006b). In the next section we will explore the benefits of these systems.

### ***2.3. How hypertext performance can be enhanced through navigational support***

To assist less advantaged users some hypertexts and websites offer navigational support (i.e. overviews, concept maps, link suggestions, etc.). Navigation support is claimed to reduce disorientation and cognitive load (Brusilovsky, 2004; Puerta Melguizo, Van Oostendorp & Juvina, 2007).

One way of giving navigational support is by providing link suggestions to help users to select among link alternatives (Figure 1 shows how the suggested link is marked with a double arrow “>>” in our experiment). Link suggestions have been shown to enhance coherence formation (McNamara & Shapiro, 2005; Van Oostendorp & Juvina, 2007). For example, Van Oostendorp and Juvina (2007) used link suggestions to help users in a navigation task. They highlighted the relevant links based on a cognitive model similar to COLIDES (Kitajima, Blackmon & Polson, 2000) that uses Latent Semantic Analysis (LSA) for computing the semantic similarity between link labels and user’s goals. Links that had the highest semantic similarity with the goal were selected. When the successful path for a task included a link that was present on the screen, it was highlighted. They found that these highlighted link suggestions were positively received and improved user performance.

But why do we want to give navigational support, limiting free navigation? With navigational support users get information about how ideas between documents are related, or which are the most related links within a set. McNamara and Shapiro (2005) suggest that as novice readers are not able to recognize important relationships between

different pages, it is necessary to make novice readers aware of these relationships. MacNamara and Shapiro propose that providing a well-defined domain structure or highlighting the links that denote heavy inter-texts relationships will help less knowledgeable students to comprehend hypertext documents.

One technique to implement navigation support systems was described by Salmerón, Kintsch and Cañas (2006b) who proposed an automated method for suggesting links based on LSA coherence measures; being on a particular hypertext page the system could signal the links with the highest LSA values regarding the just read text. Such a system could help readers to select a coherent reading order, that is, a reading order that results in a coherent text.

We propose that this system could also support hypertext learners in the reduction of cognitive load in the situations predicted by DeStefano and LeFevre. First, by suggesting some links we try to focus readers' attention on fewer link options, so the cognitive load related with decision making will be lower. Additionally, suggesting semantically related links will lead to a more coherent reading order and therefore also to a reduction on cognitive load during reading. Therefore, the above mentioned system will also permit a better comprehension and learning.

In this paper, we test hypotheses about the effects of cognitive load on hypertext performance and learning, and the efficacy of navigation support for helping users to overcome navigation problems and to achieve a better learning.

### **3. HYPOTHESES**

The main purpose of this study is to analyze the effects of number of links and navigation support on cognitive load and learning. Part of our hypotheses is derived

from the predictions of DeStefano and LeFevre (2007). First, making navigational choices in a hypertext will impose more cognitive load when the number of links is higher, either directly – when more links lead to greater requirements for link selection – or indirectly – when more links increase the probability of accessing documents in a semantically unrelated reading order. Second, and as a consequence, higher number of links can impair learning.

The other input for our hypotheses comes from a practical concern: How can we help learners to deal with those problems that DeStefano and LeFevre associated with hypertext use, that is, an increment on cognitive load and unorganized reading? Furthermore, we want to test the usefulness of giving navigation support in the form of link suggestions based on the semantic similarity between the text just read and link labels to solve these problems for learning.

Therefore, we propose the following set of hypotheses for our research:

H1: Reading Text Coherence

Typically, the links shown on a hypertext page lead to a text with different levels of semantic relatedness between successive pages. Showing a high number of links without giving cues about inter-page relations can increase the difficulty to select a coherent navigation path. On the other hand, giving navigation support in the form of link suggestions can help readers to select a coherent reading order. Therefore,

H1a: Learners using a hypertext with higher number of links will select a less coherent reading order than those using a hypertext with lower number of links.

H1b: Learners who are given navigation support in the form of link suggestions will select a more coherent reading order than those for whom no support is offered.

## H2: Cognitive Load

As we stated before, cognitive load can be affected by the number of links per page in the link selection process as well as during reading. We also propose that link suggestions help readers to reduce cognitive load in the link selection process as well as during reading. Therefore,

H2a: Learners using a hypertext with a higher number of links will experience an increase in cognitive load during link selection process as well as during reading.

H2b: Learners who are given navigation support in the form of link suggestions will experience less cognitive load during link selection process as well as during reading.

## H3: Learning

Our hypotheses about learning (H3) can be deduced as a consequence of our statements about reading text coherence (H1) and cognitive load (H2). Hypertext learning will be enhanced when using a system that allows a low cognitive load and a high coherent reading order. Therefore,

H3a: Learners using a hypertext with a higher number of links will obtain worse learning results than those using less links.

H3b: Learners who are given navigation support in the form of link suggestions will obtain better learning results than those for whom no support is offered.

## **4. METHOD**

### **4.1. Participants**

Forty-five students from the Utrecht University participated in the experiment. Since we were interested in testing our hypotheses on low prior knowledge (PK) readers we looked for students who were unfamiliar with the topic of the hypertext (brain anatomy and functioning) by recruiting them in faculties not related with psychology or medicine (most of them were Mathematics, Sociology or Information Sciences students).

The data of three participants was excluded, since they did not follow the instructions properly.

### **4.2. Design**

An experimental 2x2 design was used with number of links (3 vs. 8 links) and support (no support vs. link suggestions) as independent variables. As measures of cognitive load, the dependent variables were the average reaction times (RTs) in a secondary task (separately when reading and when selecting links). Regarding learning outcomes, textbased questions, inference questions and relatedness judgment task scores were used as dependent variables. Mean LSA cosines were used as dependent variable for characterizing participants' reading order. Also, reading and selecting times were used as dependent variables.

### **4.3. Materials**

We used a text about Neuropsychology adapted from a General Psychology introductory e-text (Boeree, 2003). The text had 4.440 words and was adapted into

hypertext format. The text was divided into 21 hypertext pages according to their topic structure.

The hypertext was constructed in a specific way to separate the reading processes from the link selection processes. The links selection menu was located on the left of the reading area (see figure 1). During reading, the links selection menu was hidden and was only shown when the participants finished reading and they pressed a button with the label “I have finished reading”. The links selection menu disappeared again when the chosen link was clicked and the new text was presented on the screen. By this manipulation (separating reading from selecting task) we were able to test independently cognitive load during text reading and during link selection.

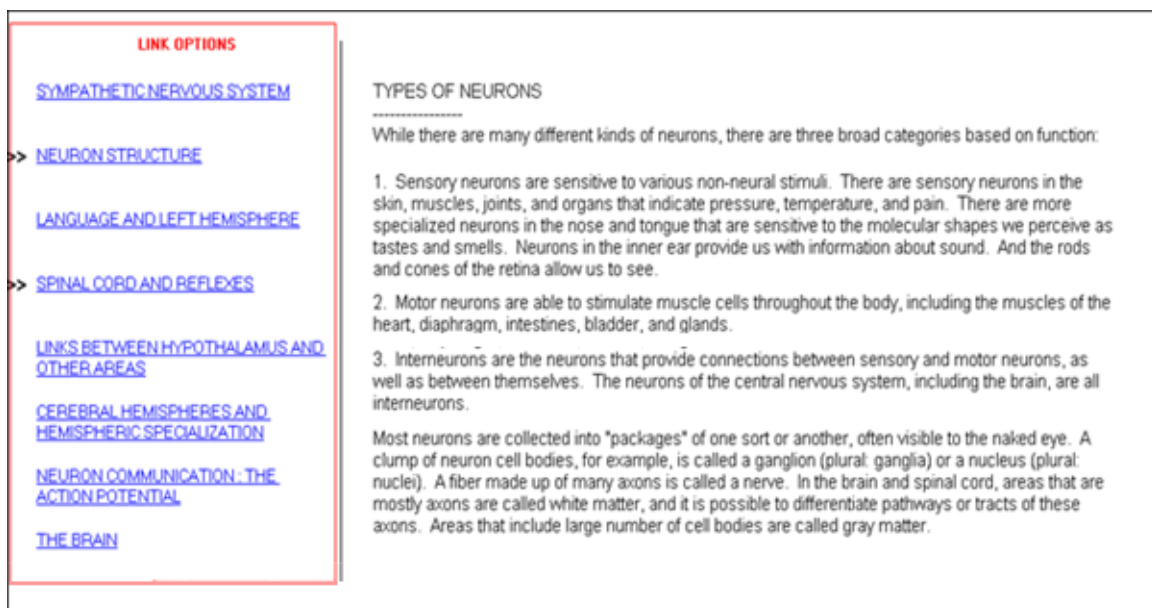


Figure 1. Screenshot showing the 8-links condition with link suggestions (>>) during link selection

Link labels and page titles were constructed using a computational method based on Latent Semantic Analysis (LSA) that allows, for instance, extracting the most representative sentence from a large text (Kintsch, 2002; see Salmerón et al. 2006b for



its application to hypertext). LSA has been used as a reliable technique to estimate semantic similarity (e.g. for assessing similarity between short summaries, Leon, Olmos, Escudero, Cañas & Salmerón, 2006). By comparing two portions of text with this method one can obtain a measure called LSA cosine that provides a measure of argument overlap (Foltz, Kintsch & Landauer, 1998). To compute all the LSA measures described in this experiment we used the University of Colorado LSA website, which provides several LSA applications (<http://lsa.colorado.edu>).

LSA was also used for selecting the link options and link suggestions to be presented at the navigation menu. In both cases, LSA cosines were computed between text contents and the link text labels. On each page, the 2 links with the highest LSA cosines with the text just read were presented, and the rest of the links to complete the menu (until 3 or 8 depending on the condition) was extracted randomly from the pool of links labels. In the support condition the two highest related links were marked with an arrow (>>) near them for making the suggestions (see Figure 1). The position order of the links in the menu was randomized.

To prevent participants reading twice the same text, links that lead to an already read text were shown in a different colour (like visited links in web pages). Participants could click on these links, but a message was then shown telling them that that content was read before and they had to select a different link.

#### **4.4. Measures**

##### ***4.4.1. Reading text coherence***

Reading text coherence was measured by using LSA to analyze page transitions as determined by the reading order the subjects selected. In our study, the mean LSA cosine between page transitions was computed for every participant as a semantic

measure reflecting the degree of text coherence of the reading order selected by the participants. This measure has been used in previous studies for analyzing reading text coherence in hypertext (Madrid, Salmerón & Cañas, Submitted; Salmerón et al., 2005; Salmerón et al., 2006a).

#### ***4.4.2. Cognitive Load***

For testing our hypothesis on cognitive load we tested participants' mental effort, i.e. the cognitive capacity that was actually allocated to the hypertext task. Mental effort is one of the most important measurable dimensions of cognitive load and in this paper we will use both terms interchangeably. Cognitive load can be measured by a dual-task methodology based on the RTs to probe sounds. This methodology requires participants to perform the main task or primary task while responding to random beeps as quickly as possible (secondary task). Since performance on a task depends on the available cognitive resources, the performance on the secondary task will be reduced if the cognitive resources required by the primary task are high. In other words, the RTs to beeps are slower when the cognitive requirements of the primary task are higher (Britton & Tesser, 1982; Bonnardel & Piolat, 2003; Brünken, Plass & Leutner, 2003; Kellog, 1987). The results obtained with the dual-task method are interpreted in terms of mental effort applied to the primary task.

In our experiment, at the beginning of the session participants had to react as quickly as possible to 10 beep sounds presented randomly to obtain their RT baseline. During hypertext reading, participants had to press the "z" key as soon as possible when a beep was presented through the headphones. Their data was corrected by subtracting the baseline RTs. Variations in RT's reveal the cognitive capacity allocated to the primary tasks: reading or selecting links. Consequently, we computed the corrected RTs

separately when selecting links and when reading the text fragments. The beeps were presented in a variable interval between 15-45 s. when reading and between 4-9 s. when selecting links. Because the process of making link decisions can be very fast, the time interval during selection was reduced in order to maximize the probability of a beep when selecting a link.

We can compute several measures of cognitive load derived from RTs (see Xie & Salvendy, 2000 for various possibilities). In our analyses, we will use the average cognitive load which reflects the intensity of the cognitive load carried out during the task.

#### ***4.4.3. Reading and link selection times***

Time spent was measured separately when selecting links and when reading. Link selection times were recorded in seconds, starting when the link menu was shown and finishing when a link label was clicked. An average link selection time was obtained for each participant by dividing the total time spent by the number of link selections in the total session (20 in all the cases). Reading times were measured in seconds for each hypertext page, and then divided by the number of words in that section, obtaining the average time spent by word.

#### ***4.4.4. Learning measures***

We used different techniques to measure the different representations constructed during reading: textbased questions for textbase representations and inference questions and a relatedness judgment task for the situation model (McNamara et al., 1996; Kintsch, 1998). We also used a questionnaire about Prior Knowledge for controlling its influence on the development of these representations.

### Prior knowledge (PK)

Although we recruited a low PK sample (at least they were not experts in the topic), we tested them for differences in PK. Prior to the reading phase, participants completed a ten-items questionnaire with questions reflecting general knowledge about the brain, which were extracted from the content of an introductory book on cognitive science (Anderson, 2005). Each question has four choice options, so chance performance was at 25 %.

### Text-based questions

A set of 21 multiple choice questions (one per text page) was also completed by the participants after reading the hypertext. It was constructed in such manner that the question and the answer could be found in the same hypertext page, so there was no need of inferences to respond to it. Chance performance was established at 25 %.

### Inference questions

Ten questions with four response options had to be answered by the participants. This type of questions required to relate information contained in at least two different nodes. Therefore this task was also intended to assess comprehension at situation model level. Chance performance was at 25%.

### Relatedness judgment task

The participants had to measure the relation between 91 pairs of concepts (as combination of the 14 most relevant concepts in the text selected by the authors of this paper). Participants had to rate pairs of concepts by using a scale from 1 to 6, in which 1 means “Highly related” and 6 means “Low Related”. We applied the Pathfinder Algorithm to the data. Pathfinder is a technique that can provide a measure of the

similarity (C) of two conceptual networks that range from 0 to 1 (a score of 1 corresponds to two equal graphs) (see Dearholt & Schvaneveldt, 1990). This method has been shown to be useful to measure comprehension at situation model level (Britton & Gülgöz, 1991). An expert in Psychobiology (Ph. D.) performed this task and his score was used as reference. We calculated the C similarity between each participant's network and the expert network in order to describe how well the situational model has been acquired.

#### **4.5. Procedure**

The participants started the session filling in the PK questionnaire. They had then to complete a detection task to determine their reaction time baseline. After that, the hypertext reading phase started, and the participants were instructed to use the hypertext. They had to read all texts. For controlling the effect of different types of strategies on link selection, we instructed the participants to always select the link that seems most related to the just read text. Therefore, participants were instructed to follow a coherence strategy with the intention of promoting text order reading with high coherence (Salmeron et al., 2006a, 2006b).

When reading the hypertext, participants performed a secondary task that consisted of pressing a key when they heard a beep through headphones. The instructions stressed that they had to respond to the sounds as quickly as possible, but that reading and comprehending the text were the main tasks. In the conditions where support was presented, it was explained that the system would show an arrow (>>) near the links that the system assessed as more related with the content just read.

When all text contents were read, participants went to the comprehension testing phase: they started with the relatedness judgment task, continued with the text-based

questions and finished with the inference questions. At the end of the experiment participants filled out a questionnaire with demographic data (age, gender, studies, etc.).

## 5. RESULTS

To control for the effect of Prior Knowledge (PK) on cognitive load and comprehension outcomes, we included the scores on the PK questions as covariate in all of the further analyses. PK scores could range between 1 and 10. In our study, PK's average was 4.98 with a standard deviation of 2.18.

All results were considered significant when  $p < 0.05$ , and marginally significant when  $p$  values were between 0.05 and 0.10. In this paper we only present the effects that were significant.

### 5.1. *Reading Text coherence*

For each participant we computed the mean LSA cosine between text transitions (see Method), and this measure was used as dependent variable in the reading text coherence analyses.

A 2x2 (number of links x support) ANCOVA revealed a nearly significant main effect for Number of Links ( $F(1,37) = 4.02$ ;  $p = 0.05$ ) and a significant main effect for Support ( $F(1, 37) = 4.84$ ,  $p < .05$ ) on reading text coherence (see Figure 2). Participants using a hypertext with more links seem to select a less coherent reading order ( $M = 0.327$ ;  $SD = 0.053$ ) than participants using a hypertext with less links ( $M = 0.348$ ;  $SD = 0.035$ ). Also, readers using a hypertext with link suggestions selected a more coherent reading order ( $M = 0.351$ ;  $SD = 0.038$ ) than readers without support ( $M = 0.324$ ;  $SD = 0.049$ ). The interaction was not significant. See Table 1.

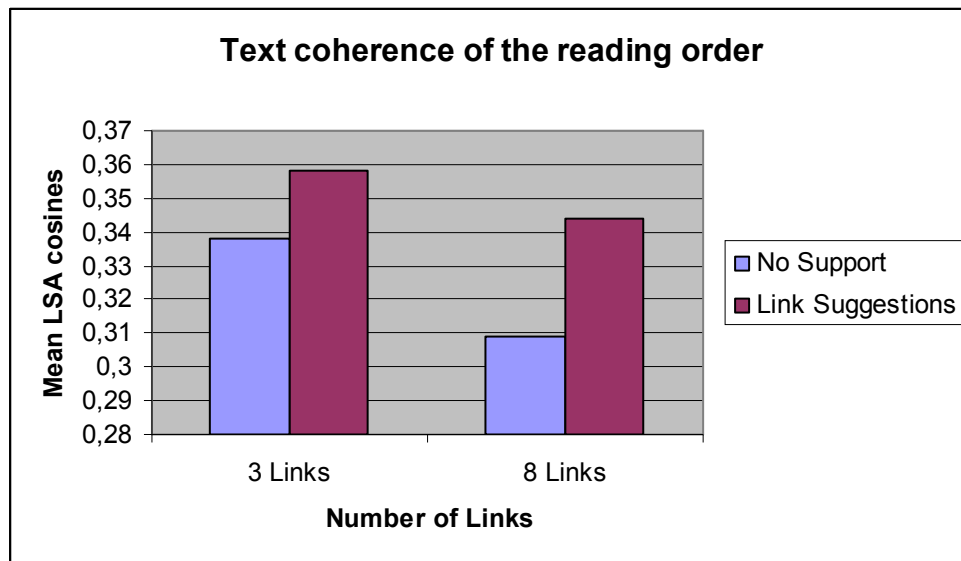


Figure 2. Effect of number of links and navigation support on the coherence of the reading order

Table 1. Mean LSA cosines (of the reading order) for number of links and support analyses

	3 Links		8 Links	
	No Supp.	Link Sugg.	No Supp.	Link Sugg.
Mean LSA Cosine	Mean (SD) 0.338 (0.039)	Mean (SD) 0.358(0.028)	Mean (SD) 0.309(0.056)	Mean (SD) 0.344(0.46)

### 5.2. Cognitive Load

Our next analyses considered the RTs to probe sounds separately when reading as well as when selecting links. Average cognitive load in link selection ( $M = 241.16$ ;  $SD = 58.36$ ) was higher than during reading ( $M = 174.42$ ;  $SD = 90.79$ ) ( $t(41) = -4.007$ ;  $p < .01$ ).

2x2 ANCOVA's using number of links and support as independent variables were performed using average cognitive load for reading and selecting links. No significant effects were found (for all,  $F < 1$ ).

### ***5.3. Reading and link selection times***

2x2 ANCOVA on link selection times shows a main effect of number of links ( $F(1,37) = 5.04$ ;  $p < .05$ ). Participants using a 3-links hypertext need less time to make the selection ( $M = 8.80$ ;  $SD = 3.74$ ) than those using an 8-links hypertext ( $M = 12.70$ ;  $SD = 6.68$ ). There were no significant effects of support neither interaction effects (all  $F$ 's  $< 1$ ). Results using mean reading times as dependent variable did not reach statistical significance (all  $F$ 's  $< 1$ ).

### ***5.4. Learning results***

A set of 2x2 ANCOVAs was conducted on the learning variables. There were no significant effects of number of links or support on scores of the textbased questions scores. On the other hand, a main effect of support on inference questions score was found ( $F(1, 37) = 4.63$ ,  $p < .05$ ). Participants' inference questions scores ranged from 1 to 9. Participants using a hypertext with link suggestions learned more at situation model level ( $M = 4.52$ ;  $SD = 2.16$ ) than participants using hypertext without support ( $M = 3.33$ ;  $SD = 1.68$ ) (See Figure 3). Results on the pathfinder networks' similarity measures did have the same tendency; participants in the support condition tend to show more similar pathfinder networks with the expert's network ( $M = 0.261$ ;  $SD=0.078$  for the no support condition,  $M = 0.275$ ;  $SD = 0.119$  for the link suggestions condition), though they did not reach statistical significance ( $p > 1$ ). None of the analyses revealed significant interaction effects ( $F < 1$ ). See Table 2.



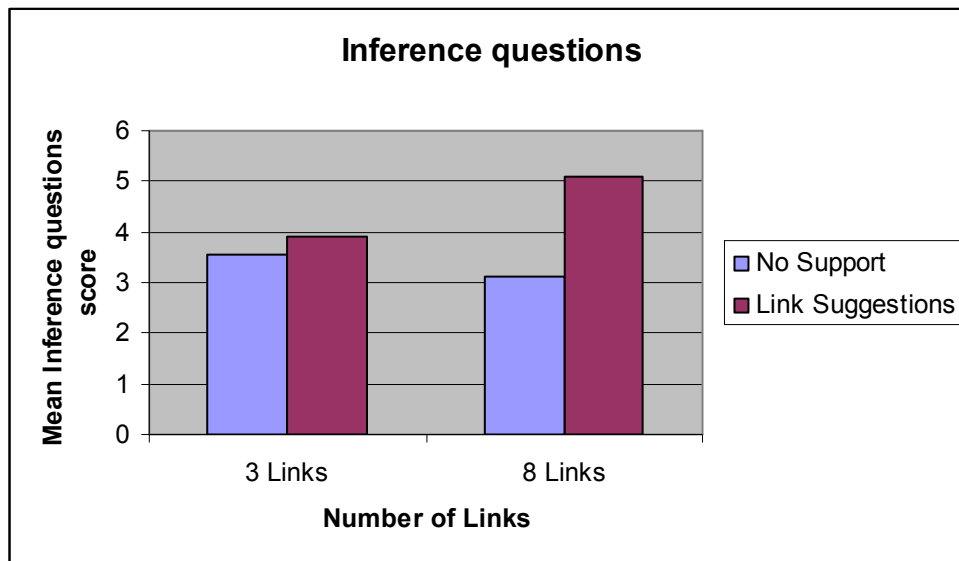


Figure 3. Result on inference questions score for number of links and support conditions

Table 2. Mean scores on learning measures for number of links and support analyses

	3 Links		8 Links	
	No Supp.	Link Sugg.	No Supp.	Link Sugg.
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Textbased questions	11.09(2.95)	8.70 (4.00)	10.30 (2.75)	12.18 (4.35)
Inference questions	3.55(1.75)	3.90(1.97)	3.10(1.66)	5.09(2.26)
Pathfinder C	0.26(0.09)	0.22(0.06)	0.26(0.06)	0.32(0.14)

### 5.5. Discussion

As the results have shown, our hypotheses are only partially supported. First, we found significant results supporting the H1 set of hypotheses: learners using the 8-links hypertext selected a less coherent reading order than those using the 3-links version, and giving navigation support helped learners to select a more coherent reading order.

Second, our hypotheses regarding learning were partially supported. As predicted, learners using the hypertext with link suggestions learned more than those

using the hypertext without support, at least at situation model level (H3b). On the other hand, we did not find learning impairments for students using a hypertext with more links (H3a).

Finally, none of our hypotheses from the set H2 were supported. Neither varying the number of links nor giving support or not had a significant effect on cognitive load. The fact that more time is needed for selecting when more links are presented can be interpreted as a direct consequence of having to read more link labels prior to make a decision.

One possible explanation for this lack of results regarding cognitive load can be found in the way in which cognitive load and the coherence of the reading order are related. Reading two unrelated text passages imposes more cognitive load than reading two related ones. When two texts are unrelated we need to draw more inferences to comprehend them properly and this consumes more cognitive resources than when texts are related (Kintsch et al., 1999; Masson & Miller, 1983). Consequently, cognitive load can be largely dependent on user actions, and not only on system manipulation. Regardless the effect of number of links and link suggestions in the reading text coherence, readers can still select a low or high coherent reading order in any condition. If some readers are able to select a high coherence reading order even in the conditions without support, the effects on cognitive load could be minimized independently of our manipulations.

We think that reading text coherence can be a strong mediating factor between hypertext design and cognitive load. To analyze this idea, two reading order groups were constructed according to participants' average reading text coherence (the mean of the LSA cosines between traversed nodes) Participants were grouped in a high reading

text coherence ( $M = 0.371$ ;  $SD = 0.013$ ) and a low reading text coherence group ( $M = 0.304$ ;  $SD = 0.041$ ), using the median score (Median = 0.353) as the cut-off. (see Salmerón et. al 2005 for a similar argument and procedure to group reading orders).

Table 3. Number of participants performing a high (HC) or low (LC) reading text coherence by condition

	No Support		Link Suggestions		Total	
	<i>LC</i>	<i>HC</i>	<i>LC</i>	<i>HC</i>	<i>LC</i>	<i>HC</i>
<b>3 Links</b>	6	5	2	8	8	13
<b>8 Links</b>	8	2	5	6	13	8
<b>Total</b>	14	7	7	14	21	21

As we can see in Table 3, 1/3 of the readers were not able to select a high text coherence reading order in the conditions with link suggestions, while the same proportion was able to get it in the conditions without support. A similar pattern is found regarding the number of links conditions: 8 participants were able to get a highly coherent reading order in the 8-links condition and also 8 participants selected a low coherent reading order in the 3-links condition. Even in the less favourable condition, 8 links with no support, 20 % of the subjects were able to select a high coherent reading order. If there is an effect of reading text coherence on cognitive load, this distribution of participants may have obscured it. It is then possible that we find differences between different levels of reading text coherence influenced by reading order but not necessarily between our manipulated conditions.

To clarify this situation we decided to perform another set of analyses focusing on the text coherence of the reading order as a mediating factor modulating the effect of

hypertext design (number of links and link suggestions) on cognitive load and learning. Results are shown and discussed in the next section.

## **6. THE MEDIATING ROLE OF READING ORDER ON COGNITIVE LOAD AND LEARNING WITH HYPERTEXT**

A new set of 2x2 analyses was performed using number of links and reading order as independent variables (see above). We omit here link suggestions because the cells would become too small. For the 2x2 analyses, the 42 participants were distributed as follows: 3-links low text coherence 8 participants; 3-links high text coherence 13 subjects; 8-links low text coherence 13 participants; 8-links high text coherence 8 subjects.

### **6.1. Cognitive Load**

A set of ANCOVA's were performed using number of links and reading order (high or low text coherence) as independent variables. A main effect for reading order ( $F(1,37) = 11.65; p < .01$ ) was found on average cognitive load during reading (see Figure 4): participants who selected a more coherent reading order get faster reaction times ( $M = 149.14; SD = 30.62$ ) than subjects who had selected a less coherent reading order ( $M = 199.70; SD = 68.57$ ). Regarding average cognitive load during link selection, there was a marginally significant main effect of reading order ( $F(1,37) = 3.02; p = .09$ ). Readers selecting a low coherence reading order seem to have suffered more cognitive load during the link selection process ( $M = 261.75, SD = 95.67$ ) than those that selected a high coherence reading order ( $M = 220.56, SD = 82.79$ ). No significant main effect for number of links and no interaction effects were found (all  $F$ 's  $< 1$ ). See Table 4 for details.

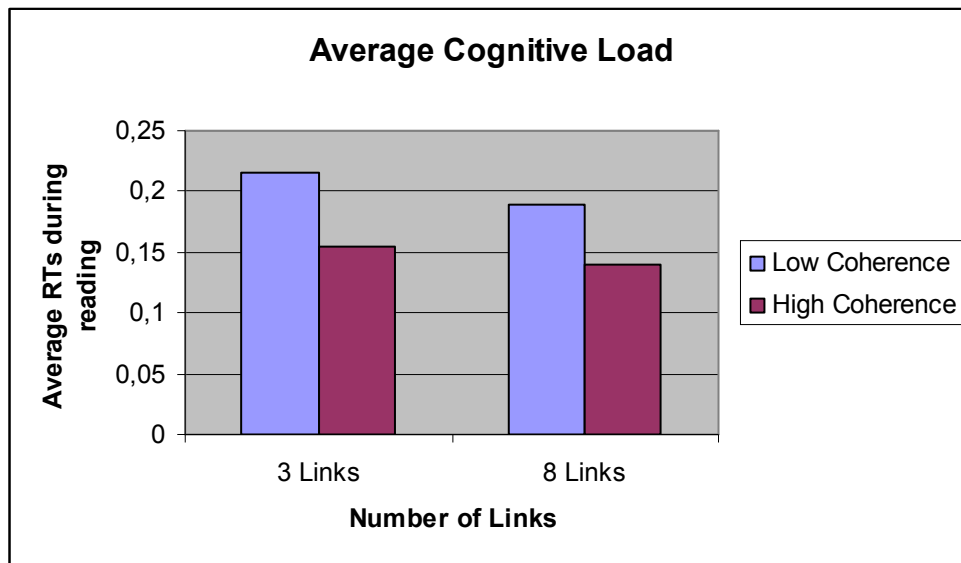


Figure 4. Average cognitive load during reading

Table 4. Average cognitive load (RTs in milliseconds) for number of links and reading order

	3 Links		8 Links	
	Low Coh.	High Coh.	Low Coh.	High Coh.
	Mean (SD)	Mean (SD)	Mean(SD)	Mean(SD)
Average cognitive load (Reading)	215.83(88.14)	154.86(31.73)	189.78(55)	139.84(28.17)
Average cognitive load (Link selection)	267.34(96.80)	235.96(78.94)	258.31(98.76)	195.54(88.02)

### 6.2. Reading and link selection times

A set of 2x2 ANCOVAs using number of links and reading order (high or low text coherence) was performed on the link selection and reading times. Analyses revealed a main effect of number of links on link selection times ( $F(1,37) = 6.51$ ;  $p < .05$ ), participants using a 8-links hypertext need more time for selecting the link to follow than those using a 3-links hypertext. There were no significant effects of reading

order neither interaction effects (all  $F$ 's < 1). Analyses on mean reading times showed no significant differences (all  $F$ 's < 1).

### 6.3. Learning results

To test directly the effect of text coherence on learning we performed a set of ANCOVAs using reading order and number of links as independent variables. We found a marginally significant effect of reading order on inference questions scores ( $F(1,37) = 3.41$ ;  $p = .07$ ), readers selecting a high text coherence reading order performed better ( $M = 4.65$ ;  $SD = 1.84$ ) on inference questions than readers selecting a low text coherence reading order ( $M = 3.27$ ;  $SD = 1.96$ ) (see Figure 5). There was not any effect of number of links or interaction effect. No significant effect was found on pathfinder networks similarities, although it presents the same tendency (higher scores for those selecting a higher text coherence reading order,  $M = 0.278$ ;  $SD = 0.122$  compared with those selecting a lower text coherence reading order,  $M = 0.258$ ;  $SD=0.072$ ) as the results on the inference questions. No effect on textbased questions reached significance level. See Table 5.

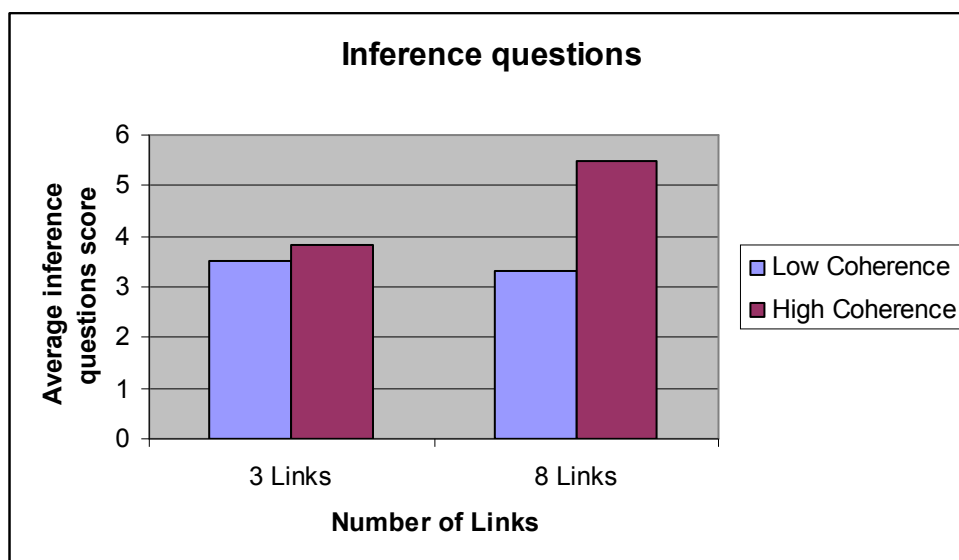


Figure 5. Mean inference questions score for number of links and reading order

Table 5. Mean scores on learning measures for number of links and reading order analyses

	3 Links		8 Links	
	Low Coh.	High Coh.	Low Coh.	High Coh.
	Mean (SD)	Mean (SD)	Mean(SD)	Mean(SD)
Textbased questions	10.12(3.14)	9.85(4.00)	10.15(3.67)	13.125(3.18)
Inference questions	3.50(1.07)	3.85(2.19)	3.31(1.84)	5.50(2.14)
Pathfinder C	0.23(0.06)	0.25(0.09)	0.27(0.07)	0.32(0.16)

#### 6.4. Discussion

The results obtained using reading order as independent variable are consistent with those obtained in the previous analyses and add new information. Readers that are able to select a high coherent reading order learned more at situation model level than those who fail in selecting a coherent reading order, independently of the number of links presented in the hypertext.

Regarding cognitive load, there are two significant effects. First, readers selecting a low coherent order suffer more cognitive load during reading than those selecting a high coherent order. No effect of number of links was found. Thus, the most relevant factor for cognitive load during reading was text coherence.

Second, subjects who were able to select a high coherent reading order also seemed to have suffered less cognitive load during link selection than those subjects who selected a low coherent reading order. Those readers with problems when selecting the most coherent link suffered higher cognitive load. The lack of effect of number of links on cognitive load during links selection can be interpreted by reminding that cognitive load depends on the interaction between task features and user characteristics.

Readers can avoid high cognitive load either with 8 or 3 links if they have the needed abilities for a successful navigation. This abilities may include prior knowledge but also experience with computers and hypertext systems, reading abilities, logical reasoning, etc.

Finally, readers selecting a high coherent reading order suffered less cognitive load during reading and obtain a better learning result than those selecting a low coherent one. This finding is experimental evidence for the usefulness of those hypertext designs and navigation support systems directed to enhance the coherence of the reading order, especially for novices.

## **7. CONCLUSION**

Hypertext design is directed not only to enable information access in an easy way, but also to lead to an optimization of readers' allocation of cognitive resources and to an enhancement in learning. This study was intended to assess the role of some hypertext features based on predictions extracted from Cognitive Load Theory (Sweller, 1988; Kirschner, 2002; Paas & van Merriënboer, 1994) and the Construction - Integration model of text comprehension (Kintsch, 1988, 1998).

This study started with predictions by DeStefano and LeFevre (2007) regarding the effect of number of links on cognitive load and learning. Results did not show any evidence of an increase in cognitive load during link selection when more links were presented nor a reduction in cognitive load when link support was offered. Actually, we found that the increase in cognitive load seems to be directly influenced by the way in which participants read the content. In other words, the coherence realized by the selected reading order mediates the amount of cognitive load that readers experience.



Our results also indicate that reading order directly affects learning as well. Participants selecting a high text coherence reading order not only suffered less cognitive load but achieved a better learning at situational level than those selecting a low text coherence reading order.

A possible explanation of the lack of effect of number of links on cognitive load can be the way in which links options were offered. DeStefano and LeFevre predicted effects of the number of links on cognitive load when links were embedded in text, in our experiment however, links were presented in a menu. The reason for this choice is that in this experiment we were also interested in assessing if the effects on cognitive load could be different during reading and during link selection, so links were separated from text. In future experiments, it will be interesting to examine the effects of the number of embedded links on cognitive load.

On the other hand, giving navigation support in the form of link suggestions based on semantic similarity (Salmerón et al., 2006b; Van Oostendorp & Juvina, 2007) helps users in navigation and learning. As predicted, most of the participants selected then a high coherence reading order and subsequently achieved better learning.

Hypertext design and educational implications from this study are related with the role of learner's control in learning with hypertext. Scheiter and Gerjets (2007) have argued that the effectiveness of hypermedia depends on how learners make use of this control. In our experiment most participants controlled their learning by means of their navigational choices. However, when using more complex hypertexts or more difficult domain knowledge than the one used in this experiment (i.e. learning about a topic that is completely new and/or very complex) the learner's ability to select the correct reading order probably decreases. In situations like this, the use of hypertext support

based on semantic similarity measures such as the one explained in this paper seems to be of big help.

Some limitations of this study are associated with characteristics of both the participants and the materials used in it. The level of prior knowledge or expertise is a reader characteristic that clearly influences learning. Indeed, some studies have demonstrated that techniques that are effective with low knowledge learners can be ineffective or even have negative consequences for learner with higher knowledge level (this is what is known as the expertise reversal effect, see Kalyuga, 2007 for a recent review). We tried to control for prior knowledge by only recruiting students that were unfamiliar with the topic of the materials used in the experiment. However, variations in prior knowledge inside our group of novices were still large, and in several analyses prior knowledge reached statistical significance as covariate. In future research a deeper analysis of the role of prior knowledge and navigational support in hypertext performance seems to be worthwhile.

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### **APPENDIX III.**

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*An earlier version of the following manuscript was published as:*

Madrid, R.I. & Cañas, J.J. (2009). The effect of reading strategies and prior knowledge on cognitive load and learning with hypertext.

*The Open Ergonomics Journal, 2, 124-132.*



**Abstract:** Variables such as reading strategies, prior knowledge and cognitive load are claimed to be related with comprehension and learning with hypertext systems. This study examined the effect of two different hypertext reading strategies (coherence vs. interest) and two prior knowledge levels (low vs. high) on cognitive load and learning outcomes. For low prior knowledge readers, data revealed that following a coherence strategy led to lower cognitive load during reading and better learning outcomes at situation model level. For high prior knowledge readers, following an interest strategy produced higher cognitive load during reading in comparison with a coherence strategy, but they learned equally from both strategies. These results are discussed taking into account the implication of two different components of cognitive load (extraneous and germane cognitive load).

## 1. INTRODUCTION

Hypertext is currently widely used as an essential component in both formal learning settings (e.g. higher education e-learning systems) and informal or incidental learning settings (e.g. Wikipedia). Hypertext systems have the advantage of fostering learner control, which is performed through sequencing (the order in which the learner want to access the different information units) and selection or content control (which contents to read from a set of documents) (Scheiter & Gerjets, 2007). The specific rules that hypertext users follow for sequencing and content control are known as reading strategies (Madrid & Cañas, 2007; Salmerón, Kintsch & Cañas, 2006).

Fostering learner control should lead to better learners' motivation, engagement and, subsequently, learning. However, in a recent review on learner control and hypermedia learning (Scheiter & Gerjets, 2007), the authors claimed that the effectiveness for learning of learner control has been shown not to be general, being affected by both system and learner characteristics. For example, there is summative evidence showing that low prior knowledge learners encounter problems using hypertext, which may be more suited for more expert learners (see Chen, Fan & Macredie, 2006 for a review).

Additionally, the authors also reviewed studies that suggest that the cognitive resources used up for learner control will not be available for learning, and if the requirements are high it can lead to cognitive overhead and impairment in learning. Therefore, an important question is under which circumstances learner control leads to high cognitive load and impairment on learning.

In this study, we examined the effects of two different reading strategies - used by low and high prior knowledge learners - on cognitive load and learning.

### 1.1 Reading strategies and prior knowledge

The C-I model of text comprehension (Kintsch, 1988, 1998; van Dijk & Kintsch, 1983) consider text coherence and prior knowledge as the main variables affecting text comprehension. Text coherence is a complex construct that depends on several factors, but it can be defined in a simple way as the extent to which a reader can understand the relations between ideas expressed in a text (Britton & Gülgoz, 1991). In some linear

text reading studies it has been shown a learning reverse effect (McNamara, 2001; McNamara, E. Kintsch, Songer & W. Kintsch, 1996; McNamara & Kintsch, 1996). Low prior knowledge (LPK) readers find high-coherence texts beneficial since they don't possess the necessary background knowledge to infer information that is not directly stated in the text. However, high prior knowledge (HPK) readers learn more with a low-coherence text. The explanation of this reverse coherence effect is that HPK readers are less likely to use their prior knowledge if the text is highly coherent, while reading a less coherent text activates their prior knowledge through inferential processes leading to better learning.

In hypertext comprehension studies, text coherence has been also shown to be important for learning, with the particularity that it can be modified through the reading strategies that readers follow (Madrid & Cañas, 2007; Salmerón, Cañas, Kintsch & Fajardo, 2005; Salmerón et al. 2006). Reading strategies can be understood as general navigation rules that users follow to select what hypertext contents to read (selection or content control) and in which order (sequencing). Several strategies have been examined, but the main ones seem to be coherence, interest and link location strategies (Protopsaltis, 2008; Salmerón et al. 2006).

For example, in two experiments Salmerón, Kinstch and Cañas (2006) examined the effects on comprehension of different criteria for selecting links, being the main ones coherence and interest:

a) Coherence strategy consists in selecting the link most related with the text just read. As stated before, text coherence in hypertext depends also on learners' control, since the reading order selected by the readers determines the coherence of the reading sequence (Salmerón et al. 2005).

b) Interest strategy is based in selecting first the links that seems most interesting to the reader, delaying the reading of the less interesting ones. Therefore the interest strategy should produce a less coherent reading sequence than the coherence strategy.

The results of the experiments conducted by Salmerón, Kintsch and Cañas (2006) showed that readers following these different reading strategies obtained different comprehension outcomes depending of their prior knowledge level: LPK readers achieved better comprehension with the coherence strategy than with the

interest strategy, but readers with higher knowledge comprehended the contents equally well using the coherence or the interest strategy. Moreover, the results suggested that the effects of reading strategies on comprehension are achieved through two different mechanisms. The first is text-induced, as in linear text reading a high-coherence text is better for LPK readers than reading a low-coherence one. On the other hand, readers with some knowledge can obtain benefits from reading low-coherence texts since this process helps them to avoid the shallow processing caused by high-coherence texts (E. Kintsch & W. Kintsch, 1995; McNamara, 2001). The second mechanism is a strategic influence: for readers with some prior knowledge following a strategy to select the reading order activates their prior knowledge and automatically mobilizes cognitive resources for learning. On the contrary, LPK readers did not get benefits from the strategic influence and they don't achieve better learning compared with reading a linear text with the same coherence level. In summary, HPK are affected both by the text-induced and the strategic influence mechanism which allow them to avoid the reverse cohesion effect found in linear text research. Therefore they learned equally both from the coherence or the interest strategy, while LPK readers are affected only by the text-induced mechanism and they achieved a better learning when they used a coherence strategy.

## **1.2 Cognitive load during hypertext reading**

The Cognitive Load Theory (CLT) aims to guide instructional design decisions based on the way in which cognitive resources are used during learning (Paas, Renkl & Sweller, 2004; Sweller, 1994; Sweller, van Merriënboer & Paas, 1998). The theory distinguishes between three types of cognitive load (CL): intrinsic CL, extraneous CL and germane CL. Intrinsic CL depends on prior knowledge and the nature of the materials to be learnt (interactivity between elements). Extraneous CL is the mental effort required by poorly designed tasks that is ineffective for learning, while germane CL (effective for learning) concerns activities related with the construction of schemas and automation leading to higher levels of comprehension. For an instructional design (e.g. educational hypertext) to be effective for learning, extraneous CL has to be reduced and germane CL has to be enhanced.

In the context of hypertext reading, CL has been analyzed to study their relation with learning (DeStefano & LeFevre, 2007; Zumbach & Mohraz, 2008). From the point

of view of the human cognitive system characteristics, hypertext navigation requires a large amount of cognitive resources to plan navigation, assess the relevance of the information found and comprehend the information and to integrate it with prior knowledge. In a recent review, DeStefano & LeFevre (2007) claimed that, compared with linear text, hypertext tasks requires extra working memory resources to be allocated to decision and comprehension processes. This increase could lead to comprehension problems, mainly for low knowledge readers. They argued that this CL increase comes from two sources. First, from the decision-making processes needed to perform navigation. Second, from the difficulty of reading and comprehending when links followed lead to read information semantically unrelated with the previously read contents, which can hinder the construction of situation models. Based on these arguments, DeStefano and LeFevre predicted that 1) if more links are offered in the hypertext, the CL related with decision making would be higher, and 2) offering only those links that lead to closely related information would reduce CL.

To test these predictions, Madrid, van Oostendorp and Puerta Melguizo (2009), run an experiment in which different types of hypertext presentations (3 vs. 8 links menu, showing or not link suggestions based on semantic relatedness) were used by LPK readers to test their CL level and learning. Participants were instructed to follow a coherence strategy, selecting after reading each text the link that they thought that were more related with the just read contents. Participants had to read all the hypertext contents, and therefore learner control in the experiment was limited to sequencing (they were not allowed to select what contents to read). Their achieved reading text coherence was measured, and two groups of low and high text coherence reading orders were constructed. Participants selecting a high text coherence reading order suffered less CL both during reading text contents and during link selection, and achieved a better learning than those selecting a low text coherence reading order. The results showed that CL during hypertext reading was mediated by the reading order that readers followed. This experiment only partially supported DeStefano and LeFevre's predictions, but confirmed the role of reading text coherence both in CL and learning, particularly for LPK readers.

Moreover, the experiment from Madrid, van Oostendorp and Puerta Melguizo (2009) showed that readers' activities are more important for learning than hypertext



design characteristics. In a similar way, Gerjets and Scheiter (2007) proposed an extension of the CLT based on the assumption that instructional design is not directly determining cognitive load, but it is moderated by learning activities.

As it has been shown before, readers' prior knowledge is a main variable affecting learning with hypertext systems. However, there is little research concerning the role of prior knowledge on CL during hypertext reading. An exception is the study carried out by Amadiou, Tricot and Marinee (2008) who conducted two experiments exploring the relation between prior knowledge, CL, navigation and learning. Although one of the experiments failed to find differences between low and high knowledge readers in CL, the results of the other experiment suggested that prior knowledge could have a negative relation with CL (i.e. the higher the prior knowledge, the lower the CL).

Summarizing, the studies described above suggest that certain features of reading strategies (as reading text coherence, i.e. text-induced mechanism) and readers' prior knowledge affect CL and, subsequently, they could determine learning. However, it is needed to emphasize that the relationships between CL and learning would be misunderstood if the nature of CL is not considered. In this sense, the study from DeStefano and LeFevre focused in the idea that the more CL invested in hypertext, the worse the performance. This statement should be only true if CL exceeds the limits of working memory (Xie & Salvendy, 2000). On the contrary, if CL remains within the limits of working memory, a higher investment of mental effort could also produce better learning when the extra resources are used for active processing (Zumbach, 2006).

## **2. RESEARCH OBJECTIVES**

This study is an extension of the line of research started by Madrid, Van Oostendorp and Puerta Melguizo (2009). Their experiment had two main limitations concerning the role of cognitive load in hypertext reading.

First, only low prior knowledge readers participated in the experiment, who according to the results of a previous study (Salmerón, Kintsch & Cañas, 2006) are only influenced by the text-induced mechanism (i.e. there is not a strategic influence of following a reading order). Since readers who performed a less coherent reading order

got higher CL during reading and worse learning, we can reach the conclusion that the increase in CL was mainly composed of extraneous CL. However, for readers with some prior knowledge, following a less coherent reading order could lead to better learning. Moreover, the strategic influence mechanism could produce germane CL for HPK readers that are not available for LPK readers. Therefore, to test the hypothetical effects of the strategic influence mechanism on CL, new experiments are needed in which learners with higher prior knowledge are also included.

Second, to control for the effect of different strategies all the participants were instructed to follow the coherence strategy. However, trying to achieve high reading text coherence is not the only reading strategy that readers could perform, and following different reading strategies may have differential effects on CL as it does on learning (Salmerón, Kintsch & Cañas, 2006). This effect could be mainly relevant during link selection, since different reading strategies could need different amounts of resources to assess the relevance of link labels for their goals, but also during reading, since different reading strategies could lead readers to focus in different aspects of the text. Supporting these ideas, evidence coming from the field of cognitive ergonomics shows that people that use alternative strategies for doing a task differ in the amount of mental effort needed for task performance (Brainbridge, 1974; 1998).

To solve these limitations, in this study we tested the effect of different reading strategies at different levels of prior knowledge on CL and learning. As in the experiment from Madrid, Van Oostendorp and Puerta Melguizo (2009), the participants read all the contents and they could only control sequencing. The aim of this experiment was two-fold:

**1) *The effect of reading strategies on CL:*** We examined the way in which two different reading strategies – coherence and interest - could affect the CL that low prior knowledge (LPK) readers and high prior knowledge (HPK) readers experience during hypertext reading. For both LPK and HPK readers, we predicted that the coherence strategy would produce higher CL during link selection than the interest strategy, since performing the coherence strategy requires several semantic relatedness judgments to select the most related link, while the interest strategy only needs of personal preferences decisions which a priori would consume less cognitive resources. Conversely, we expected that both LPK and HPK readers following the interest strategy

would experience higher levels of CL during reading - because of the lower reading text coherence achieved using that strategy - than those following the coherence strategy.

**2) *The relation between reading strategies, CL and learning:*** We tested the effect of reading strategies and prior knowledge on learning, and putting together with CL, we used the overall pattern of results to analyze the relation between CL and learning. Since all participants read the same amount of information, is expected that differences in learning caused by the type of strategy used will appear on situation model measures, but not on textbase measures. According with Salmeron, Kintsch and Cañas (2006) and the Cognitive Load Theory (Paas, Renkl & Sweller, 2004), we expected that the increase of CL during reading for LPK readers using an interest strategy in relation with those using the coherence strategy would be mainly composed of extraneous CL, and therefore their learning would be lower. On the other hand, for HPK readers both strategies could be good for learning: by using the interest strategy they probably obtain reading orders with lower text coherence and a higher overall CL, but they could transform the extra processing into germane CL during reading. Additionally, based on the strategic influence mechanism, HPK readers could use coherence breaks to activate prior knowledge and invest extra germane CL if they follow a coherence strategy, and therefore they could avoid the shallow processing induced by high coherence texts.

### **3. METHOD**

#### **3.1 Participants**

Fifty-six students of the University of Granada participated in the experiment. Half of them were second-stage Psychology students (at least 3 years studying Psychology), and the other half were Psychology freshmen (less than one semester studying Psychology) or students from other disciplines (Education, Language or Sport Sciences) with only an introductory course on Psychology. They received course credits for their participation.

#### **3.2 Design**

The study followed an experimental 2x2 design with type of reading strategy (coherence vs. interest) and prior knowledge level (low vs. high prior knowledge) as

independent variables. We used two kinds of dependent variables: cognitive load measures and learning measures. To measure cognitive load we used, average reaction times to a secondary task (both during text reading and during link selection) and reading and link selection times. To measure learning we use three different measures: a textbase questionnaire, an inference questionnaire and a relatedness judgment task.

### 3.3 Materials

Participants read a text in Spanish about Neuropsychology, extracted from a General Psychology introductory e-book. The text had 4599 words and was divided into 21 pages.

After reading each text page, readers went to the link selection menu, where they had to select the next text to read within 8 options. The menu was constructed by showing the two most related links with the text just read, and six links more that were extracted randomly from the list of link labels.

Participants had to select the next text to read following the specific instructions for their type of strategy condition. Participants in the coherence condition had to select the link that they assessed as the most similar to the text just read. Readers that were assigned to the interest condition had to select the link that they assessed as the most interesting to them.

### 3.4 Measures

#### Prior knowledge

**Prior knowledge score:** Participants were recruited from two distinct sources to allow for manipulations in their prior knowledge level on Neuropsychology. Additionally the participants were pre-tested before the reading phase using a prior knowledge questionnaire, containing ten questions reflecting general knowledge about the brain.

#### Reading strategies

**Reading text coherence:** Based on the reading order followed by the participant, we computed the mean LSA cosine of their text transitions (see Salmerón et al., 2005 for a detailed explanation of this method). This measure can be used as an index of the

coherence of the reading order followed by the readers (Madrid, van Oostendorp & Puerta Melguizo, 2009; Salmerón et al. 2005; Salmerón, Kintsch & Cañas, 2006).

### Cognitive Load

***RTs to secondary task:*** This technique has been widely used to measure the CL associated with different experimental treatments (Bonnardel & Piolat, 2003; Britton & Tesser, 1982; Brünken, Plass, & Leutner, 2003; Kellog, 1987). It requires participants to perform the main task or primary task while responding to random beeps as quickly as possible (secondary task). RTs to beeps are slower when the cognitive requirements of the primary task are higher, and therefore they can be used to measure the CL associated with performing a certain task. This measure has been shown to be sensitive to extraneous CL and inefficient learning (Brünken et al., 2004; DeLeeuw & Mayer, 2008; Madrid, van Oostendorp & Puerta Melguizo, 2009).

In our experiment, at the beginning of the session participants had to react as quickly as possible to 10 beep sounds presented randomly to obtain their RT baseline. During hypertext reading, participants had to press the “z” key as soon as possible when a beep was presented through the headphones. Their data was corrected by subtracting the baseline RTs. Variations in RT’s reveal the cognitive capacity allocated to the primary tasks: reading or selecting links. Consequently, we computed the corrected RTs separately when selecting links and when reading the text fragments.

Several measures of cognitive load derived from RTs can be computed (Xie & Salvendy, 2000). In our analyses, we will use the average RTs both for reading and selecting links which reflects the intensity of the cognitive load carried out during the task. However, some authors have claimed that not only the intensity but also the duration of the CL is relevant (de Bruijn, de Mul & Van Oostendorp, 1992; Paas, Tuovinen, Tabbers & Van Gerven, 2003).

***Reading and link selection times:*** To cope with the duration aspects of CL, the time spent during reading and during link selection was measured and analyzed separately. Time has been used to test the cognitive load required both in reading (e.g., Just & Carpenter, 1992) and in menu navigation tasks (e.g., Hochheiser & Schneiderman, 2000). Link selection times were recorded in seconds for each page,

starting when the link menu was shown and finishing when a link label was clicked. Reading times were measured in seconds for each hypertext page. A total reading and total link selection time was computed for each subject by adding the times spent for each task in each page.

### Learning Measures

Several mental representations are constructed in the process of learning from text (Kintsch, 1994). The textbase and the situation model can be considered the most important for learning. Textbase are constructed as a hierarchical propositional representation of the information contained in the text. Situation model is considered the deepest mental representation, formed when the textbase propositions are integrated with prior knowledge. We constructed a questionnaire with questions based on the text to measure textbase acquisition, and a relatedness judgment task and a questionnaire with inference questions to measure situation model acquisition.

***Textbase questionnaire:*** A set of 21 multiple choice questions (one per text page) was presented after reading the hypertext. It was constructed in such manner that the question and the answer could be found in the same hypertext page, so there was no need of inferences to respond to it. Chance performance was at 25 %.

***Relatedness judgment task:*** The task required participants measuring the relation between 91 pairs of concepts (as combination of the 14 most relevant concepts in the text, Madrid, Van Oostendorp & Puerta Melguizo, 2009). Participants had to rate pairs of concepts by using a scale from 1 to 6, in which 1 means “Highly related” and 6 means “Low Related”. Pathfinder Algorithm (see Dearholt & Schvaneveldt, 1990) was used to obtain a similarity index between readers’ conceptual network and that of an expert in Psychobiology. This method has been shown to be useful to measure comprehension at situation model level (Britton & Gülgöz, 1991).

***Inference questionnaire:*** In this experiment, a questionnaire composed of ten inference questions was administered to all participants after they completed the hypertext reading task. It was constructed in such manner that the questions and the answers appeared in different hypertext pages. The score in this questionnaire was used as a measure of situation model acquisition. Chance performance was at 25%.

#### 4. RESULTS

All results were considered significant when  $p < .05$ , and marginally significant when  $p$  values were between  $.05$  and  $.10$ . Effect sizes are included for proper interpretation. The data of one participant was excluded from the analyses as extreme outlier. Therefore the following results are based in a sample of 55 participants.

##### 4.1 Preliminary analyses: Reading strategies and prior knowledge

Two 2x2 ANOVA analyses were conducted to test the independent variables used in this study against two objective measures: reading text coherence and prior knowledge questionnaire score. Table 1 shows a summary of descriptive statistics.

**Table 1. Mean and SDs (between parentheses) for reading text coherence and prior knowledge scores**

	Low Knowledge		High Knowledge	
	Coherence	Interest	Coherence	Interest
Prior knowledge questionnaire scores	4.46 (1.39)	3.43 (1.16)	7.0 (1.92)	7.36 (1.55)
Reading text coherence (LSA cosines)	0.309 (0.049)	0.206 (0.059)	0.324 (0.046)	0.216 (0.068)

##### Prior knowledge score

The results showed a main effect of prior knowledge level (low vs. high) on the prior knowledge questionnaire score ( $F(1,51)=61.10$ ,  $p<.001$ , partial  $\eta^2=0.55$ ). The participants in the high prior knowledge group scored higher on the prior knowledge questionnaire ( $M=7.18$ ,  $SD=0.29$ ) than those in the low prior knowledge group ( $M=3.95$ ,  $SD=0.30$ ). There was not main effect of type of strategy and no interaction effect (all  $p$ 's  $> .1$ ).

##### Reading text coherence

In order to confirm the effect of following different reading strategies on reading order (sequencing), a preliminary ANOVA analysis was performed using type of strategy and prior knowledge level as independent variable and reading text coherence as dependent variable. Results showed a main effect of type of strategy ( $F(1, 51) = 48.18$ ,  $p < .001$ , partial  $\eta^2=0.46$ ). The participants in the coherence condition selected a

more coherent reading order (i.e. higher mean LSA cosine) ( $M = 0.317$ ,  $SD = 0.047$ ) than those in the interest strategy ( $M = 0.211$ ,  $SD = 0.011$ ). No other results reached significance (all  $p$ 's  $> .1$ ).

#### 4.2 Cognitive load measures: RTs to secondary tasks and reading and link selection times

A set of 2x2 ANOVAs was performed using prior knowledge and type of strategy as independent variables, and reading text coherence, mean RTs and reading and link selection times as dependent variables. See Table 2 for a summary of mean and SD results per group.

**Table 2. Mean and SDs (between parentheses) for the cognitive load dependent variables used**

	Low Knowledge		High Knowledge	
	Coherence	Interest	Coherence	Interest
Average reaction times (link selection)	202 (61.5)	216 (105.7)	198 (82.4)	276 (73.8)
Average reaction times (reading)	150 (29.7)	135 (68.6)	151 (59.4)	180 (68.5)
Link selection times	293.77 (127.74)	162.86 (65.88)	225.14 (90.20)	147.86 (60.08)
Reading times	1561.92 (361.33)	1783.35 (306.01)	1199.43 (300.47)	1340.66 (419.08)

##### Reaction times to secondary task

Average reaction times during reading: Contrary to our expectations, results on mean reaction times during reading did not reach statistical significance (all  $p$ 's  $> .1$ ).

Average reaction times during link selection: Results showed a significant main effect of type of strategy ( $F(1, 51)=4.25$ ,  $p < .05$ , partial  $\eta^2=0.08$ ). Readers using the interest strategy got higher reaction times ( $M = 246$ ,  $SD = 94$ ) than those using the coherence strategy ( $M = 200$ ,  $SD = 72$ ). There were not main effects of prior knowledge or interaction effects (all  $p$ 's  $> 0.1$ ).

Figure 1 shows the results both for link selection and reading RTs.



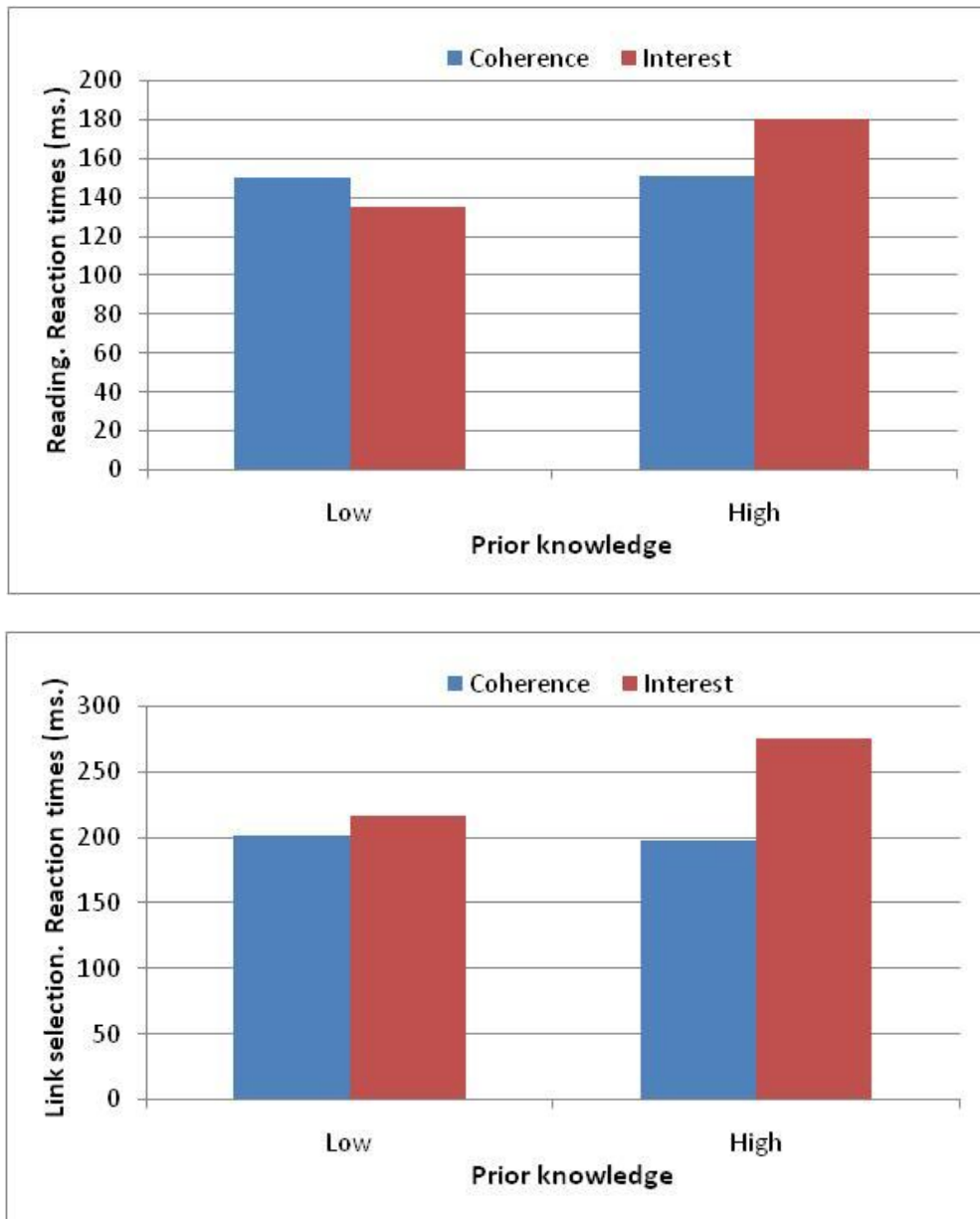


Figure 1. Average reaction times during link selection (left) and during reading (right).

#### Reading and link selection times

Figure 2 shows the results both on link selection and reading times.

**Link selection times:** Time devoted to link selection was higher for those using the coherence strategy ( $M = 259.46$ ,  $SD = 17.16$ ) than for those using the interest strategy ( $M = 155.36$ ,  $SD = 16.84$ ), ( $F(1, 51) = 18.75$ ,  $p < .001$ , partial  $\eta^2 = 0.27$ ). A main effect of PK was found marginally significant ( $F(1, 51) = 3.02$ ,  $p < .09$ , partial  $\eta^2 = 0.06$ ), LPK readers seem to expend more time selecting links ( $M = 228.31$ ,  $SD =$

17.16) than HPK readers ( $M = 186.50$ ,  $SD = 16.84$ ). The interaction did not reach significance ( $p > .1$ ).

**Reading times:** Results showed a main effect of prior knowledge ( $F(1,51)=18.19$ ,  $p < .001$ , partial  $\eta^2=0.26$ ), LPK readers devoted more time to reading ( $M= 1672.64$ ,  $SD = 67.37$ ) than HPK readers ( $M = 1270.05$ ,  $SD = 66.11$ ). The analyses also showed a marginally significant effect of type of strategy ( $F(1,51)=3.69$ ,  $p=0.06$ , partial  $\eta^2=0.07$ ), the interest strategy group seems to have devoted more time to reading ( $M=1562$ ,  $SD=66.11$ ) than the coherence strategy group ( $M=1380.68$ ,  $SD=67.38$ ). The interaction did not reach significance ( $p > .1$ ).

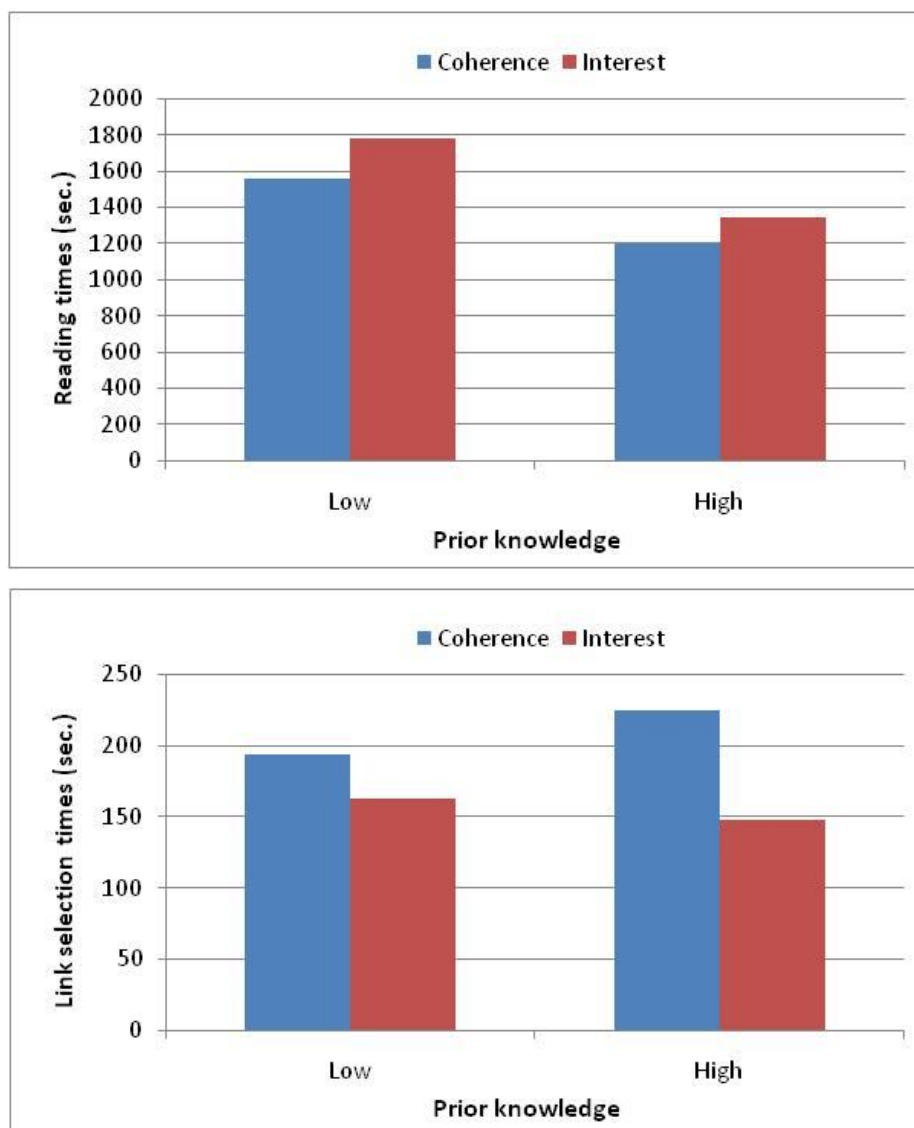


Figure 2. Results on link selection times (down) and reading times (up)

### 4.3 Learning measures: Score on textbase and inference questionnaires and judgment relatedness task

A 2x2 ANOVA was performed using prior knowledge and type of strategy as independent variables, and inference questions score as dependent variable. Mean and standard deviation are showed in Table 3. See also Figure 3 for a graphical representation.

**Table 3. Mean and SDs (between parentheses) for the learning dependent variables used**

	Low Knowledge		High Knowledge	
	Coherence	Interest	Coherence	Interest
Textbase questionnaire	9.15 (1.99)	9.57 (3.18)	13.29 (3.60)	13.5 (4.20)
Relatedness judgment task	0.254 (0.077)	0.256 (0.067)	0.360 (0.092)	0.319 (0.045)
Inference questionnaire	4.15 (1.91)	2.79 (1.37)	4.86 (1.99)	5.71 (1.94)

#### TEXTBASE ACQUISITION

**Textbase questionnaire.** Results showed a main effect of prior knowledge ( $F(1,51)=19.70$ ,  $p < 0.001$ , partial  $\eta^2=0.28$ ). Low prior knowledge readers scored lower ( $M=9.37$ ,  $SD=2.63$ ) than high prior knowledge readers ( $M=13.39$ ,  $SD=3.84$ ). No additional significant effects were found ( $p > .1$ ).

#### SITUATION MODEL ACQUISITION

**Relatedness judgment task.** Analyses of pathfinder similarity measures showed a significant main effect of prior knowledge ( $F(1,51)=18.82$ ,  $p < .001$ , partial  $\eta^2=0.27$ ). High prior knowledge readers scored higher ( $M=0.339$ ,  $SD=0.07$ ) than low prior knowledge readers ( $M=0.255$ ,  $SD=0.07$ ) in this task. There was not significant main effect of type of strategy or interaction effect ( $p > .1$ ).

**Inference questionnaire.** Results showed a main effect of prior knowledge ( $F(1, 51) = 13.70$ ,  $p = .001$ , partial  $\eta^2=0.21$ ), and a significant interaction effect ( $F(1, 51) = 5.14$ ,  $p < .05$ , partial  $\eta^2=0.09$ ) (See Table 2 and Figure 3). Pairwise comparisons showed that LPK readers seem to acquire a better situation model when using the coherence strategy ( $M= 9.15$ ,  $SD=1.99$ ) than when using an interest strategy ( $M=0.57$ ,  $SD=3.18$ )

(near significant,  $F(1,51)=3.82$ ,  $p=0.56$ , partial  $\eta^2=0.07$ ), but no differences were found for HPK ( $p > .1$ ). Comparisons also showed that HPK readers scored higher on the inference questionnaire ( $M=13.5$ ,  $SD=4.2$ ) than LPK readers ( $M=9.57$ ,  $SD=3.18$ ) when they used an interest strategy ( $F(1,51)=18.16$ ,  $p<.001$ , partial  $\eta^2=0.26$ ), but both learned equally when they use the coherence strategy ( $p > .1$ ).

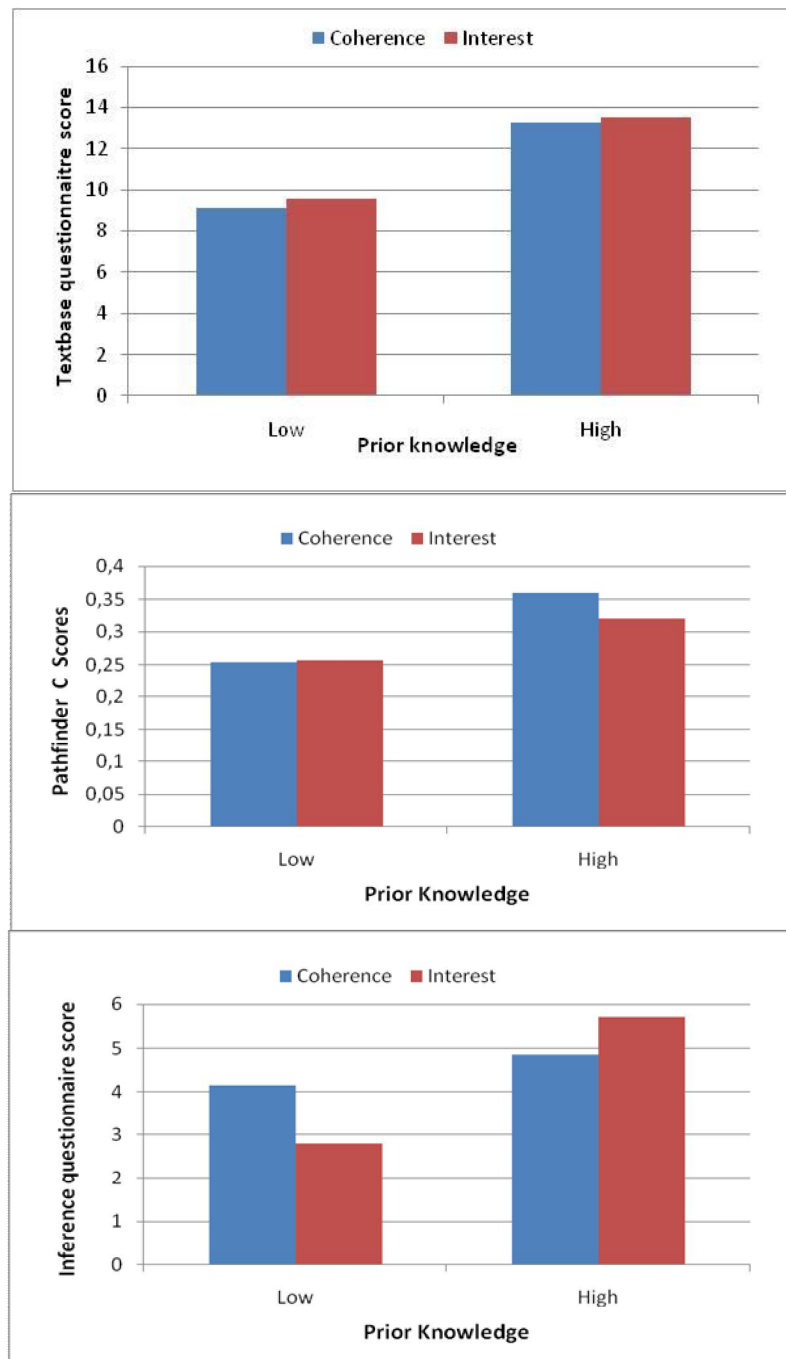


Figure 3. Data on the textbase questionnaire, the relatedness judgment task and the inference questionnaire.

## **5. DISCUSSION AND CONCLUSIONS**

The main objective of this experiment was to analyze the effect of reading strategies and prior knowledge on cognitive load and learning outcomes.

First of all, we assumed that the interest reading strategy would lead to a less coherent reading order than the coherence strategy. Confirming that assumption, mean LSA cosines were quite lower for those following the interest strategy.

### **5.1 The effect of reading strategies and prior knowledge on cognitive load**

We predicted that following a coherence strategy would result in higher CL during link selection both for LPK and HPK readers. This assumption was based in the nature of cognitive processes underlying link selection, since interest is an automatic and motivational process while the coherence strategy requires performing several semantic similarity comparisons between link labels and text contents which “a priori” consume more cognitive resources. Contrary to our expectations, the intensity of the CL (measured with RTs to secondary task) was higher for the interest strategy. In addition, we expected that both LPK and HPK readers using the interest strategy would experience higher CL during reading than those using the coherence strategy. However, both groups experienced a similar intensity of CL. This last prediction was based on the study from Madrid, Van Oostendorp and Puerta Melguizo (2009) that showed that those LPK readers following a reading order with lower coherence got higher intensity of CL. Although the reading text coherence for the interest strategy group was considerably lower than for the coherence strategy group their mean RTs were similar.

These results could seem difficult to reconcile with our hypotheses. However, before discussing results on CL based on intensity measures we have to take into account also the duration measures. The notion of “volume of attention” can be relevant here: both the intensity and duration of the CL are important for learning (Hidi, 1995; Reynolds, 1992). The “volume of attention” hypothesis shows the dynamics of CL: task A can be more cognitive demanding than task B, but it can be performed using the same intensity of CL if the reader devotes more time to it. Therefore, to discuss our results we also have to take into account reading and link selection times.

On the one hand, analyses of link selection times reflected that time requirements were higher for the coherence strategy than for the interest strategy, both

for LPK and HPK readers. Therefore, those readers following the coherence strategy showed higher duration but lower intensity of CL than the interest group. This pattern of CL results prevents us to make any conclusion about which strategy required higher CL, but it can be interpreted as an evidence for a different tradeoff between intensity and duration for both strategies.

On the other hand, the analyses of reading times showed that the interest strategy required more time to read contents than the coherence strategy both for LPK and HPK. Since no differences were found on the intensity of CL, it can be concluded that a higher reading and link selection times mean higher cognitive requirements for the interest condition. Conversely, in the experiment from Madrid, Van Oostendorp and Puerta Melguizo (2009), higher reading text coherence led to higher intensity of CL (average RTs) but no differences were found on reading times.

Summarizing this section, it can be argued that our prediction on the role of reading strategies on CL is partially supported. Both LPK and HPK readers who followed the interest strategy had higher CL during reading than those who followed the coherence strategy. Regarding the effect of reading strategies on link selection, those who followed a coherence strategy had not higher requirement than those who followed an interest strategy, but they showed a different tradeoff between intensity and duration of CL.

## **5.2 The effect of reading strategies and prior knowledge on learning**

In general, learning outcomes confirmed our predictions. All learning measures were affected by prior knowledge level, and HPK readers achieved a better learning than LPK readers. As expected, the type of strategy used did not affect textbase acquisition. On the contrary, the situation model construction as measured by inference questions has been shown to be affected by the type of strategy used, being this effect different for LPK and HPK readers. The score on the inference questionnaire was higher for LPK readers that used the coherence strategy than for those that used the interest strategy. Otherwise, HPK readers learn equally either using the interest or the coherence strategy.

These results also support the widespread idea that reading hypertext in a semantically unrelated order is harmful for LPK readers' learning (DeStefano &

LeFevre, 2007; Madrid et al. 2009; Salmerón et. al., 2006; Shapiro & Niederhauser, 2004).

### **5.3 The relation between CL and learning**

As this pattern of results shows, the relation between cognitive load and hypertext reading are far from being simple. Following the Cognitive Load Theory (Paas, Renkl & Sweller, 2004), there are three components of cognitive load that are additive (intrinsic, extraneous and germane cognitive load). Intrinsic cognitive load depends on the complexity of the materials and learner expertise. Extraneous cognitive load is related with inefficient learning. Finally, germane cognitive load is related with active processing and deep learning. This distinction between different types of CL is very useful from a theoretical point of view, but it has some methodological problems. First of all, experimental manipulations can influence more than one type of cognitive load at the same time, and it could have different effects on learning for LPK and HPK learners (Sawicka, 2007). Second, the techniques used to measure CL do not clearly distinguish between these CL components since they offer a global measure of CL (Paas, Tuovinen, Tabbers & van Gerven, 2003). If different measures were sensitive to different CL components, we could predict learning results based on the balance between intrinsic, extraneous and germane CL.

Recently, DeLeeuw and Mayer (2008) have discussed some research findings in the field of multimedia learning suggesting that different measures of CL (RT to secondary task, mental effort during learning and difficulty ratings) could be sensitive to different types of CL. In two experiments, participants (mainly low knowledge learners) watched different versions of a 6-minutes multimedia lesson, in which the three measures of CL were obtained. Results showed that RT to secondary task was mainly sensitive to manipulations in extraneous CL, whereas mental effort and difficulty ratings were sensitive to intrinsic and germane CL respectively. Regarding extraneous CL, the measurement method (RT to secondary task), participant characteristics (low prior knowledge) and task timing features (no differences between conditions in relation to duration of the session) were similar to those in the Madrid, Van Oostendorp and Puerta Melguizo (2009) experiment in which the group with higher RTs also achieved less learning. Comparisons with the current experiment are difficult since participants had different levels of prior knowledge and reading and link selection times were also

used as measures of CL, which a posteriori appeared as more sensitive to complexity variations than RTs. Unfortunately, the duration of the session in the DeLeeuw and Mayer (2008) experiment was kept constant for all participants and therefore the results did not offer information on which component of CL could be related with performance time. Additionally, the authors pointed out some limitations on their study and they proposed replication with different learners and materials.

In spite of this lack of distinctive CL measures, in order to explore how reading strategies, CL and learning are related, the pattern of results on CL measures and learning measures can be analyzed. However, in this discussion we will not consider CL during link selection, focusing in CL during reading. The main reason to exclude that measure is that the result on intensity and duration of CL showed an inverse relation between them and therefore there is a lack of a clear measure of CL during link selection that could be used for the comparison. Additionally, it can be argued that reading is the main task for learning with hypertext and therefore the effect of CL during link selection on learning could be overshadowed by the influence of CL during reading.

In line with prior research (DeStefano & DeFevre, 2007; Madrid, van Oostendorp & Puerta Melguizo, 2009), low knowledge participants that read the hypertext in a high coherent order - by following a coherence strategy - got lower cognitive load when reading and better comprehension than those in the interest condition (who read the hypertext in a low coherence order). This result is another support for the idea that the low reading text coherence that could be obtained by following the interest strategy leads to higher extraneous CL for LPK readers. Conversely, the pattern of results for HPK readers was different: those participants in the interest condition (who performed a less coherent reading order) got higher cognitive load than those in the coherence condition, but they achieved the same learning outcomes than those using the coherence strategy. Contrary to LPK readers, HPK readers can get higher germane CL with the interest strategy by activating prior knowledge and investing extra cognitive resources in learning. Moreover, the coherence strategy leads readers to follow a high coherence reading order which would hamper the activation of prior knowledge and would lead to extraneous CL for HPK readers, but the active selection of the reading order in the coherence strategy helps them to avoid the



shallow processing induced by high coherent texts. Therefore, it seems that for HPK readers there are a tradeoff in the coherence condition between extraneous CL and germane CL, and a higher investment of germane CL in the interest strategy. This balance of CL components helps them to learn equally from both strategies.

#### **5.4 Practical implications**

In this study we have demonstrated that using different reading strategies affect differently cognitive load, and subsequently learning with hypertext. Thus, by determining which strategy is better for a certain level of prior knowledge it is possible to match readers and strategies to enhance learning. Following this argument we can draw two practical implications of this experiment.

First, novices learn better when they follow a strategy that promotes text coherence. Indeed, some authors argue that, to maximize learning, linear text is a better instructional design than hypertext for low prior knowledge readers (e.g. DeStefano & LeFevre, 2007). However, maximize learning could be not the only reason to use hypertexts instead of linear text, and ease of access, interactivity, teacher control or economic factors could also recommend the use of an educational hypertext instead of linear text. Under these circumstances, it is important to support the learner in reading the materials in a coherent manner. In this sense, McNamara and Shapiro (2005) have proposed that it can be done with reading strategy training or including hypertext design features for user support.

Second, both low prior knowledge and high prior knowledge readers requires more time to perform an interest strategy. However, this increment is not related with a benefit in learning compared with the coherence strategy. Therefore, under instructional conditions in which duration is an important factor (e.g. educational programs defined on an hourly basis) to select a coherence strategy will be more time-saving.

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