Universidad de Granada

Cognitive Accessibility to Hypertext Systems

The role of verbal and visuospatial abilities of deaf and hearing users in information retrieval

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Accesibilidad Cognitiva a Sistemas Hipertexto
La implicación de las habilidades verbales y visuoespaciales de usuarios sordos y oyentes en tareas de búsqueda de información

Memoria para optar al grado de doctor en Psicología presentada por

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Resumen de la Tesis

El escaso conocimiento existente acerca de los problemas de accesibilidad a la Web, y a sistemas hipertexto en general, que encuentran las personas con deficiencia auditiva es debido, en gran parte, a que en este contexto suele prestarse poca atención a las consecuencias que conllevan algunos tipos de sordera a nivel cognitivo (Ej. dificultades de adquisición de lectura funcional, diferente organización del conocimiento en la memoria semántica, etc.). La serie de experimentos que se describen en esta tesis fue diseñada con el objetivo de ampliar la investigación a este respecto. Dichos experimentos se encaminaron al estudio de una tarea hipertexto específica, la búsqueda de información y su interacción con ciertas habilidades verbales y visuoespaciales de las personas sordas y oyentes (especialmente sordos pre-locutivos usuarios de la lengua de signos). Haciendo uso de la metodología experimental, se observó cómo un rango de procesos cognitivos ha mostrado ser diferencialmente relevante para personas sordas y oyentes en la tarea de búsqueda en hipertexto. Entre dichos procesos se encuentran la compresión lectora, la memoria semántica, la memoria episódica (reconocimiento) y la capacidad de almacenamiento visuoespacial de la memoria operativa. Por otra parte, el formato de la interfaz (verbal vs. gráfico), la estructura del hipertexto y la localización de los objetivos en la estructura hipertexto han mostrado interaccionar con los citados procesos cognitivos así como con la forma en que los mismos trabajan en cada tipo de usuario de hipertexto examinado. Estos hallazgos son discutidos en relación a diversos modelos de interacción Web (Ej. CoLiDes and SNIF-ATC). Finalmente, se proporcionan algunas guías de diseño Web para personas sordas o con problemas similares.

En lo que se ha dado en llamar “era digital”, la Web se ha establecido como un repositorio de información y servicios primordial que, paradójicamente, lejos de sus iniciales intenciones de mejorar y servir de apoyo al sistema cognitivo (Bush, 1954), resulta no ser igualmente accesible para todos sus usuarios, especialmente, para los usuarios sordos. Por tanto, en la actualidad ha tomado especial relevancia el concepto de Accesibilidad a la Web que se define como el grado con el que Internet y sus servicios están disponibles para todos los individuos, cualquiera que sean sus requerimientos de hardware o software, su infraestructura de red, su lengua nativa, su cultura, su localización geográfica o sus aptitudes físicas o mentales. De esta manera, en la medida que un sitio Web no se diseñe teniendo en cuenta todos estos elementos, generará problemas de accesibilidad.

Así pues, el principal objetivo de Cogniweb, el proyecto que enmarca esta tesis, fue estudiar y los problemas de accesibilidad a la Web observados en los usuarios sordos encontrar soluciones. Este objetivo práctico llevó a formular preguntas teóricas y básicas sobre procesamiento cognitivo como son ¿Cuáles son los problemas de accesibilidad cognitiva a la Web que encuentran las personas sordas? ¿Qué procesos cognitivos están envueltos en la interacción con la Web? ¿Qué capacidades o habilidades de los usuarios podrían limitar o, por el contrario, favorecer la interacción Web?, Cogniweb y la serie de 4 experimentos que se describen en esta tesis se centraron en el estudio de una tarea Web en concreto, la tarea de búsqueda de información, y su interacción con ciertas habilidades verbales y visuoespaciales de personas oyentes y sordas (principalmente personas con sordera pre-locutiva y usuarias de la lengua de signos).

El Experimento 1 fue diseñado con la finalidad de explorar la influencia de las habilidades de comprensión lectora y del tipo de estructura hipertexto en la ejecución de usuarios sordos y oyentes en una tarea de búsqueda de información. Partimos del hecho comprobado empíricamente de que las personas sordas muestran problemas en la adquisición de niveles de lectura funcionales (Leybaert et al., 1982; Marschark, 2003). Por lo tanto, la dificultad de acceso a la información textual que generalmente componen los sitios Web, estaría en el origen de los problemas de accesibilidad sufrido por este tipo de usuarios. Parece ser que el tipo de estructura hipertexto puede varias las la cantidad o el tipo de procesamiento de texto demandados (Larson and Czerwinski, 1998; and Lee and Tender, 2004). De este modo, el tipo de estructura podría contribuir a superar el problema de accesibilidad Web de los sordos. Para poner a prueba esta hipótesis, en el Experimento 1 se pidió a los usuarios que buscaran una serie de titulares de noticias en un periódico implementado en formato hipertexto. Los usuarios realizaron la tarea de búsqueda en una de las siguientes estructuras hipertexto: estructura ancha (alta proporción de links verbales por nodo/páginas y pocas capas de nodos), estructura profunda (baja proporción de links por nodo repartidos en numerosas capas de nodos) y estructura intermedia. Aproximadamente la mitad de la muestra estuvo compuesta por personas sordas signantes y la otra mitad por oyentes. Finalmente se midieron las habilidades de compresión lectora y el conocimiento previo sobre el dominio de los diferentes grupos de usuarios y se correlacionaron con la ejecución. Las variables dependientes de la tarea de búsqueda en hipertexto para los 4 experimentos fueron: porcentaje medio de objetivos encontrados, tiempo de respuesta medio para encontrar los objetivos y desorientación media durante la búsqueda.

El Experimento 2 se llevó a cabo con el fin de investigar los efectos de la sustitución de links verbales (palabras) por links gráficos (iconos) sobre la ejecución de los usuarios sordos signantes en la tarea de búsqueda en hipertexto. La hipótesis de partida fue que diferentes formatos de la información de la interfaz de un hipertexto podrían dar lugar a que los usuarios accedieran a la información almacenada en sus memorias semánticas con diferente eficiencia, lo que consecuentemente afectaría a la ejecución. De acuerdo al Efecto de Superioridad de la Imagen (Nelson, Reed and Walling, 1976), se predijo que la interfaz gráfica posibilitaría a los usuarios, principalmente a los usuarios sordos, ser más eficientes en la tarea de búsqueda. Para comprobar esta hipótesis ello se pidió a dos grupos de usuarios, sordos signantes y oyentes, que buscaran una serie de secciones de noticias en el periódico Web del experimento 1. En este caso tan sólo se usó la estructura profunda pero se varió el formato de la interfaz. La mitad de los sujetos realizaron la tarea en la interfaz verbal y la otra mitad en la interfaz gráfica (igual a la verbal salvo que los links textuales se sustituyeron por iconos altamente relacionados con su función que fueron seleccionados en un estudio normativo previo). Asimismo, se manipuló la longitud de la ruta o número de nodos que era necesario recorrer para encontrar los objetivos en la estructura del hipertexto (3 nodos vs. 4 nodos vs. 5 nodos).

Los objetivos del Experimento 3 fueron examinar el efecto de repetidas exposiciones a las mismas tareas de búsquedas y al mismo hipertexto y su interacción con los diferentes formatos de interfaz (verbal y gráfica). Por último, se exploró la contribución de ciertas habilidades visuoespaciales de los usuarios a la tarea de búsqueda. Se predijo que las diferencias entre los diferentes formatos de interfaces podrían ser suavizadas por el efecto de la experiencia. La hipótesis de partida fue que, a falta de claves semánticas, los usuarios utilizarían la memoria episódica de los ensayos previos para valorar la probabilidad de que la selección de un link llevara al objetivo. En esta ocasión sólo participaron usuarios oyentes por lo que no se hicieron predicciones acerca del tipo de usuario. Se utilizó un diseño similar al del

Experimento 2 pero en este caso los usuarios realizaron tres sesiones de búsqueda en lugar de una. Además, completaron tres cuestionarios de habilidades visuoespaciales que midieron las habilidades de rapidez perceptiva, la orientación espacial y la capacidad de visualización) que fueron correlacionados con la ejecución.

Finalmente, en el Experimento 4 se profundizó en la exploración de la metáfora espacial de hipertexto aplicando el paradigma de doble tarea, con el objetivo de analizar la implicación de los almacenes visuoespacial y fonológico de la memoria operativa en la búsqueda de información en hipertexto. De acuerdo a la metáfora espacial, si los sistemas hipertextos tienen características espaciales, la interacción con la Web demandaría a los usuarios, de alguna manera, el mismo tipo de procesamiento cognitivo demandado en espacios físicos. Por ejemplo, uno de los procesos que podrían ser puestos en juego sería la agenda visuoespacial, el almacén temporal de la información de este tipo del sistema cognitivo, ya que ha mostrado estar involucrada en tareas de navegación en ambientes físicos (Garden, Cornoldi & Logie, 2002). Para probar esta hipótesis se utilizó el paradigma de doble tarea, con el objetivo de poder establecer no sólo correlaciones entre variables (como en estudios previos de este fenómeno), si no relaciones de tipo cause-efecto. Se usó un diseño similar a los del experimento 2 y 3 pero adicionalmente se manipuló el tipo de búsqueda: búsqueda con tarea concurrente visuoespacial, búsqueda con tarea concurrente verbal, y búsqueda control. Si la tarea de búsqueda usaba recursos visuoespaciales, su ejecución se vería interferida por la realización concurrente de la tarea visuoespacial.

La organización de la tesis es la siguiente. El capítulo 2 se centra en la descripción de los principales procesos cognitivos afectados en la deficiencia auditiva y que son particularmente relevantes para la interacción con los sistemas hipertexto. El capítulo 3 presenta una revisión de los principales modelos de búsqueda de información en la Web, los procesos cognitivos implicados en dicha tarea y las hipótesis exploratorios iniciales de la tesis. Del capítulo 4 al 7 se describen detalladamente los resultados de cada experimento (cuatro en total). En el capítulo 6 se exponen las conclusiones teóricas y empíricas de la investigación.

Conclusiones Teóricas

Tal cómo era el objetivo de esta serie experimental, un amplio rango de procesos cognitivos ha resultado ser relevante para los usuarios sordos y oyentes en las tareas de búsqueda de información en hipertexto: comprensión lectora, memora semántica, memoria episódica (reconocimiento) y memoria operativa visuoespacial. Del mismo modo, se ha comprobado que la manipulación del formato o la estructura del hipertexto pueden variar el efecto de las peculiaridades en el funcionamiento de cada uno de esos procesos para ambos tipos de usuarios.

Los datos del Experimento 1 mostraron que las dificultades de comprensión lectora estaban a la base de los problemas de accesibilidad a la Web de las personas sordas signantes. Concretamente, se observó que los usuarios sordos malos lectores encontraron menos objetivos, fueron más lentos y se desorientaron más que los usuarios oyentes buenos lectores durante la tarea de búsqueda. Una de las explicaciones argumentadas es que los sordos malos lectores, no completan satisfactoriamente alguno de los componentes de la tarea de búsqueda, por ejemplo, el proceso selección entre opciones (en términos del modelo CoLiDeS). Para seleccionar un link en cada nodo del hipertexto, el usuario debe juzgar el grado de similitud semántica entre las opciones de links que aparezcan y el objetivo que desea encontrar y, para ello, tendrá que leer previamente cada opción. Si el proceso de lectura no es automático y consume gran cantidad de recursos, los usuarios, como en el caso de los usuarios sordos, verán interferido el proceso de selección (Foltz, 1996) y, por tanto, la ejecución en la tarea de búsqueda de información.

Por otro lado, el Experimento 1 reveló que el tipo de estructura hipertexto puede reducir la influencia de las dificultades lectoras en los usuarios sordos (aunque esta tendencia no fue significativa). Concretamente, las estructuras estrechas y profundas posibilitaron que los usuarios sordos encontraran más objetivos, fueran más rápidos y se desorientaran menos durante la tarea de búsqueda en hipertexto (aunque, en cualquier caso, obtuvieron índices por debajo de los usuarios oyentes). Una posible explicación podría ser que el número de ítems que deben ser leídos en cada nodo se reduce en la estructura estrecha y profunda (8 ítems) con respecto a la ancha (62 ítems), de manera que los usuarios sordos malos lectores no se verían sobrecargados por la cantidad de información simultánea. Por el contrario, los usuarios oyentes buenos lectores son más eficientes en la estructura hipertexto ancha que en la estrecha y profunda, patrón que es el más frecuentemente encontrado en la literatura (Ej. Norman, 1991; Lee and Tedder, 2004). Norman (1991) sugiere que estos resultados pueden deberse a que las estructuras profundas aumentan la incertidumbre acerca de la localización del objetivo, aumentando las demandas de procesamiento semántico e interfiriendo con la ejecución. Aunque esta variable también afectaría a los usuarios sordos (recordemos que también en esta condición obtienen peores resultados que los oyentes), no llegaría a producirles sobrecarga como en el caso de las excesivas demandas de lectura que impusieron las estructuras anchas.

Tal como se esperaría partiendo de la hipótesis de Norman (1991), en el Experimento 2, se observó que ambos tipos de usuarios obtenían peores resultados (en términos de tiempo, porcentaje de errores y desorientación) a medida que aumentaba la longitud de la ruta para encontrar el objetivo en las estructuras profundas. Además, contrariamente al Efecto de Superioridad de las Imágenes, el procesamiento semántico llevado a cabo durante la búsqueda en hipertexto parece ser más interferido por links gráficos (iconos) que por links verbales (palabras), sobre todo en el caso de los usuarios sordos. El experimento 2 mostró que el formato de la interfaz no fue relevante cuando los objetivos se localizaron en las primeras capas de nodos del hipertexto (de hecho la diferencia entre usuarios no fue significativa en estos casos). Esta variable toma relevancia con el aumento de las demandas semánticas, es decir, cuando los objetivos están en capas más profundas de la estructura. En estos últimos casos, los usuarios que realizaron tarea de búsqueda en la interfaz gráfica encontraron menor porcentaje de objetivos y fueron menos eficientes (en términos de tiempo de respuesta y desorientación) que los usuarios de la interfaz verbal.

Estos datos sugieren la reconsideración de algunos modelos de interacción hipertexto que tan sólo tienen en cuenta el proceso de búsqueda. Más bien, estos resultados apoyan la hipótesis de los modelos teóricos de búsqueda en hipertexto que consideran el procesamiento semántico como primordial para realizar la tarea (Ej. CoLiDeS, SNIF-ACT). Sin embargo, otros procesos podrían estar asimismo implicados en la búsqueda de información en hipertexto. Los usuarios podrán estar usando la familiaridad, el reconocimiento o la frecuencia de las rutas exitosas para hacer selecciones entre las alternativas (Kitajima et al., 2000; Payne et al., 2000). En ausencia de claves semánticas, como podría ser el caso de interfaces con iconos desconocidos, el reconocimiento de rutas exitosas puede ayudar a reducir la desventaja de las interfaces gráficas. De hecho, en el Experimento 3, la desventaja de las interfaces gráficas en términos de tiempo, porcentaje de aciertos y número de nodos re-visitados se redujo tras tres sesiones de búsqueda. Se asumió que este efecto fue debido a que los usuarios, después de repetidas sesiones de búsqueda, recuperaron información episódica acerca de las alternativas que fueron correctas en ensayos previos para usarla en la búsqueda actual.

El segundo hallazgo del Experimento 2 parece estar más relacionado con el *literal matching*, una de las restricciones que los usuarios tratarían de satisfacer durante la selección de links en la tarea de búsqueda en hipertexto según el modelo CoLiDeS. El *literal matching* sucede cuando la representación del objetivo que el usuario se forma es exactamente igual un elemento real presente en la interfaz. Para satisfacer esta restricción, pueden ser relevantes varias habilidades de los usuarios relacionadas con la búsqueda visual. En el experimento 3 se comprobó que los usuarios que fueron más rápidos escaseando y comparando símbolos (habilidad de rapidez perceptiva), completaron antes la tarea de búsqueda.

Considerando estos datos, y a pesar que en los experimentos previos las habilidades verbales y el procesamiento semántico han mostrado estar altamente implicados en las tareas de búsqueda, es apropiado contemplar la metáfora espacial de hipertexto. Esta metáfora establece que si los sistemas hipertexto presentan características similares a ambientes físicos, los mimos procesos cognitivos que están implicados en la navegación real deberían estar presentes en la navegación en hipertexto (Ej. La memoria operativa visuoespacial). En el Experimento 4, se utilizó la metodología de tarea doble para explorar la implicación de los dos subsistemas que componen la memoria operativa (lazo fonológico y agenda visuoespacial). Encontramos que la tarea concurrente espacial fue interferida por la tarea de búsqueda, lo que significa que los recursos de la agenda visuoespacial están siendo invertidos durante la realización de la tarea de búsqueda, por lo que no quedarían recursos suficientes para realizar dicha tarea concurrente simultanea. Auque es necesario salvar varios problemas metodológicos que surgieron en el Experimento 4, este resultado parece estar de acuerdo con los resultados de estudios de correlación y regresión previos que apoyan que los ambientes físicos y los sistemas hipertexto presentan características cognitivas similares (Ej. Zhang & Salvendy, 2001; Nilsson & Mayer, 2002). En este caso, el efecto de las ayudas usadas para mejorar la navegación en espacios físicos, debe ser explorado en el contexto de la navegación en hipertexto para usuarios sordos.

En resumen, se ha puesto de relevancia la implicación de un amplio rango de procesos cognitivos en la tarea de búsqueda en hipertexto, entre los que sobresale el procesamiento semántico y la habilidad lectora. En este sentido, en la medida en que el formato o la estructura del hipertexto no favorezcan la lectura o el acceso a la información semántica por parte de los usuarios, la ejecución se verá interferida. Este razonamiento puede ser incluso más relevante si los usuarios, debido a las peculiaridades de su sistema cognitivo, difieren en sus habilidades lectoras o en la organización y forma de acceso a la información (Experimentos 1 y 2). Por otro lado, las manipulaciones llevadas a cabo en los experimentos 3 y 4 mostraron que las habilidades y la memoria visuoespaciales repercuten en la eficiencia de la tarea de búsqueda. Aunque no queda claro el papel que cumplen, se argumenta que estarían implicadas en los procesos de *literal matching* y orientación.

Los hallazgos de los Experimentos 3 y 4, deben ser replicados en usuarios sordos signantes y se hace necesario centrarse no sólo en aquellas características limitantes sino también en aquellas que pueden favorecer su rendimiento en este tipo de tareas (por ejemplo, la memoria espacial). En este sentido, pensamos que esta tesis abre una gran cantidad de futuras líneas de investigación, señalando un rango de posibles aspectos que deberían ser considerados en la investigación de la accesibilidad a la Web de las personas sordas.

Otra conclusión, derivada de la observación de un amplio rango de procesos cognitivos implicados en la interacción en hipertexto, es la importancia de formular modelos de búsqueda en hipertexto que den cuenta de la interacción entre dichos procesos. Tal como sugiere Wright (1993), estos modelos podrían suponer un reto para la Psicología y la Ergonomía Cognitiva. Uno de las aproximaciones que más se ha encaminado a este objetivo es formulada por el modelo CoLiDeS, que propone una diversidad de procesos interaccionando como la atención y la compresión. Otras aproximaciones interesantes son el modelo SNIF-ACT (Pirolli, 2004) y el modelo de búsqueda interactiva de Howes y Payne (2001). Entre los valores de esos modelos encontramos que están basados en arquitecturas cognitivas que juegan un importante papel en el modelado de usuario (Howes & Young, 1996). Por otro lado, de acuerdo a Pirolli (2004), el problema más relevante de los modelos computacionales de rastreo de información (*information scent*) concierne al análisis de claves de información no textuales, como iconos gráficos, animaciones, etc. tomando en consideración los resultados de los tres últimos experimentos de esta tesis, este análisis no sería un asunto trivial a la hora de encontrar soluciones para mejorar la ejecución de los usuarios con problemas de accesibilidad a la Web como los usuarios sordos signantes.

Conclusiones Aplicadas

Aunque esta tesis abre numerosas cuestiones para la investigación futura, pesamos que es posible presentar un conjunto de guías de diseño derivada de nuestros resultados que pueden ser útiles para mejorar el rendimiento de las personas sordas signantes en tareas de búsqueda en hipertexto:

1) Evitar sobrecargar cada nodo del hipertexto con contenido verbal. Si no es posible o deseable quitar información verbal del hipertexto, una posible solución es distribuirlo a lo largo de capas de nodos en el hipertexto. Sin embargo, esta solución entraña ciertos riesgos como el incremento en la incertidumbre acerca de la localización de los objetivos (Norman, 1991). Por lo tanto, es necesario encontrar un compromiso entre anchura y profundidad de los diseños hipertextos.
2) Es importante tener en cuenta que la longitud del las rutas (dada por número de nodos visitados para encontrar un objetivo), aumenta el número de decisiones semánticas y la ambigüedad de las alternativas en las capas superiores del hipertexto, lo que puede afectar especialmente a los iconos cuya función se desconoce. Una solución razonable podría ser localizar los iconos más importantes en las capas más superficiales del hipertexto o enseñar explícitamente a los usuarios el significado y las funciones de los iconos en el hipertexto concreto.
3) Proporcionar a los usuarios claves para la comprensión de los contenidos. Algunos investigadores miden la distancia semántica

entre los objetivos y las alternativas por medio de Cosenos LSA (Soto, 1999; Blackmon, Polson, Kitajima & Lewis, 2002; Tamborello and Byrne, 2005). Una posible solución sería seleccionar un conjunto de etiquetas para los enlaces relacionados entre sí con poca distancia semántica entre ellas.

4) El uso de imagines o iconos en lugar de palabras no es recomendable sin un estudio previo de la distancia semántica de los iconos, la complejidad y *distintividad* o la familiaridad de los usuarios con tales representaciones gráficas (ver McDougall et al., 1999, para una revisión).
5) La implicación de cierto tipo de procesamiento visuoespacial durante las tareas de búsqueda de información en hipertexto apoyan el uso de claves espaciales como mapas o puntos de referencias visuales para ayudar a los usuarios a permanecer orientados, especialmente en el caso de usuarios con pocas habilidades espaciales o aquellos que no pueden usar claves semánticas verbales.

Abstract

The problems that deaf people have to access the Web (or in general hypertext systems) are neither well-understood nor sufficiently researched. The lack of understanding is often due to the lack of attention to the cognitive characteristics of deafness by web designers. The series of four experiments which composes this thesis was designed with the aim of overcoming the research lack associate to this topic. The experiments focused on studying a specific web task, the hypertext information retrieval and its interaction with some verbal and visuospatial abilities of deaf and hearing people (mainly signer pre-locutive deaf people who are users of the sign language). Making use of the experimental methodology, a range of cognitive processes has shown to be differentially relevant to deaf signer users and/or hearing users in hypertext information retrieval: reading comprehension, semantic memory, episodic memory (recognition) and visuospatial working memory. In addition, the interface format (verbal vs. graphical), hypertext structure and target location have shown to interact with such cognitive processes and their functioning in each type of hypertext user. These findings are discussed with regard to models of web interaction (e.g. *CoLiDes* and *SNIF-ATC*). Finally, some provisional guidelines of accessible web design for deaf and users with similar problems are provided.

1

Framework: Empirical Study of Cognitive Accessibility of Deaf People to the Web (*Cogniweb*)

The aim of this chapter is to provide readers with the applied and multidisciplinary context in which Cogniweb, the project which framed this thesis, was born. Furthermore, the chapter is intended to explain how the applied goal of the project led us to formulate theoretical questions which were empirically embraced by means of the experiments that are described in this document.

In this way, the main goal of the Cogniweb project was to study and find solutions to the web accessibility problems of deaf users. *Web accessibility* is the degree to which the internet and its services are put available to *all individuals, whatever their hardware or software requirements, their network infrastructure, their native language, their cultural background, their geographic location, or their physical or mental aptitudes* (Tim Berners-Lee, W3C). In this way, if a web site has not into account some of these elements, it will generate accessibility problems. The provision of accessibility is important because, in the called "digital age", the Web has been established as a fundamental repository of information and services which makes possible to be social and professionally competitive. Paradoxically, aside from its initial good intentions to enhancing and supporting cognitive processing (Bush, 1954), the web is currently far from being accessible to all users, especially to deaf people due to the reasons that we will see later.

Precisely, Cogniweb arose when a collective of deaf people (working in the design and multimedia company *K.I.-Comunic*), communicated to the Laboratory of Human Computer Interaction for Special Needs-LIPCNE (UPV-EHU) the high incidence of web accessibility problems that they observed in their community and suggested collaborating to find technological solutions to the problem. The team of Computer Scientists which composed the LIPCNE considered that the accessibility problems of deaf people should not only be embraced from a technological perspective but also from a cognitive point of view because no technology could be provide unless the *a priori* simple question of "why should deaf people have problems interacting with a *visual* medium as the web?" was answered. For that reason, the LIPCNE contacted the Cognitive Ergonomic Group (University of Granada-UGR) formed by Cognitive Psychologists who could investigate this and other similar questions. Both groups conjunctly designed the project Cogniweb, which was financed by the IMSERSO and the

Diputación Foral de Gipuzkoa and counted on the participation of the mentioned Universities, Ki-Comunic and the Federations of Deaf People Associations from the Basque Country (Euskal Gorrak) and from Granada (FAAS).

One of the first goals of Cogniweb was to delimitate the problem to be studied. Therefore, in order to achieve this goal we started defining the relevant terminology such as Web and Hypertext, which we will utilise as synonyms in the present document. The concept of hypertext was envisioned by Vannevar Bush in his book "As we may Think" more than three quarters of century ago. The original name was Memex and it was in 1965 when Theodor Nelson coined the term Hypertext. The objective of memex was to enhance human memory and to automate, in general, human thinking. At the same time, the functioning of human memory inspired it. The basic idea was to make available a set of documents linked by associations, just as the human memory is formed by associations between ideas (Jonassen, 1990), which would allow users to quickly and flexibly store and retrieve them.

Nowadays, the World Wide Web (WWW), named also the Web, is composed of hypertext with a net structure and has become an instrument of daily usage. Among its diversity of functions, the web is used to communicate, acquire information, learn, buy or enjoy in a fast and economic way. Therefore, people who can efficiently use it have larger possibilities of being social and professionally competitive. Contrarily, those people who present some kind of physical or mental disability, which makes difficult the access to some of the web functions, are in a grave social disadvantage (WAI, Madrid, 2004). For instance, let imagine a blind person who want to read a digital newspaper. If the concrete web site has textual alternatives to all the elements (e.g. images, photos or icons), then such textual alternatives can be read by the synthetic voice of a screen reader and this site will be accessible to him/her. If not, it will be absolutely inaccessible. For that reason, it is not strange that the collectives of users with disabilities make public complains when they are affected by the socio-professional handicaps that some hypertext designs represents for them.

Attending to the demands of the disabled people collectives, there exist diverse international organizations (e.g. ISO, WAI) offering guidelines for providing accessible web designs. Apart from the lack of empirical validation (Ivory and Hearst, 2001), these guidelines often result insufficient and unsatisfactory. The shortage of satisfaction stems from an almost exclusive focus on the physical and sensorial features of the deficiencies (e.g. Seeman, 2002), forgetting the cognitive limitations that they can involve (Fajardo, Abascal and Cañas, 2004). As we will develop through this document, that especially happens in the case of the pre-locutive deafness (Marschark, 2003)[1]. The research which is aimed at filling this lack of knowledge has enormous applied repercussion. For instance, cognitive problems of deaf people related to memory and language (e.g. short term verbal memory or reading comprehension) would also affect to other types of users such as elderly people, people with dyslexia, people navigating in a website using a foreign language or people with low literacy.

The presented applied problem offers us the coverage not only to obtain empirically validated cognitive accessibility guidelines of web design but also to generate and test hypotheses about the cognitive functioning of hearing and deaf people in general (for instance, how knowledge about the world is structured and differently stored by the linguistic experience, McEvoy, Marschark & Nelson., 1999) and in the specific context of interaction with hypertext. The hypertext systems offer a new and complex way of interaction which is changing the habitual ways of knowledge acquisition and that could be influencing the way in which our cognitive system works (Dix, Howes and Payne, 2003). For that reason, it is important that the cognitive science is able of providing explicative answers and generating predictive models about the interaction with hypertext. In addition, as Wright (1993) suggests, hypertext may be important probe field of psychological theories which try to explain how to integrate a range of cognitive processes (e.g. attention, comprehension and memory).

In short, this thesis arose from the necessity of finding solution to a pragmatic problem, the improvement of hypertext accessibility, which led us to formulate theoretical and basic questions about cognitive processing such as *Which are the cognitive accessibility problems of deaf people to the web?*, *Which cognitive processes are involved in web interaction?*, *Which capabilities or abilities of users could be limiting or, contrarily, favouring web interaction?*, Such cognitive questions should be resolved by means of empirical research.

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[1] Pre-locutive deafness makes reference to such deafness acquired before learning oral language

Due to the magnitude of the exposed problem, Cogniweb and the series of 4 formal experiments which composes this research were constrained to study a specific web task, the information retrieval task (considered a basic requirement of computer literacy, Dillon and Song, 1997), and its interaction with some verbal and visuospatial abilities of hearing and deaf people (mainly pre-locutive deaf people who are users of the sign language or signers). Experiment 1 was designed to test the effects of the reading comprehension abilities and the type of hypertext structure in a Hypertext Information Retrieval (HIR) task from a digital newspaper for deaf and hearing users. Experiment 2 and 3 were conducted to explore the effects of substituting textual with graphical links on the performance of deaf signer users and hearing users in the HIR. It was hypothesized that different interface formats could make users to access the information in semantic memory with different efficiency which would consequently affect their performance. In addition, Experiment 3 tested the effect of repeated expositions to the same search tasks and hypertext, its interaction with the different interface formats and the involvement of some visuospatial abilities of users in HIR. Lastly, in experiment 4, we went in deep in the exploration of the spatial metaphor of hypertext using the dual task paradigm to analyse the involvement of the visuospatial sketchpad and the phonological loop of Working Memory in HIR task.

We are aware that the title of the thesis does not embrace the complexity of the performed research since we tried to manipulate and measure different cognitive processes (e.g. language, semantic memory, episodic memory and working memory) which are not reflected in such a title. However, all these processes are related to the verbal and visuospatial abilities of the users and, for that reason, the thesis's title may serve to summarize and achieve parsimony. Furthermore, we wanted to note that the thesis is framed by the area of Cognitive Ergonomic which, though it is inside of the Cognitive Psychology field, presents some methodological particularities. The more relevant particularity to the topic we are discussing is that Cognitive Ergonomic does not focus in an isolated cognitive process (e.g. working memory) but in a task (e.g. information retrieval in hypertext) and the objective is to split the specific task in the cognitive processes that integrate it and to analyse the interaction between them.

Next, chapter 2 focuses on the description of the main cognitive processes affected in deafness that are particularly relevant to hypertext interaction. Chapter 3 presents a revision of the main models of HIR, the cognitive processes involved in it and the initial explorative hypothesis of the thesis. From chapter 4 to 7, we present the detailed results of each experiment (4 in total) preceded by its rationale and hypothesis. Experiment 1 and 2 counted with the participation of deaf signer users, while only hearing users participated in the experiments 3 and 4. Finally, theoretical and practical conclusions of the research are presented in Chapter 6.

2

Cognitive Processing in Deafness: deaf users are not simply hearing users who can not hear

> *...for the purposes of assessment and education, treating deaf children as though they are simply hearing children who cannot hear denies them their unique experiences, their language, and their culture.* (Marschark, 2000, p. 3)

Deafness is commonly understood as a sensorial problem, that is, an inability to process auditory information through the sense of hearing. For that reason, the answer to the question "which accessibility problems do deaf users find when interacting with the Web?" seems to be obvious: they will have problems with the acoustic elements of the Web (sounds or speech). In this case, the solution could be easy: to design web sites with graphical or textual alternatives to acoustic ones. However, this solution is too simplistic since there exist different types of deafness and each one may have different consequences to the Web interaction. As we said before, we are interested on the pre-locutive deafness, which is acquired before learning oral language. In this case, the sensorial problem coupled with the use of sign language lead to some cognitive peculiarities, most of them, related to language and memory processes that must be taken into account to answer the accessibility question. In the next section we will describe the functioning of three related factors which seem to be affected in deafness: Working Memory, Long Term Memory and Reading.

2.1. Working Memory

Although, *a priori*, we may think that a deaf person should store or recall the information in a similar way than a hearing person does, we still could formulate the question of whether "there is any relationship between deafness and memory". It seems that the answer could be "yes" since the structure and functioning of memory would depend on the information that this process uses. Therefore, as deaf people can not use sounds and oral phonology, their memory process could be affected.

Memory can be defined like a store where the perceived and processed information is saved. Atkinson and Shiffrin (1968) proposed a model of human memory which posited two distinct memory stores: a temporal store (short-term memory or Working Memory), and a permanent store (long-term memory).

Working Memory is of special importance in the relation between memory and deafness. For instance, Baddeley's model of Working Memory (WM) (1986) has repeatedly supported research on "memory and deafness" (Emmorey, 2002; Wilson, 2001). This model proposes that the WM is a temporal storage system used for maintaining information active while it is being used. The WM is composed of three subsystems: (1) the Articulatory or Phonological Loop, a slave subsystem which stores and manipulates verbal information (2) the Visuospatial Sketchpad, a slave subsystem which stores and manipulates visual information, and (3) the Central Executive, which supervises the storage process and coordinates the slave subsystems. In addition, the Articulatory Loop is composed of two elements: the phonological buffer and the articulatory component. The phonological buffer is in charge of holding traces of acoustic or speech-based material for about two seconds, while the articulatory component is able to prolong this time by means of a sub vocal rehearsal.

Since, oral language phonology (composed of sound) is not processed by deaf people or at least not in the same way as hearing people do (see Leybaert, 1993), we could think that the mentioned model of WM would not be applied to deaf people. In fact, there are some differences between deaf and hearing people in their capacity and functioning of the Articulatory Loop. For example, one of the most supported findings is that the verbal span is smaller in deaf people compared to that of hearing people (e.g. Chincotta and Chincotta, 1996, Flaherty, 2000; Logan, Maybery and Fletcher, 1996). For example, Chincotta and Chincotta (1996) found that hearing subjects obtained a larger digit span of visually presented digits than deaf children (6.00 versus 3.89).

However, we should be cautious before we accept this data as supporting the conjecture that a person who uses a non-oral language (such as Sign Language) does not have an effective Articulatory Loop, and, further, an effective WM. Emmorey and her collages (Emmorey, 2002; Wilson and Emmorey, 1997b) have an alternative explanation; they consider that the WM architecture, at least some of its components, is not fixed and can adapt to the kind of information that is processed. Therefore, deaf signer people would also have an Articulatory Loop with two components involved in the processing of sign-language: the phonological buffer and the articulatory component. In this case, the phonological buffer would store traces of visual and spatially-based material (signs) and the articulatory mechanism would be in charge of rehearsing the phonology of linguistic visuogestual stimuli instead of the phonology of words (see Figure 1.1). According to this interpretation, similar effects supporting the existence of the Articulatory Loop in hearing people have been found in Sign Language research (Bellugi, Klima & Siple, 1975 and Wilson and Emmorey, 1997a, b). For example, Wilson and Emmorey (1997a) found evidence of the articulatory suppression effect in Sign Language: whereas in hearing people the recall of a list of words is interfered with sub-vocal articulation, in deaf people the interference of a list of signs is brought on by the inducement of irrelevant hand movement.

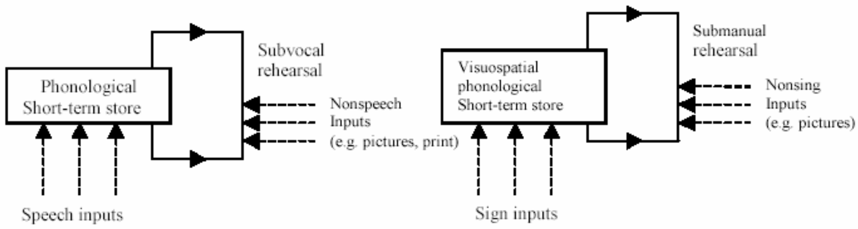

Figure 1.1. The picture on the left represent an oral based phonological loop and the picture on the right represents a sign based phonological loop. The later stores visuospatial phonology instead of oral phonology and the rehearsal processes is Submanual instead of Subvocal.

However, in spite of some similarities in the effects, there are also various differences between an articulatory loop based on signs and an articulatory loop based on speech. For instance, the speech loop seems to rely more on temporal coding and the sign loop relies more on spatial coding (Logan et al., 1996; Wilson and Emmorey, 1997b). Related with this fact, Wilson and Emmorey (2001) observed that when deaf people were presented with an immediate serial recall of signs, they used a strategy that consisted of responding by producing each sign at a separate spatial location. Apparently, the spatial nature of the inputs modality let signers codify the information by means of spatial clues, strategy which is not accessible to hearing non-signers.

At that point, it is possible to consider other variants of research in sign language and deafness which hypothesise that the effect of the use of sign language is generalised to other non linguistic, working memory tasks (Wilson & Emmorey, 2000). There are three basic abilities involved in comprehension and production of American Sign Language (Emmorey, Kosslyn & Bellugi, 1993): (1) image generation, (2) image maintenance, and (3) image rotation. These abilities are partially dependent on the other WM store, the visuospatial sketchpad. It has been proven that deaf signers have a larger WM spatial memory span than hearing non signers (Wilson & Emmorey, 1997b). This high visuospatial capacity may have it made possible for deaf signers to score higher than hearing non signers in complex stimuli recognition tests, such as faces or shoes (Arnold & Mills, 2001). If we consider that HIR has visuospatial components, deaf signer users could also generalise their abilities to this task. This is an open line of research which could explore the hypothesis that the effect of the use of sign language on the WM may be generalised to non-exclusively linguistic tasks (Emmorey, 2002) such as hypertext navigation.

All that considered, and according to the Emmorey hypothesis, it is possible to conclude that the phonological loop is not a speech-based store but a linguistic one. That is, the WM is a flexible structure which develops in to order to maintain linguistic information either oral or visual. In the case of deaf signers the phonological loop would process visuospatial phonology. In addition, the especial capacity to processes linguistic visuospatial information of deaf signers could be generalized to non linguistic visuospatial tasks. However, although these conclusions is interesting, one of the most important consequences of deafness en relation to the topic of web accessibility is that the lack of oral phonological rehearsal could affect more complex cognitive processes such as reading. We will discuss this issue later.

2.2. Long Term Memory

The information stored and processed in the WM can either be lost or transferred to another place of storage of the human memory system known as the Long Term Memory-LTM (Atkinson & Shiffrin, 1968). Contrary to the WM, information is stored permanently in the LTM. There are other series of experimental findings which lead us to think that deaf and hearing people could differ in the amount and organization of knowledge in LTM (Marschark, 2003).

One illustrative example of the differences on knowledge access or organization comes from a study performed by Marschark & Everhart (1999) in which deaf and hearing children used different strategies in the 20 questions game. In this game, players must find an objective in a set of 42 pictures by asking a maximum of 20 questions. Marschark and Everhart found that hearing children asked more "constraint questions" which, apart from eliminating more choices each turn, denoted a categorical knowledge organization of players. However, deaf children asked more specific questions such as *is it the cow*? According to the authors, those results could be due to differences in both the organization of knowledge and the strategies of information retrieval from LTM.

With the aim of measuring directly the amount and organization of verbal concepts (Lexicon) in deaf people, McEvoy et al (1999) utilized the classical task of *controlled association norms* (Deese, 1965). In that task, users had to say the first word which came to their mind after the individual presentation of a word (80 words in total). Although, the results of deaf and hearing subjects were quantitatively similar, the qualitative analysis revealed that the within-group coherence in the answers was higher for hearing than for deaf subjects. In addition, deaf individuals left more items without associates than hearing individuals which was interpreted as smaller concepts availability in the former.

The difference between deaf and hearing in the organization and use of the mental lexicon seem to be generalised to academically relevant tasks as a verbal analogy task. Marschark, Convertino, McEvoy and Masteller (2004) used this task to explore the application of taxonomic knowledge. The subjects were given a concept and asked to select the appropriate alternative according to a specific type of analogy (e.g. superordinate, subordinate, coordinate, rhyme, etc.). The authors found significant differences between deaf and hearing individuals for six types of analogies. Particularly, deaf subjects found difficulties in coordinate analogies, finding which was interpreted as a difficulty to use category information in semantic memory task.

Finally, other authors have found that deaf people have problem with tasks involving relational processing of information such as reading (e.g. Banks, Gray & Fyfe, 1990; Marschark, De Beni, Polazzo & Cornoldi, 1993; and Ottem, 1980). Once again, this data may be interpreted as evidences of differences between deaf and hearing individuals in the access strategies or the organization of knowledge in LTM: deaf people would tend to store concepts details more than relations between them. Banks et al. (1990) observed that, even though hearing and deaf subjects remember a similar overall amount of information after reading a text, deaf subjects remembered isolated fragments rather than related phrases. Similarly, Marschark et al. (1993) examined memory for prose in hearing and hard of hearing students. They observed that hard of hearing students had better memory for individual words but this advantage disappeared when the global paragraph coherence was eliminated, that is, hard of hearing students were not able to integrate text information across idea units.

All that considered, it is reasonable to expect that, if hypertext interaction requires the use of taxonomical knowledge or relational processing of information, for instance, in order to make selection between choices, deaf users will show disadvantages with regard to hearing in a HIR.

2.3. Reading Abilities

The reading difficulty is one of the major problems that the hearing loss implicates. A variety of studies performed in different cultures have shown that deaf people have difficulties in achieving functional level of comprehensive reading (e.g. Leybaert et al., 1982; Asensio, 1989; and Silvestre & Valero, 1995; and Alegría, 1999).

Phonological processing is fundamental to acquire reading abilities because it allow to associate written words and spoken words which finally access their meaning in LTM. This association would make possible to read unknown written words in alphabetic languages as the Spanish language (Martínez de Antoñana & Augusto, 2002). Therefore, as deaf people do not process phonologic-acoustic information, they find difficulties during reading. Going down one level in the language processing hierarchy, we find the syntactical processing where the maintaining of the words in the presented order is necessary. This means that the temporal parameters of the information are very relevant at this level. Verbal working memory would be specialized in the processing of temporal information and consequently, as this process is affected in deaf people, the syntactic processing is interfered (Hanson & Lichtenstein, 1990).

At the semantic processing level, the problems of deaf people could be due to the way in which words or concepts are connected in the LTM (Marschark, 2003). Deaf people seem to store the specific details of the items rather than the relationship between them. For that reason, they will not perform a top-down process during reading, that is, they do not use the context but read word by word. Due to this, the WM is overloaded and comprehension is interfered. Alternatively, as we explained in the previous section, the storing of item-specific information by deaf users would lead them to have difficulties in integrating text information across idea units and consequently to show deficiencies to the semantic level of reading (Banks et al., 1990; Marschark, et al., 1993).

Obviously, if the usage of reading abilities is involved in HIR, the particular reading strategies observed in deaf people could be affecting their performance. The same logic could be applied to the semantic memory organization and access and to the capacity of WM. However, we know neither if these particularities affect in a positive or in a negative way nor if they interact with the information format or organization in the hypertext interface. In the next section we describe the involvement of these processes and abilities in HIR.

3

Models of Information Retrieval in Hypertext and Users Abilities

A hypertext system is composed of a set of graphical, textual, audible or even haptic information nodes connected by links. According to this definition a website would be considered a hypertext system. Unlike traditional media of information transmission (books, newspapers, journal), the structure of information nodes is not fixed and the user can access it in different ways. As the amount of information nodes and links between them can be huge in a hypertext system, one of the main tasks of the users is to find the information without becoming disoriented and in an acceptable time.

Various models of visual search have been used to explain user's behaviour in HIR tasks and menu-driven interfaces (Liu et al., 2002; Pearson and Schaik, 2003; Scott, 1993). However, these models appear to be unsatisfactory because they can not embrace the complexity of hypertext interaction. As it was first noticed in the case of menu searches (Norman, 1991), the visual search is just one component of the information retrieval tasks (or interactive search task in terms of Payne, Richardson & Howes, 2000[2]) and other factors, like lexical-semantic factors, could also be involved.

Pirolli and Fu (2003) have proposed the *SNIF-ATC* model (*Scent-Navigation and Information Foraging in the ATC architecture*), whose goal is to simulate users as they perform unfamiliar information seeking task on the World Wide Web (WWW). The authors consider that the interaction with the semantic of web content is the core process in the information search. To make navigation decisions, users must use information scents, that is, interpretations of the relevance of local cues such as textual links and images. If the user's goals and a local cue are associated (association strength is based on spreading activation models through declarative memory, Anderson & Lebiere, 1998), such a local cue will be judged as being relevant to their goal and the user will select it to go forward the hypertext structure (see Figure 3.1).

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[2] The information search performed in systems such as menus, hypertexts or databases is named Interactive Search Task by Payne et al. (2000).

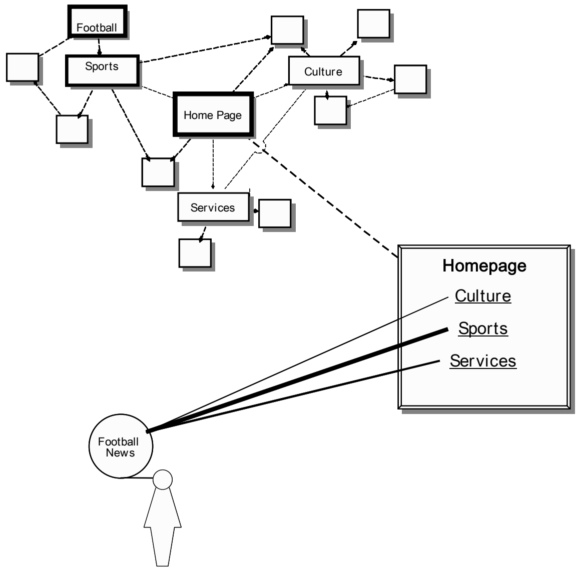


Figure 3.1. The graphic represents a semantic similarity judgement in a HIR task. The continue lines represent the semantic comparison between the user goal and the page choices. The thicker the line, the higher the semantic similarity is.

CoLiDeS model (*Comprehension-based Linked model of Deliberate Search*) proposed by Kitajima et al (2000), incorporates also the idea of information scent. The authors describe four cognitive processes as central to the CoLiDeS model: parsing, focusing on, comprehension and selection. At least in three of them, the knowledge stored in the LTM of users could be relevant. When *parsing* the users can use a top-down process controlled by their prior knowledge on the interface conventions to subdivide the page in manageable and meaningful parts. For instance, let imagine that a user have to parse the web page presented in the Figure 3.2. The user may use her/his knowledge on interface conventions to divide the page in three parts: 1) advertising, 2) main menu and 3) content. When *comprehending* users elaborate their goal and the node objects under attention based again on their knowledge about domain or interface convention. In our example, if user has to find the timetable of the cinema and has to elaborate what type of activity is cinema and which the meanings of the available choices are. Finally, to go forward the users have to *select* an item judging the degree of relatedness (scent) between them and their elaborated goal. The output of the judgement must satisfy one of three constraints which compete between them:

similarity, frequency and literal matching. To satisfy similarity users will use their semantic knowledge about the domain (see again Figure 3.1). Episodic memory and visuospatial abilities of users could account for frequency and literal matching strategies respectively. The use of episodic memory to guide the search process in interactive search tasks has also been postulated and investigated by some authors as we will discuss in experiment 3. Finally, in the *Human-Web Interaction Cycle* (*HuWI*) model, Farris (2003) also proposes that the system knowledge (content or structure knowledge) directs the interaction, proving in an experimental series that the domain and the lexical understanding influence how users explore the system.

Figure 3.2. Sample of the parsing process during a deliberate web search. The users would use a top-down process controlled by their prior knowledge on the interface conventions to subdivide the page in manageable and meaningful parts, for instance: 1) advertising, 2) main menu and 3) content.

Several authors consider that a diversity of cognitive processes may be involved in the performance of a task with the complexity of the HIR task described in the previous paragraphs (e.g. Campagnoni & Erlich, 1989; Juvina & van Oostendorp, 2004; Larson & Czerwinski, 1998; Nilsson & Mayer, 2002; Vicente & Williges, 1987; Zhang & Salvendy, 2001). For instance, it has been proposed that the users' reading skill and vocabulary are strongly related to their learning capacity from hypertext (Alexander, Kulikowich & Jetton, 1994; Foltz, 1996; Niederhauser, Reynolds, Salmen, & Skolmoski, 2000). Foltz suggests that bad readers, whose reading process is not automatic and consumes a great amount of resources, may suffer a lot of interference by having to make choices of where to go next as they read. Vicente and Williges found that reading comprehension and vocabulary were suitable predictors of performance in menu IR task. On the other hand, within a range of verbal factors, Juvina and van Oostendorp showed that the verbal working memory was a suitable indicator of disorientation in different navigation tasks, among them, information search. In that sense, Larson and Czerwinski observed that search task performance correlates more with verbal memory span than with spatial memory span.

We may think that the involvement of verbal abilities in interacting with a system based on textual information like hypertext is simply obvious. However, these abilities may interact with some characteristics of the hypertext structure and that interaction might change the direction of this influence. Experiment 1 was designed to explore both whether the reading ability is a factor contributing to the accessibility problems of pre-locutive deaf signer people and whether an interaction between this factor and the hypertext structure is produced. The rationale of this hypothesis is presented in the next chapter.

4

Experiment 1. Reading Abilities and Web Structure

Hypertext Information Retrieval (HIR) may be a difficult task for people with restricted reading comprehension abilities (Foltz, 1996). Deaf people whose first language is Sign Language usually display weaknesses in reading and the comprehension of text (Leybaert et al., 1982; Marschark, 2003). The design of hypertext structure may contribute towards overcoming this problem. This experiment was designed to test the effects of the type of users (deaf signers vs. hearing non signers), the reading comprehension abilities and the type of hypertext structure in an HIR task from a digital newspaper.

The flexible hypertext structure or the absence of such a structure constitutes the essence of hypertext and the largest difference with regard to traditional or linear text. Some authors have tried to test the performance and processing consequences of this differentiation. Take the case of Lee and Tedder (2004) who compared scrolling text (where all information is presented in one node and linearly as in traditional text) and paged hypertext (where the information is distributed along layers of nodes, not hierarchically) (see figure 4.1.).

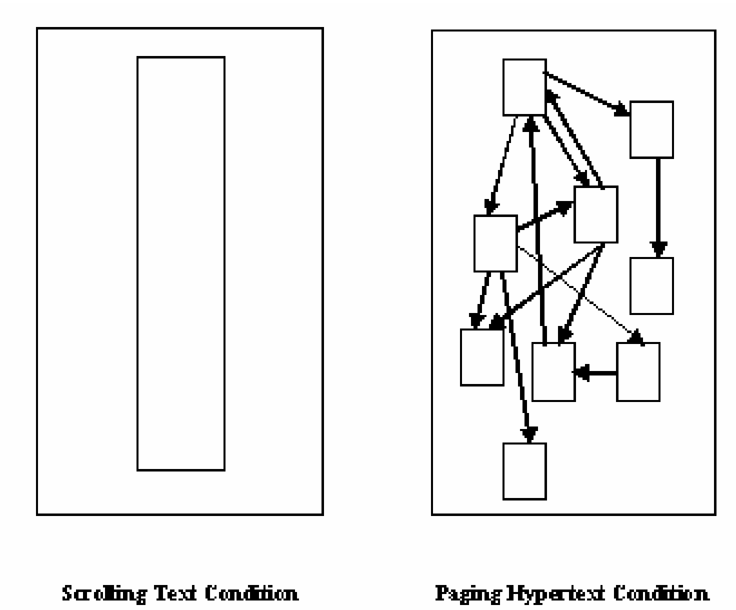


Figure 4.1. Scrolling Text and Paging Hypertext condition used in the experiment of Lee and Tedder (2004).

Users were asked to read three articles in each structure and take a posterior factual recall text. They found that scrolling text produced higher recall scores than the hypertext for users with poor verbal WM capacity (measured with the reading span test of Daneman and Carpenter, 1980). This result means that layered structures would be more demanding of the verbal working memory. Lee and Tedder hypothesised that, in absence of a structure in paged hypertext, the users have to find by themselves the related parts of the text to continue reading, which being an additional task would produce cognitive overload to individuals with low verbal span and would consequently prevent them from codifying factual information. However, the task in this experiment was a reading task and not a search task. It is possible that these two tasks, even though reading is involved in the search task, are demanding different resources.

In a prior experiment, Larson and Czerwinski (1998) specifically used a search task and manipulated two dimensions of the Web structures: depth (defined as the number of layers of nodes in the Web structure) and breadth (defined as the number of items of information located in the same node of the structure). They found that users who conducted searches with an intermediate structure (medium depth and medium breadth) were faster and felt less disorientated than those using a wide and a deep structure. In addition, there was a higher negative correlation between verbal span measured with the Auditory Number Span Test (Ekstrom, French, Harman and Derman, 1976) and response time in structures with less deep/greater breadth than in deep and shallow structures, that is, better verbal span was predictive of faster search time in wide structures. This would mean that the resources of verbal memory are highly demanded in wide structures in order to maintain and process the large number of choices per node of wide structures (32 and 16 respectively). In contrast to Lee and Tedder (2004), who argued that deep structures may overload WM due to a great relational processing demand, Larson and Czerwinski considered that the interaction with the deep structures would require less verbal memory resources than the wide because the number of choices per items is low (8 items in their experiment).

On the other hand, the manipulation of hypertext structural dimensions such as breadth and depth could also affect non verbal variables. In that sense, Snowberry et al. have found that the depth of the structures affects the visuospatial complexity (users have to remember more complex paths to the target information or maintain a more complex map of the structure in the visuospatial memory). Although in general it though that the nature of hypertext is essentially spatial and, for that reason, hypertext would require more visuospatial processing than linear text (we will talk about this topic in the Experiment 3 and 4), the type of processing required by deep and breath structures in HIR has not been extensively studied. Therefore, while it seems to be a consensus in considering that breadth is more preferable than depth in a HIR task (Fraser & Locatis, 2001; Norman, 1991, Snowberry, Parkinson & Sisson, 1983), it is not clear which dimensions of web structure would affect the verbal complexity more.

To sum up, we may say that verbal memory and reading skills coupled with the type of web structure may be partially accountable for performance in HIR text-based. Consequently, we may hypothesise that deaf signers with low reading comprehension and whose first language is not oral language will have more problems interacting with some types of web structures than with others. However, it is not clear which type of hypertext structure could be more verbally demanding, which is an important aspect to consider especially in the case of deaf signer people. Therefore, these were the first explorative questions derived from the theoretical review: 1) Do deaf signer users have difficulties in HIR text-based due to their low reading abilities? And 2) If it is so, which type of hypertext structure could facilitate their performance? In the next section, we present the results of Experiment 1 designed to test these questions. The questions tested in the rest of experiments which compose this document will be explained in the correspondent chapter.

4.1. Method

Participants

Fifty-seven people participated in this study, twenty-seven deaf signer (DS) people from the Basque Country's Federation of Deaf People Associations (Euskal Gorrak) and thirty hearing non-signer (H) people from the universities of Granada and of the Basque Country. The first language of the DS people was Spanish Sign Language (with the Spanish acronym *LSE*). The group of DS people was composed of 12 women and 15 men. The average age was 25.0 years old. Within the group of H people, there were 23 women and 7 men and the average age was 22.4 years old. Twenty of the H people were from the University of Granada and participated in exchange for extra credits for an experimental course. The remaining 10 H people were students from the University of the Basque Country, who participated in exchange for compensation. Three participants were removed from the analysis owing unsuccessfully recorded data.

Apparatus

One problem of hypertext research is the lack of instruments and methodological approaches for registering and analysing the large amount of data generated by human-hypertext interaction. A tool was needed to automatically register and analyse the users' logs and display the targets of the search tasks to the users. In order to avoid building an ad-hoc tool, a generic tool named EWeb was designed to automate all of these processes (Basque Country University and University of Granada, 2002; López, 2004). In the version of EWeb used in this experiment, the tool did not randomly assign subjects to experimental conditions. Experimenters performed the randomization with another program (E-Prime) and introduced the subject condition in the corresponding field of the EWeb interface each time a subject started an experimental session.

Material

On-line newspaper. With the aim of testing our hypothesis we selected a search task from a Digital Newspaper. The selection of the sections of the newspaper started with a review of some of the most important Spanish newspapers. As a result of this review, 8 sections and 82 subsections were selected, which were used as the main content of this newspaper. The next step was to create three different structures of the Website containing the 90 sections. The three structures were in a hierarchical format. The 8 main sections were at the top of the hierarchy and each one had 12 subsections below it, except the *Opinion* and *Political* sections, which had only 3 and 11 subsections respectively.

Setting off from the described hierarchic semantic structure, the sections were organized in three different physical structures:

<u>Wide Structure</u>: The total number of nodes was 63. This structure has one depth level. The home page had 62 items (sections) of weight. Pages in level 1 (the first layer of nodes under the home page) had 3 items of weight.

Mid Wide Structure: The total number of nodes was 80. This structure is composed of two depth levels (see Appendix A). The home page had 8 items (sections) of weight. Pages in level 1 had 12 of width (except one with 11 items), although only 9 (or 8) items were clickable. Pages in level 2 had 3 items of weight.

Deep Structure: The total number of nodes was 104. This structure is composed of three depth levels (see Appendix A). The home page had 8 items (sections) of weight. Pages in level 1 had 3 items of weight. Pages in level 2 had 3 items of weight (except one with 2 items). Pages in level 3 had 3 items of weight.

The 3 web structures were implemented by graphic designers from KI-COMUNIC, a Graphic Design company whose employees are deaf people.

Content and headlines of the newspaper. The researchers generated three headlines with their corresponding texts for each subsection; therefore, there were 246 headlines in total. To prevent a strange effect of headline difficulty, we procured a representative index for each headline. Seven judges (bachelors with experience in reading newspapers) evaluated the extent to which each headline represented the section where it was located by means of a test. The representative index was used to select the target headlines in the search task. For example, the headline “Halle Berry wins the Best Actress Oscar” was the most representative headline of the *Culture* Section.

Relatedness judgment task. The task was used to evaluate the knowledge or mental model of the system that users had, that is, the way in which the users organised the conceptual structure of the system in memory (Cooke, & Schvaneveldt, 1987; and Cañas et al., 2003). In this case, the system was a newspaper. We use this variable in two ways, 1) as a measure of system learning. In this way, participants performed the judgement task pre and post search task and, 2) as a covariate variable to prevent a confound. Since the domain used in this experiment was relatively common domain (a newspaper), it was supposed that the participants could have a prior mental model about its organization which could influence their performance (e.g. Niederhauser, Reynolds, Salmen, & Skolmoski, 2000; and Bhavnani, 2002).

Before and after the HIR task, the participants were required, in accordance with their experience of newspaper reading, to cast judgment about the relationship between pairs of concepts that usually appear in a normal newspaper (we used the names of the sections and subsections pertaining to the experimental material). The participants used a scale of 6 points (where "1" meant no relationship and "6" high relationship) presented in a written format to both deaf signers and hearing non signers. To analyse this dependent variable, a vector of users' responses (judgments) was compared to a theoretical vector which reflected the conceptual organization of the on-line newspaper. To build the theoretical vector, two concepts were considered to be "related" when they both were in the same main section of the newspaper (e.g. "Football" and "Cycling"). If two concepts were not in the same main section, they were considered to be "non-related" (e.g. "Football" and "Politic"). Once compared with the theoretic vector, the users' scores in non-related pairs of concepts were subtracted from related pairs. If a participant had a good mental model of a newspaper at the end of the search task, his or her score would be high (close to 6). In this way, we obtained two measures of the Mental Model which we respectively called Prior Knowledge- and Knowledge Acquisition.

Reading Comprehension abilities. This variable was measured by means of the CLT-Cloze Test (Suarez & Meara, 1992). This test measures comprehension abilities by giving them a short text with blanks where some of the words should be, and asking them to fill in the blanks. The test consisted of two parts (A and B) and the application lasted 35 minutes. Part B was not used in this experiment.

Measurement of Hypertext Disorientation. Several metrics exist that allow us to operationalise disorientation for statistical analysis (e.g. Cribbin & Chen, 2001). One of the most accepted formulae is the measure of *Lostness* proposed by Smith (1996), which establishes that $L = \sqrt{((N / S - 1)^2 + (R / N - 1)^2)}$. Where: N is the number of different nodes visited; S is the number of total nodes visited; and R is the minimum number of nodes needed to fulfill the target search. The values of the L index of *Lostness* are between 0 and 1, where 0 indicates an absence of disorientation and 1 indicates the highest level of disorientation.

Procedure

Participants were tested in groups of 4 to 7 on individual computers in the same room. For DS users, the instructions for the Relatedness Judgment Task, Search Task and Reading Comprehension Test were translated into Sign Language before each task was performed. Each type of user was randomly assigned to one of the three levels of Web Structure. To begin with, participants performed a Relatedness judgment task, whose concepts were the most significant names of the newspaper's sections and subsections selected by the researchers. These concepts were grouped in 40 pairs and presented to participants who judged the relationship between them by means of a 6 point scale. Five additional pairs of concepts were used as practice trials. The numbers on the scale and the pairs of concepts were presented in a textual format for both types of users. Next, participants performed practice session (six trials) of the HIR in the structure corresponding to their experimental condition (see Figure 4.1) followed by the experimental session.

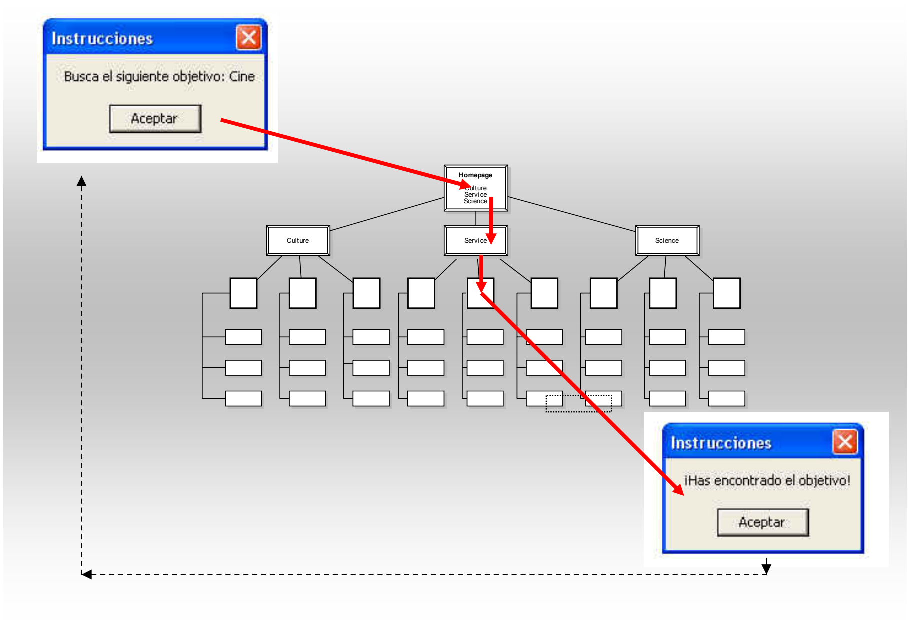


Figure 4.1. The procedure of a search trial in the deep hypertext structure. The continuous arrows show the user sequence of actions.

They had to search twenty one headlines in the on-line newspaper. Each target headline was presented on an independent Web page with a hyperlink to the main menu page. Therefore, the twenty one trials started from the main menu page. The order of the twenty one trials was fixed for all of the experimental conditions. If users found the correct headline and clicked on it, an announcement page was displayed. This page consisted of the message "Correct Answer" and a link to another page where the next headline to be searched was presented. If users clicked on an incorrect headline, an announcement page with the message "Incorrect Answer" and a link to return to the previous page and continue the search was displayed. The feedback messages were presented in a textual format for both types of users. The users had 2 minutes to complete each target search; if the time limit expired, then the next headline was displayed. All of the newspaper's pages had links to the main menu and to the pages that immediately preceded and followed them in the hierarchy.

Once the twenty one trials of the HIR tasks were completed, participants performed the Relatedness judgment task again and to finish with, they completed the Test A of the CLT-CLOZE.

Design

The study followed a 3 x 2 quasi-experimental design, where *Web Structure* was a between groups Independent Variable with 3 levels (Wide, Mid-Wide, and Deep) and *Type of User* was a Selected Independent Variable with two levels (Deaf Signers [DS] Users vs. Hearing non-signer [H] users). The dependent variables were the average of total response time to find a headline, the percentage of correct answers (headline found), average of disorientation (measured with the Smith' formula) and mental model acquisition. The total response time was only computed for correct answers and considered the time that a user lasted to find each target from its presentation. Finally, the average of total response time in correct answers was computed by subject and this value was used in the statistical analysis. As in the case of total response time, the average of disorientation was only computed for correct answers.

4.2. Results

Reading Comprehension Ability and Prior Knowledge as predictors of HIR performance

Firstly, we analysed whether deaf signers indeed had poor reading comprehension skills. We compared the reading comprehension scores of the users with the two types of language modalities. The difference between them was significant, ($t(51) = -11$; p=0.00). DS users (M = 10.2; SD = 5.4) obtained worse scores in Reading Comprehension than H users (M= 27.1;

SD = 5.7). The maximum score in the Z-Cloze Test was 47 for Test A and the mean and standard deviation of the sample which participated in the test validation (Suarez and Meara, 1992) were 23 and 5 respectively. Therefore, H users obtained higher scores than the mean of the sample and DS users were below this value. With regard to the prior knowledge measure, H users (M=1.6; SD = 0.6) obtained better scores in the judgement task pre-search than DS users (M= 0.6; SD = 0.8). The difference between type of users in this variable was significant, t (51) = -5.2; *p* = 0.00).

Predictor	Dependent Variable	R^2	BETA	t(50)	p-level
Reading Comprehension	Correct Answers	0.77	0.65	7	0.00
	Response Time	0.44	-0.74	-5.12	0.00
	Lostness	0.41	-0.51	-3.39	0.001
	Knowledge Acquisition	0.78	0.34	3.8	0.00
Prior Knowledge	Correct Answers	0.77	0.29	3.1	0.00
	Response Time	0.44	0.12	0.83	0.4
	Lostness	0.41	-0.18	-1.18	0.25
	Knowledge Acquisition	0.78	0.61	6.78	0,00

Table 4.1. The Regression summary shows the R^2 and BETA values for dependent variable and predictor

In addition to this, we performed several Standard Multiple Regression Analyses with Reading Comprehension and Prior knowledge as predictors, and Correct Answers, Reaction Time, Lostness and Knowledge Acquisition as dependent variables. Correct Answers, Response Time, Lostness and Knowledge Acquisition were predicted by Reading Comprehension (see Table 4.1). In the cases of Correct Answers and Knowledge Acquisition, the BETAs were positive, that is, the higher the level of reading comprehension, the more targets found and the better the users acquired a mental model of the web structure. In the cases of Response Time and Lostness, the BETAs were negative, that is, the higher the level of reading comprehension, the faster the users found the targets, the less they got disorientated. The users' Prior Knowledge was also a good predictor of Correct Answers and Knowledge Acquisition but not of Response Time and Lostness. That means that, a good prior mental model of newspaper structure helps users to find targets but does not help them in getting faster or in getting less disorientated.

Differences between DS users and H users in the HIR task

Our first explorative question was if DS users would be less efficient in a HIR task text-based than H users. In Table 4.2, we present a resume of descriptive data for each dependent variable.

Measures	Type of User	Means	Standard Deviations	Adjusted Means with reading abilities as a covariate variable	Adjusted Means with prior knowledge as a covariate variable
Correct answers	DS users (n=24)	60,1	10,2	72,6	65,3
	H users (n=29)	88,2	27,1	75,7	83
Response Time (in seconds)	DS users (24)	37,54	11,78	30,69	36,6
	H users (29)	23,24	9,81	30,09	24
Disorientation	DS users (24)	0,24	0,13	0,19	0,22
	H users (29)	0,10	0,05	0,15	0,1
Knowledge Acquisition	DS users (24)	0,67	1,07	1,45	1,2
	H users (29)	2,14	0,79	1,36	1,6

Table 4.2. Means, Standard Deviation and Adjusted Means of each measures of HIR performance after considering the covariate variables Reading Comprehension and Knowledge Acquisition.

To test this hypothesis, we performed two ANOVAs with Type of Users as factors for each dependent variable (Correct answers, Response Time, Disorientation and Knowledge acquisition). As Table 4.3 shows, the main effect of type of users was significant for all dependent variables.

Dependent Variables	df Effect	MS Effect	df Error	MS Error	F	p-level
Correct Answers	1	10338,46	51	171,1	60,42	0,00
Total RT	1	2685,49	51	115,48	23,26	0,00
Disorientation	1	0,25	51	0,01	25,75	0,00
Know Acquisition	1	28,67	51	0,86	33,27	0,00

Table 4.3. The main effect of type of users was significant for correct Answers, Total response time, disorientation and knowledge acquisition.

Supporting the hypothesis of difference between type of users, DS users were slower than H users, found fewer targets, became more disoriented and learn less than H users (see Figures 4.2, 4.3 and 4.4).

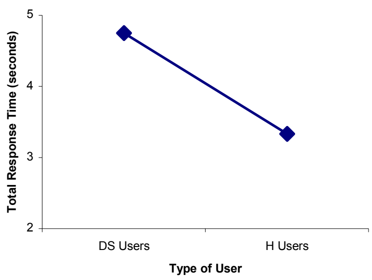


Figure 4.2. The average of total response time to find a target during the Hypertext Information Retrieval Task for DS and H users.

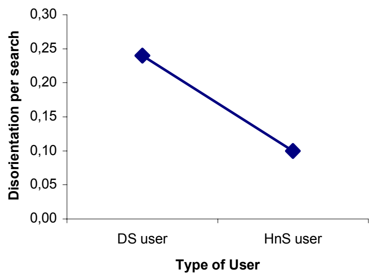


Figure 4. 3. The average of disorientation to find a target during the Hypertext Information Retrieval Task for DS and H users

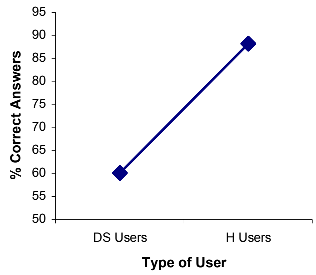


Figure 4.4. The average of the percentage of target found during the Hypertext Information Retrieval Task for DS and H users.

Since the results from the t-Student test and the Regression Analysis showed respectively that DS and H users differed in Reading comprehension abilities and that this variable predicted the HIR performance, we repeated the previous Analyses of Variances introducing the scores of the Reading Comprehension Test as a covariate variable. In this way, if the differences between types of users disappeared, it could be proved that reading comprehension abilities were responsible for such differences. However, if differences persisted, we could think that other factors, as well as to reading Comprehension Abilities, could be responsible for the difference in performance between the two kinds of users in each web structures. Verifying our first prediction, the main effect of type of users for all dependent variables disappeared (Correct Answers, F (1,50)=,36; Ms_e= 105; p=,5508; Total Response time, F (1,50)=0.01; MS_e= 96,8; p=,9055; and Disorientation, F (1,50)=,82; MS_e= 0,001; p=,3692). In Table 4.2, we can see the adjusted means for DS and H users after introducing Reading Abilities as a covariate. Therefore, we can say that Reading Comprehension abilities could be responsible, at least partially, for the variance between subjects of different language modalities in the HIR task designed.

As regression analysis revealed, prior knowledge positively predicted the number of Correct Answers and Knowledge acquisition during the HIR task, we performed also several ANCOVAs with Type of User as a factor and Prior Knowledge as covariate variable for such dependent variables. In this case, the main effect of type of users did not disappear for neither correct answers, F (1,50)=22,2; MS_e=120,4; $p=0.0$01, nor knowledge acquisition, F (1,50)=5,05; MS_e= 0,37; p=,0291 (see adjusted means in the table 4.2).

Taking into account this data we can discard that the difference between groups of users in this variable was determining the difference in accuracy and knowledge acquisition in the HIR task.

Effect of web structures

The second objective of this study was to explore if the manipulation of the web structure by means of the variation of the Depth and Breadth dimensions would affect differentially the performance of DS users in the HIR task.

We performed several ANCOVAs for the group of DS users with the type of web structure as an independent variable and reading comprehension abilities as a covariate variable for each dependent variable. DS users obtained different results in each web structure as we can see in Table 4.4 (means and SD for all dependent variables). Although, DS users obtained more correct answers, were faster and learn more in deep structures than in mid-wide and wide, the main effect of Type of Web Structure was not significant for any dependent variable.

		DS			H		
Measure		Wide	Mid	Deep	Wide	Mid	Deep
Correct answers	mean	57,14%	55,95%	68,71%	93,07 %	87,3%	83,07%
	SD	8,88%	8,5%	13,86%	27,45%	27,67%	26%
	ad mean	59,74%	59%	53,1%	92,57%	86,54%	84,33%
Response Time	mean	39,44	38,63	33,86	18,55	26,33	25,89
	SD	10,20	12,60	13,62	6,01	13,42	7,93
	ad mean	38,74	37,80	35,39	18,95	26,95	24,86
Disorientation	mean	0,20	0,31	0,22	0,08	0,11	0,14
	SD	0,07	0,15	0,16	0,03	0,03	0,07
	ad mean	0,19	0,30	0,24	0,08	0,11	0,14
Knowledge Acquisition	mean	0,46	0,32	1,32	2,36	2,52	1,51
	SD	0,91	0,31	1,57	0,36	0,82	0,84
	ad mean	0,55	0,55	1,01	2,21	2,23	1,94

Table 4.4. Means, Standard Deviations and Adjusted Means with reading comprehension scores as covariate for correct answers, response time and disorientation for DS and H users in each level of hypertext structure. In the case of knowledge acquisition the adjusted means was obtained introducing two covariate variables: reading comprehension and prior knowledge.

These analyses were also applied to H users. There were significant differences between web structures in the case of disorientation, F (2,25)=5,09; MS_e= 0.002; p=0.014; and nearly significant in the case of response time, F (2,25)=3,07; MS_e= 56,8; p=0.064. Contrary to DS users, H users got significantly more disorientated in Deep structures than in Mid Wide and Wide structures, F (1, 25)= 6,95; MS_e=0.002; $p=0.01$. In the case of response time, the analyses of the simple effects showed that H users were faster in wide structure than in mid-wide and deep structure, F (1, 25)= 5,8; MS_e= 56,8, p= 0,02.

4.3. Discussion and Conclusion

Our results show that, compared to H users, DS users are less successful in finding the target information, are slower, get more disorientated and learn less about the content of hypertext. One of the factors which contribute to this effect is the restricted reading comprehension ability of DS users. When this factor is introduced as a covariate variable in the ANOVA, the differences between users disappear. In addition to this, the regression analysis reveals that reading comprehension abilities predict performance in HIR tasks for all users and not only for DS users.

This finding supports the idea that deafness should not only be considered a sensorial deficiency when we try to design accessible websites. Deaf people, mainly those whose first language is not oral language, could suffer problems in the comprehension of texts, which in turn could affect their performance in HIR task. As Foltz (1996) has expressed, bad readers could consume a great amount of resources in decoding the meaning of the text displayed in a hypertext system. In this way, the process of searching a target would require more time for bad readers than for good readers as we can see reflected in the scores of DS users with regards to response time. The time to find a target in the digital newspaper used in this experiment was limited, so someone who is slower in comprehending texts could spend more time searching and not find the target information. In addition to the slow reading process, users with restricted reading comprehension abilities could not understand or would misunderstand the targets (which in this case were long sentences) and, for this reason, they find very few and select no effective paths (visiting more nodes of the web structures).

Added to the efficiency problem, the results show that DS users with poor reading comprehension abilities learn less about the conceptual organization of content in the hypertext (the scores in relatedness judgment task post-search task were low for this users). In terms of CoLiDeS model, it is possible that, in absence of reading abilities, literal matching was the constraint more frequently satisfy by DS users during the selection process in this experiment. To satisfy this constraint a visual “search and match” strategy may be enough, which would mean that users are not processing in any way the meaning of the text based-choices and, for this reason, they do not learn the content structure of the hypertext.

On the other hand, our second objective was to explore the effect of different web structures in DS performance. When the reading abilities differences within the group of DS users are controlled statically, the effect of hypertext structure is not significant for DS users. However, in spite of the significance lack, there is a tendency showing that they find more targets, are faster and learn more in the deep structure than in the other two. As Larson and Czerwinski (1998) suggest, this result may be due to an excessive number of textual choices in the wide structure which overloads the verbal capacity of users. Our wide structure condition had 62 nodes in the home page, even more than in the case of the Larson and Czerwinski’s wide conditions (16 and 32 respectively), where better verbal span predicted faster search time. In the case of the deep structure, the number of choices in the homepage is eight, that is, the users could make selections among a number of alternatives which does not overload their memory capacity. This interpretation based on a verbal WM overload is a mere speculation because our experiment was not designed to test this issue that must be explored in further research.

In the case of H users, the pattern of results is opposite to this of DS users, that is, they find more targets, are faster, become less disoriented and learn more in the wide structure than in the deep one (in the case of disorientation and response time these differences are significant). The pattern of results of hearing users is coherent with previous findings on the superiority of weight over depth (Fraser & Locatis, 2001; Norman, 1991, Snowberry et al., 1983). According to Norman (1991), depth structures augment the uncertainty about the location of a target, increasing consequently the semantic processing demands between nodes and interfering with the performance. As Lee and Tedder (2004) argue, the relational processing demands in deep structures could overload the WM capacity of users which would be in charge of this type of processing.

Then, why does the opposite pattern of results occur in deaf users? Perhaps each type of user is applying different strategies which may be affected by different factors. Since DS users are not good readers, they would apply a visual search and match process strategy and then the set size would be influencing this process. However, H user may be applying a strategy based on a semantic similarity judgement, where the semantic distance between goal and choices (which seem to be higher in deep structures) would be relevant and affect the performance. The contribution of these two possible variables (visual vs. semantic) to HIR performance were explored in the subsequent experiments. The effect of semantic judgement complexity for both DS and H users was explored in Experiment 2 by means of the manipulation of target location in deep structures and the target format (graphical vs. verbal). On the other hand, the contribution of visuospatial factors was explored in Experiments 3 and 4 by means of regression analysis and the dual task paradigm.

From an applied point of view, these findings suggest that is important to have into account the verbal and reading limitations of deaf users during HIR to design accessible web sites. A solution that may reduce the influence of verbal factors could be to substitute text with visual representations or provide visual notifications instead of acoustic ones (Emiliani, 2000). The beneficial effect of visual information (e.g. icons) has been reported in numerous researches in Human Computer Interaction (e.g. Blankenberger & Hahn, 1991; Dillon & Song, 1997). The use of graphic information would also be supported by the great amount of empirical evidence on the privileged access of pictures to semantic memory (e.g. see Snodgrass & McCullough, 1986). This is the main hypothesis that we explored in Experiment 2.

5

Experiment 2. Semantic Processing, Graphical Interface and Path Length

Deaf Signers' low reading comprehension abilities and prior knowledge were the main factors contributing to their low search efficiency in Experiment 1. In the experiment 2, we explored the possibility of improving deaf users' performance by substituting text-based with graphic-based links.

The different models applied to explain hypertext interaction (SNIF-ATC, CoLiDeS or HuWI) consider that user knowledge on the domain or interface conventions is rather important in the process of information search. The users have to make selections evaluating the semantic similarity between the alternatives and their goal. It is during this semantic comparison when they may use their prior knowledge. This knowledge, which is mainly stored in the semantic memory of users, must be retrieved to be used. Therefore the question is: how would hypertext information format (graphic vs. verbal) affect the access to semantic knowledge and consequently hypertext performance?

In traditional semantic tasks, such as categorization or symbolic comparison, pictures have proved to be faster than words, effect known as *Picture Superiority* (Nelson, Reed and Walling, 1976). However, there is also empirical evidence not supporting this effect (see Snodgrass and McCullough, 1986, for a revision). In the field of Human Computer Interaction (HCI) the results regarding the comparison of graphical and verbal interfaces are also contradictory (e.g. Dillon et al., 1997 vs. Weidenbeck, 1999). On the other hand, the format of hypertext items may interact with their location. It has been argued that the structure of information in hypertext could influence the difficulty of the semantic similarity judgement (in terms of CoLiDeS). In a tree structure with several levels of depth, the user goal could be placed in the last node of the hierarchy. In these cases, the semantic ambiguity of the top-choices could be higher (Norman, 1991) and consequently, the semantic judgment would become a difficult task. Therefore, if pictures have a privileged access to semantic representation, searching items in deep structures would be facilitated by choices in graphical format.

Finally, Individual differences in semantic memory could be reflected in hypertext performance and even interact with information format. The users under consideration, deaf people, have shown differences in comparison to hearing pears in the access strategies and organization of knowledge in Long Term Memory-LTM (e.g. Marschark, 1998; McEvoy et al., 1999). These topics and the hypotheses derived from them are explained more extensively the next section.

5.1. Pictures, Graphical Interfaces and Semantic Processing in Hypertext

As we said previously, the available information in the hypertext (proximal cues or objects) could be differentially effective eliciting the semantic knowledge of subjects. Theoretically, pictures (e.g. graphical icons) should be superior to words (e.g. verbal links) in a semantic task such as "similarity judgement" in hypertext. In next paragraphs, a brief revision of pictures' effects in both basic cognitive research and HCI research is presented.

Pictures vs. Words processing in Cognitive Psychology

The *Picture Superiority Effect* (PSE) has been reported in a great variety of semantic (e.g. Pellegrino, Rosinski, Chiesi, & Siegel, 1977) and episodic tasks (Paivio and Csapo, 1973, Kinjo and Snodgrass, 2000). The Sensorial-Semantic Model proposed by Nelson, et al. (1976) is one of the models which tries to explain this effect and postulates an abstract and a-modal store of semantic representations which is accessed by both pictures and words (Figure 5.1).

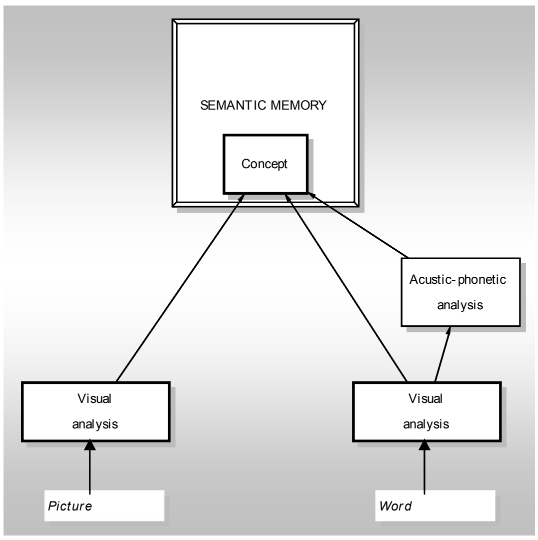


Figure 5.1. The Sensorial-Semantic Model proposed by Nelson, Reed and McEvoy (1976).

Pictures, in addition to having a larger sensorial distinctiveness, may access this abstract store faster than words which must be phonologically pre-processed. Dual Code Theory (Paivio, 1971, 1991) brings an alternative explanation to PSE as it postulates that verbal and pictorial information would be represented in different formats in LTM (Figure 5.2). One of the Paivio's explicative hypotheses is that pictures would have more possibilities of being represented in both formats due to a referential processing (a pictures would evoke a verbal label more easily than a word would evoke a picture, Paivio, 1977, 1991) and, for this reason, may facilitate performance in recognition or categorization tasks.

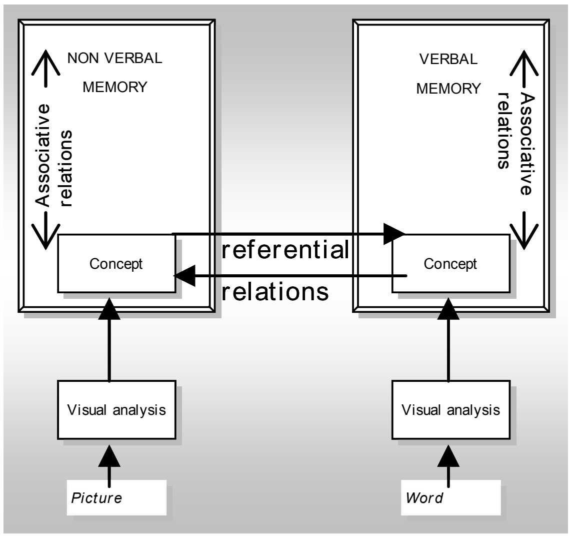


Figure 5.2. Graphic representation of the Dual Code Theory (Paivio, 1971, 1991).

However, there is also inconsistent evidence on PSE in different types of semantic tasks (see Amrhein, McDaniel, and Waddill, 2002, for a review). For instance, in a single-stimulus classification task (classify stimuli in one of two categories), Snodgrass and McCullough (1986) demonstrated that pictures superiority disappeared when the two categories were visually similar (e.g. fruits and vegetables), suggesting that pictures will not facilitated a faster access to semantic representations, PSE being a visual and not a semantic effect. On the other hand, Lotto, Job and Rumiati (1999) suggested that the results obtained by Snodgrass and McCullough (1986) may be due to an artefact as visual similarity and conceptual similarity of pictures vary normally together. They proved that when the effects are separated experimentally, the conceptual similarity of between-categories affected both pictures and words while visual similarity only affected pictures, reversing the PSE (words better than pictures). These data suggest that PSE may be both semantic and visual. However, in order to observe PSE, a high visual and conceptual dissimilarity between categories may be necessary. In the context of HIR, these findings would mean that the effectiveness of icons might be conditioned by both the degree of semantic processing demanded by the tasks (or the semantic cues available) and the visual discriminability of the icons themselves.

Graphical Interfaces effects in HCI

The facilitation of graphical information has also been observed in more complex task such as programming (Navarro-Prieto & Cañas, 2001), text comprehension (see revision of Levie & Lentz, 1982; Kruley, Sciama & Glenberg, 1994), text comprehension from multimedia (Gyselinck, Cornoldi, Ehrlich, Dubois, & de Beni, 2002) and information retrieval in data base systems (Blankenberger & Hahn, 1991; Dillon et al, 1997).

The results of diverse authors point out that the effect of pictures may vary due to different variables related to factors such as the configuration and location of pictures in the system (Byrne, 1993), the visual distinctiveness (Arend, Muthig, & Wandmacher, 1987), the visual grouping (Niemelä & Saarinen, 2000), the articulatory distance (Hutchins, Hollan & Norman, 1986; Blankenberger & Hahn, 1991) or the familiarity (e.g. McDougall, Curry & Bruijn, 1999; Wiedenbeck, 1999). For instance, Arend et al. found that highly distintictive icons (due to the manipulation of the colour and the size) were faster in a search and match task than words. Niemelä and Saarinen (2000) observed that icons which are grouped by spatial closeness and similar appearance in a computer interface were faster matched during a visual search than ungrouped icons and file names. Not only the grouping but also the location of icons in the interface may affect the search processes and interact with other variables as the articulatory distance. The articulatory distance is the subjective psychological distance between meanings of expressions and their physical form (Hutchins et al., 1986). Blankenberger and Hahn (1991) manipulated the articulatory distance of a group of icons to explore its effect in menu search tasks. The users previously learnt the relation between a set of commands and their icons. Then, the concepts were individually presented and the users have to select the appropriate icon each time. Icons with low articulatory distance facilitated the search and match speed compared to the text condition but only when the icon location was random. That is, when the spatial clues are not reliable, users have to process the meaning of the stimuli which is supposed to be easier when the articulatory distance is low.

On the other hand, other authors have found that graphical information (e.g. icons) shows disadvantages or no differences with regard to verbal information in complex tasks (Guastello, Traut, & Korienek, 1989; Benbasat & Todd, 1993; Wiedenbeck, 1999). Benbasat and Todd compared the performance with icons or text in two types of interfaces: direct manipulation and menus. The subjects were asked to find certain information in each type of interface by selecting the appropriate options (e.g. file folder, help, send messages, etc.). They found no differences between icons and text but direct manipulation interfaces were more efficient than menus. The authors suggest that these two variables are frequently confused in HCI research as icons tend to be used in direct manipulation interfaces while text is used in menus. However, in a direct manipulation interface where users have to select the appropriate alternatives to make use a simulated electronic mail programme, Wiedenbeck did find a superiority of textual labels or labels plus icons with regard to the usage of only icons, which suggests that not only the implementation of icons in context (direct manipulation interface vs. menus) but also their inherent properties could be relevant in search tasks (e.g. faster access to semantic knowledge or high distinctiveness).

In addition to these contradictory data about the efficiency of pictures versus words and graphical versus verbal interface, individual or group differences in the organization or access strategies to knowledge on semantic memory may influence the effect of pictures and words in HIR. As we exposed in Chapter 2, this kind of differences may exist between deaf and hearing people.

In short, our pragmatic objective was to improve the accessibility of deaf people to hypertext. If deaf people have problems with textual information, we may substitute it with graphical information. Theoretically, accessing semantic information is necessary to perform the different phases of a HIR (Kitajima et al., 2000) which could be faster with pictures than with words and perhaps the only alternative for deaf people. Therefore, this solution should benefit both deaf people and even people without problems with textual information processing. However, we though that this hypothesis must be tested since the picture superiority effect does not always happen, neither in traditional semantic tasks nor HCI tasks. In addition, the location of the targets in the hypertext structure may affect the number of selections and the difficulty of the semantic similarity judgement. Finally, differences between deaf and hearing people in the semantic knowledge organization or access strategies may also affect HIR.

Therefore, the goals of the Experiment 2 were to test whether graphical hypertext interfaces actually improved the performance of deaf people in HIR and whether there was an interaction between the type of interface (textual of graphical) and the type of user (deaf and hearing users). We predicted that the disadvantage of DS with regard to H users will disappear in the graphical interface. Furthermore, we expected that the increase of path length will affect negatively the performance of both types of users in HIR due to a consequent higher complexity of semantic processing. Finally, as path length affects the semantic similarity judgement and pictures improve such a process, the graphical interface will be less affected by this variable than the verbal one.

5.2. Method

Participants

Twenty-one deaf signer users (DS) from the Federations of Deaf People Associations of the Basque Country (Euskal Gorrak) and Granada (FAAS) and twenty-four hearing users (H) from the University of Granada (in exchange for experimental credits or an economical remuneration) participated in this experiment. The DS group was composed of 10 women and 11 men and the H group was composed of 18 women and 6 men. The first language of the DS was Spanish Sign Language (with the Spanish acronym *LSE*).

Design and Material

The study followed a 2 x 2 x (3) quasi-experimental design. The independent variables were *Interface Format* (Graphical vs. Verbal), *Type of*

User (DS vs. H users) and *Path Length* (Short, Medium and Long). The dependent variables were the percentage of *correct answers* (targets found), the *response time* (total time to find the target from the homepage) and the *disorientation* in the hypertext structure measured with the formula of *Lostness* (Smith, 1996). The variable *Path Length* referred to the minimal number of nodes which the users have to visit to find the target. In this way, in short, medium and long paths the users had to visit 3, 4 or 5 nodes respectively to find the targets. We used the hypertext of the newspaper built for Experiment 1. The newspaper was composed of 8 main sections and 82 subsections. The total number of nodes was 52. The structure of the hypertext was hierarchical, with 5 levels of depth and 3 items of weight per node. In the graphical interfaces the verbal links where substituted by icons (Figure 5.3).

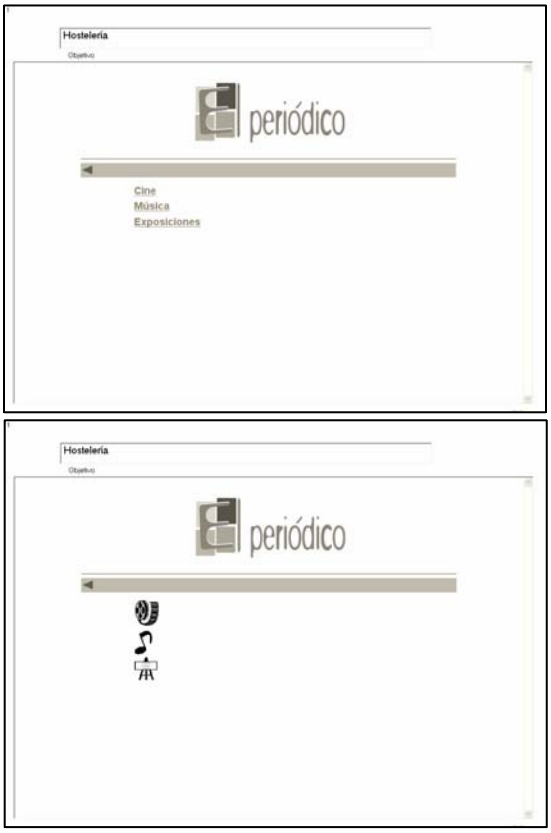


Figure 5.3. The top picture represents a node of the digital newspaper with verbal links. In the bottom picture the verbal links were substituted with graphical links.

The icons were selected from a set of 153 in a previous study of semantic distance, that is, how direct the relation icon-function is (Hutchins et al, 1986). For each verbal link (representing a section of the newspaper), three icons in black and white were selected. In the study of semantic distance, 28 individuals participated (11 DS and 17 H) who had to answer in a 5-points scale, where 1 meant low relation icon-referent and 5 meant high relation icon-referent (see Figure 5.4.). We selected the sets of icons with higher relation icon-referent, that is, with lower scores in semantic distance. The semantic distance average of this set was 3.75 (SD = 0.48). There was not significant difference in semantic distance between DS and H users.

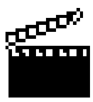
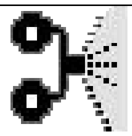
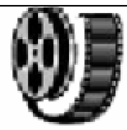
Concept	Cinema		
Icons			
Picture-Concept relation From 1 (low) to 5 (high)			

Figure 5.4. Example of the Distance Semantic Questionnaire. User had to indicate the below each icon, the degree of relation between the graphic representation and the concept which appeared above (e.g. Cinema). "Low relation" (1) meant long semantic distance and "high relation" (5) meant short semantic distance.

Task and Procedure

The main task of the users was to find sections of a newspaper implemented in hypertext. After reading the general instructions of the experiment (in the case of DS, the instructions were explained in sing language), users completed a training session in the search task supervised by the researcher. Previous to the experimental search task, the participants completed a relatedness judgment task with the aim of evaluating and controlling the prior knowledge on the concepts which composed the newspaper and the relation between them. In this task, users had to evaluate in a 6-points scale the relation between 55 pairs of concepts extracted from the hypertext (words or icons depending on the experimental condition). "1" meant a low relation between concepts and "6" meant a high relation. Once finished the relatedness judgment task, users were asked to search for 12 targets in the newspaper hypertext (4 per each level of path length). Each target was presented individually in the format corresponding to the experimental condition of the user (icon or word) and the search started from the main menu. For example, in the condition *Verbal Interface,* users received the message “Find the next target: Cinema”. The target *cinema* was in a short path, therefore, the user had to visit 3 nodes “menu ->culture-> cinema” (Figure 5.5). Users had 1 minute to find each target. The same order of target presentation was used in the Graphical and Verbal Interface.

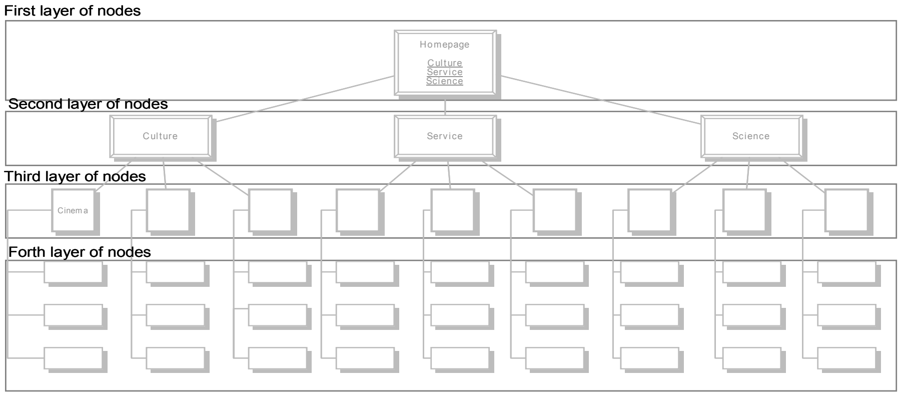


Figure 5.5. Example of a hypertext structure with four layers of nodes. In this structure the target “Cinema” may be found in the third layer of nodes.

5.3. Results

With the aim of filtering the possible variability between targets, we performed an ANOVA by Item instead of by subjects for each dependent variable (correct answers, total response time and disorientation). *Interface Format* (Graphical-GI vs. Verbal-VI), *Type of User* (DS vs. H users) were introduced in the analysis as intra-item variables and *Path Length* (Short, Medium and Long) as between-items variables.

Interface Format

The effect of interface was significant for correct answers, F (1,9)=31,31; MSe; 199,3; p=0.0003 (see Figure 5.6.), response time, F (1,8)=13,09; MS_e= 56, 7; p=0.007; and disorientation, F (1,8)=29,9; MS_e= 0,02; p=0.001. However, contrary to our hypothesis on graphical interface superiority, both types of users found fewer targets (57% [8.1] vs. 80% [4.7]), were slower (26” [13.3] vs. 18” [7.3]) and became more disoriented (0.3 [0.2] vs. 0.1 [0.1]) in the Graphic Interface than in the Verbal hypertext Interface.

The difference among users was significant for correct answers, F $(1,9)=8,51$; $MS_e= 316$; $p=0.0171$, and response time, F $(1,8)=10,13$; $MS_e= 48$; $p=0.0130$. DS users found fewer targets (61% [7.2] vs. 76 % [5.6]) and were slower (25”[10.8] vs. 18”[9.9]) than H users. There were no significant interactions between interface format and type of user.

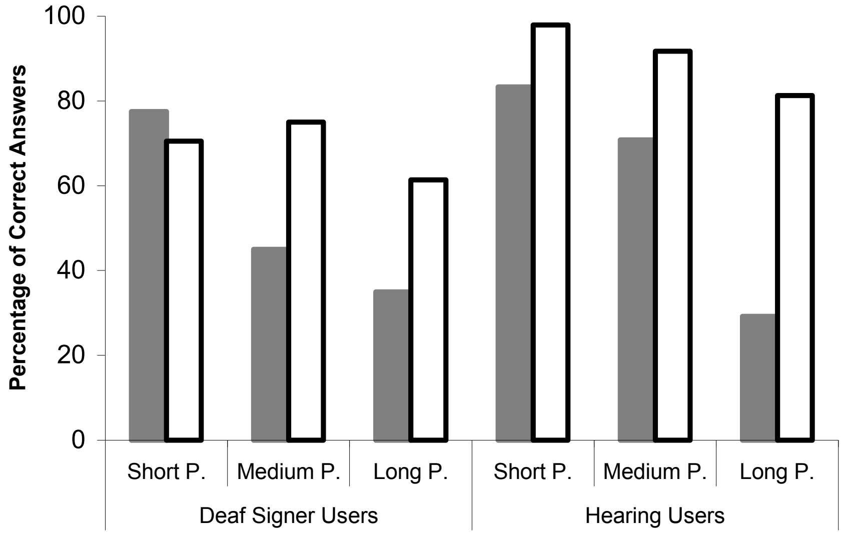


Figure 5.6. Percentage of Correct Answers in each Path Length for both deaf signer users (left) and hearing users (right). The grey bars represent performance in the Graphical Interface and the white bars represent performance in Verbal Interface.

Path Length

In the Table 5.1, we can see the average score for each experimental condition in each dependent variable. The effect of Path length was significant for correct answers, F $(2,9)=4,77$; $MS_e= 801$; $p=0.04$; and response time, F $(2,8)=9,19$; $MS_e= 103$; $p=0.009$. As the second hypothesis stated, users found more targets in shorts than in medium and long paths (82 % vs. 71 % vs. 52 %). In addition, users were faster in short than in medium and long paths (15” vs. 20” vs. 31”).

Users	Path Length	Correct Answers		Response Time		Disorientation	
		Graphical I.	Verbal I.	Graphical I.	Verbal I.	Graphical I.	Verbal I.
Deaf	Short	77,5 (18,9)	70,5 (20,2)	22,3 (14,8)	14,3 (2,2)	0,3 (0,3)	0,07 (0,1)
	Medium	45 (20,8)	75 (26.1)	27,1 (17,7)	18,4 (4,2)	0,2 (0,1)	0,05 (0,1)
	Long	35 (26,5)	61,4 (23,9)	42,4 (4,7)	26,6 (3,5)	0,5 (0,1)	0,1 (0,2)
Hearing	Short	83,3 (0,0)	97,9 (4,2)	11,2 (3,3)	10,4 (3,7)	0,16 (0,1)	0,1 (0,1)
	Medium	70,8 (14,4)	91,7 (6,8)	19,4 (10,7)	14,8 (4,3)	0,2 (0,2)	0,1 (0,1)
	Long	29,2 (24,1)	81,3 (12,5)	33,4 (4)	21,8 (8,3)	0,5 (0,1)	0,2 (0,1)

Table 5.1. Averages and Standard Deviations (in brackets) of Correct Answers, Response Time and Disorientation in the HIR task for each experimental condition.

The interaction Interface Format x Path Length was significant for correct answers, F (2,9)=6,41; MS_e= 199; p=0.017. Therefore, the second prediction was refined since, in spite of existing differences between the levels (long= 71%; medium= 83%; y short= 84%), the effect of path length was not significant for the Verbal Interface. However, contrarily our third hypothesis, which predicted a smaller effect of path length over the Graphical Interface, the difference between long paths (32%) and medium (58%) and long paths (80%) considered together resulted significant, F (1, 9)= 11.2; MS_e= 658; p= 0.01. Furthermore, the difference between interfaces was only significant in medium, F (1, 9) = 13; MS_e= 199; p= 0.005 (GI= 58% vs. VI= 83 %) and long paths, F (1, 9) = 30.9; MS_e= 199; p= 0.000 (GI=32 % vs. VI= 71%) but not in short paths (GI=80 % vs. VI= 84%), F (1, 9)= 0,29; MS_e= 199,3; p= 0, 6.

The 3-way interaction Interface Format x Path Length x Type of User was significant for correct answers, F (2, 9)=5,24; MS_e= 64; p=0.031. Weakly supporting our first hypothesis, DS users found more targets in the short paths with the graphical interfaces than with the verbal interface (although the difference was not significant). The opposite pattern was found in the rest of levels of path length where the differences between interface formats were significant (medium path, F (1, 9) = 10.3; MS_e= 174; p= 0.01; and long path, F (1,9) = 8; MS_e= 174; p= 0.02). However, H users obtained always better performance in the Verbal than in the Graphical Interface, although the differences among interfaces were only significant in medium, F (1, 9)= 9,2; MS_e= 85; p= 0,01; and long paths, F (1, 9)= 57,4; MS_e= 95; p< 0,001.

Finally, the condition verbal interface/long path in Experiment 2 was similar to the condition of deep hypertext structure in Experiment 1. For that reason, we expected that the results of both experiments in those conditions were similar for DS and H users. In order to test this hypothesis we performed several ANOVAs by subjects with Experiment (Exp1 vs. Exp2) as independent variable for each type of user and each dependent variable. As expected, the analysis showed that the averages of correct answers were almost identical between experiments for both DS, $F(1,16)=0,49$; $MS_e=469,7$; $p=0,5$ (DS= 68,7 % in Experiment 1 vs. 61.3% in Experiment 2) and H users, $F(1,18)=0,19$; $MS_e= 315, 8$; $p=0,7$ (83.1% vs. 79.5%). The average of total response time to find a target was also similar between experiments for both DS, $F(1,15)=0,45$; $MS_e= 151,4$; $p=0,5$ (33,9 vs. 29.8) and H users, F (1,18)=1,34; $MS_e= 50,8$; $p=0,3$ (25,9 vs. 22.2). Finally, the difference between experiments with regard to disorientation was not significant either for neither DS, F (1,16)=,28; $MS_e= 0,05$; $p=0,6$ *(*0,22 vs. 0.16) nor H users, F (1,18)=0.00; $MS_e= 0,01$; $p=0,9$ (0.14, vs. 0.14).

Prior Knowledge about Hypertext Content

The user prior knowledge was measured with the same procedure than the in Experiment 1. A vector of users' responses (judgments) was compared to a theoretical vector which reflected the conceptual organization of the on-line newspaper. To build the theoretical vector, two concepts were considered to be "related" when they both were in the same main section of the newspaper (e.g. "Football" and "Cycling"). If two concepts were not in the same main section, they were considered to be "non-related" (e.g. "Football" and "Politic"). Once compared with the theoretic vector, the users' scores in non-related pairs of concepts were subtracted from related pairs. If a participant had a good mental model of a newspaper at the end of the search task, his or her score would be high (close to 6).

All users in general had better prior knowledge about the verbal labels (M=1.7, SD =0.8) than about the icons (M=0.42, SD =0.5), F (1,37)=38,11; MSe = 0,43; $p=0.000$. For each dependent variable, we performed an ANCOVA with type of user, interface format and path length as independent variable and prior knowledge as covariate variable. The previous interface format effect disappeared for all dependent variables with the introduction of the covariate variable in the analysis, which means that the prior knowledge about the interface elements and their relations was an important contributor to the difference between interface formats.

In contrast to what could have been expected derived from the theoretical revision and from the results of Experiment 1, there were neither significant differences between DS and H users in prior knowledge nor interaction with the type of previous knowledge evaluated (icons or verbal labels). However, we re-analysed the differences in prior knowledge between users for each pair of items (icon or word) instead of using the average scores of all items of each subgroup. We performed two MANOVAs to compare the prior knowledge on the relation between each pear of concepts (see results in appendix B). One MANOVA was performed for related pairs of concepts and another for un-related pairs. In the case of unrelated pairs, we found a significant interaction between type of user and type of related pair, F (39,1521)=1,49; MS_e= 2.4; p=0.0276. For example, DS found less relation than H between the pairs of concepts: Culture-Medicine, F (1,39)= 6.2; MS_e= 3.6; p 0.02, and Hotel business-Culture, F (1, 39)=4.9; MS_e= 3.6; p= 0.03. However, DS found more relation than H between the pairs: Culture-Real Estate Agency, F (1,39)= 4.1; MS_e= 3.6; p= 0.05, Expositions- Real Estate Agency, F (1,39)= 4.2, MS_e= 2.99; p= 0.04, and Informatics-Services, F (1,39)= 4.4; MS_e= 3.6; p= 0.04. With regard to related pairs, the 2-way interaction between type of user and type of related pair was also significant, F (14,546)=1,72; MS_e= 2.9; p=0.0483. DS found less relation than H between the related pairs: Science-Nutrition, Science Medicine, Exhibitions-Culture and Service- Hotel business, though only this last difference was significant, F (1, 39) = 10.8; MS_e= 3.9; p= 0.002. In related pairs, DS only found more relation than H in the case of pair Nutrition-Computer Sciences; however, the difference was not significant.

In general, DS found more relation between unrelated pairs and less relation between related pairs than H users (although weakly, we can conclude that the organization of semantic knowledge or Mental Model about hypertext content was not equivalent in deaf and hearing users), which could have made difficult the semantic similarity judgement for DS during the HIR. Therefore,

5.4. Discussion

The main hypothesis of Experiment 2 states that, as deaf signers are inefficient in HIR tasks mainly due to their low verbal and reading competencies, the substitution of textual links for graphical may reduce such inefficiency. This hypothesis derives from the next arguments: 1) the semantic similarity judgment is an important process during information search in hypertext, according to HIR models, and 2) pictures have a privileged access to semantic memory, according to a central assumption in Cognitive Psychology. Additionally, several findings in the field of HCI seem to support the advantage of graphical interfaces with regard to verbal interfaces.

In contrast to our main prediction, this experiment shows that there are advantages of the verbal hypertext interface over the graphical for both deaf signer users and hearing users, advantages which mainly appear in long paths when it is hypothesised that semantic processing becomes more difficult. The finding of verbal superiority agrees with the data of other authors with regard to direct manipulation interfaces or information retrieval (Guastello et al., 1989; Benbasat and Todd, 1993; Wiedenbeck, 1999), who find that users are better with verbal or mixed interfaces (icons plus verbal labels) than with the graphical versions.

The effect of interface format may be due to the differences in pictures (icons) and word knowledge or the access to this knowledge (favourable to words in this case). Therefore, we re-analysed the data, taking into account the prior knowledge on interface elements (icons or words depending on the condition). For each dependent variable, we performed an ANCOVA with type of users, interface format and path length as independent variables and prior knowledge as a covariate variable. The previous interface format effects disappeared for all dependent variables with the introduction of the covariate variable in the analysis. This data support the hypothesis that semantic memory is involved during HIR as the models of HIR suggest (e.g. SNIF-ATC, Pirolli & Fu, 2003; CoLiDeS, Kitajima) and that this process is more relevant when the information is located in deep layers of hypertext nodes since the top choices are more ambiguous and unrelated with the target. Consequently, the models of visual search (e.g. Niemelä & Saarinen, 2000; Liu et al., 2002; Pearson & Schaik, 2003; Scott, 1993; Fleetwood & Byrne, 2003), in spite of being helpful to predict the search process in each node of the hypertext, do not seem to be enough to explain and predict the users' interaction with hypertext interfaces and other complex systems where semantic processing is involved.

Additionally, the data on prior knowledge enables us to explain the general superiority of H users over DS users found in this experiment. In general, DS users found more relation between unrelated pairs and less relation between related pairs than H users which may have made the semantic similarity judgments during the HIR difficult for DS users. The knowledge difference between users agrees with the findings of Marschark and Everhart (1999) and McEvoy et al (1999) who found that deaf and hearing people utilized different strategies to access their semantic knowledge about words. In that way, although deaf signer people would have more visuospatial capacity to maintain and manipulate visual (e.g. icons) and spatial information derived from the sign language usage, when there also is semantic information involved, their different organization of knowledge in LTM would prevent the facilitation.

Although Experiment 2 was not designed to contrast the underlying model of information representation in LTM, it is interesting to discuss this phenomenon. Several authors in the field of cognitive psychology suggest that, even without having prior experience, pictures would show a privileged access to a common semantic representation in LTM (te Linde, 1982; Bajo, 1988) [3]. However, our results in both the relation judgement task and the HIR task suggest that either the hypothesis of such privileged assess is incorrect or pictures and words access to different semantic representations, which would agree with dual coding models (see figure 5.2). In the second case, it is obvious that if users do not have information stored in the picture code, the semantic processing may be interfered because pictures may only indirectly access semantic knowledge by means of the referential processing and, therefore, the picture superiority will not occur in the HIR task. However, it is also possible that the word superiority in both tasks was due to uncontrolled factors such as the concreteness of the categories used (some categories of concepts could be more abstract than others, "Culture" vs. "Sport", and abstract concepts would be faster processed by the verbal code,

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[3] Although most researchers who have found the PSE make sure that subjects know the category of to which pertain the pictures to be judged (e.g. Job, Rumiati, Lotto, 1992), te Linde (1982) and Bajo (1988) found the PSE in categorization tasks even without this previous familiarization phase.

Paivio, 1986) or the visual distinctiveness, which would invalidate the support to dual coding models. The PSE has been contrasted with normalized set of pictures and words in Cognitive Psychology research while, in Experiment 2, we only control the semantic distance of icons and their colour (black and white). Therefore, a further research is necessary to test if the absence of PSE in our experiment is due to a non-comparable set of pictures and words in a series of measures such as the visual distinctiveness or the typicality and frequency of the concepts represented, which could vary between or within the set of icons and words utilised.

In spite of the data limitations to definitively support dual or common coding models, the value of these findings is that show that the substitution of words with icons may affect the semantic processing during HIR task and that this solution does not guarantied the improvement of accessibility of deaf signer users. Then, the question arising is how the users guide the search process in hypertext when they do not have available semantic cues. Payne et al., (2000) have found that in absence of knowledge or semantic cues (scents), the mere familiarity with the choices could strategically guide the search. Familiarity would be a new constraint added to those proposed by the CoLiDeS model: semantic similarity, literal matching and frequency. When neither literal matching nor semantic similarity or frequency is satisfied, users would try to satisfy familiarity constraint to select a choice (e.g. choices which have already been selected on the current search would be avoided, Howes, Payne and Richardson, 2002). However, it also important that users know the source of the familiarity, distinguishing the within-trial familiarity from the between trials familiarity as the answer to each one may be different. That is, it is necessary that individuals make use of their episodic memory to recognize the correct choices. In direct manipulation interfaces, Wiedenbeck (1999) have found that the increase of trials sessions reduces the disadvantage of graphical interfaces in terms of response time with regard to verbal interfaces, which may be due to a recognition memory effect. Therefore, we designed Experiment 3 to test the hypothesis of icon disadvantage reduction in HIR by means of increase the number of expositions to the task and system.

At that point, before continuing with Experiment 3, we are able to hint at some provisional guidelines for the design of hypertext based on the results of Experiment 2. For instance, the substitution of verbal links with icons may interfere instead of favouring HIR tasks when users do not have enough prior knowledge on the meaning and functions of those icons in the hypertext system. In such cases, it would be recommended to explicitly teach the users the meaning and function of icons in the specific hypertext or to use concrete icons which are easily interpreted (McDougall et al., 1999). In addition, it is important to take into account that the path length augments the number of semantic judgments and the ambiguity of top-level choices, which may mainly affect icons.

6

Experiment 3. Recognition Memory and Visuospatial Abilities

The main objective of Experiment 3 was to test if the increase of the users experience with the same hypertext (by doing three sessions of searches with the same target) would reduce the disadvantage of graphical interfaces in HIR. We hypothesised that, in the absence of semantic cues, users will use their episodic knowledge on successful and unsuccessful choices per target in first searches to guide the subsequent searches. For instance, users may recognize that a choice lead to the current goal in a previews session of trials and then select it or vice versa. If recognition influence users' behaviour between sessions of searching (being constant the semantic cues), then we may predict a lower disorientation, fewer revisited pages and faster response time per trial in repeated searches than in first searches. That is, users in the Graphical Interface condition will have more cues to the selection process in the repeated searches than in the first searches and, in this way, the disadvantage with regard to the Verbal Interface condition will decrease. In Experiment 3, the sample was composed of hearing users exclusively, therefore we did not make predictions concerning to the type of user.

The second objective of Experiment 3 was to broad the knowledge about the users abilities involved in HIR. Specifically, we were interested in exploring the involvement of several visuospatial abilities which could be explaining the variance of the previous experiments. In addition to verbal abilities, users' visuospatial abilities seem to be involved in different search tasks (e.g. Dahlbäck, Höök & Sjölinder, 1996; Vicente et al., 1987). For example, Dahlbäck et al. observed that mental rotation correlated with the search efficiency for one piece of information in a hypermedia system. This correlation between visuospatial abilities and navigation in hypertexts is normally interpreted as the evidence that hypertext systems and physical environments have similar characteristics to (e.g. distance, directions, etc). Therefore, to explore this hypothesis in different hypertext formats, we measured 3 visuospatial abilities and used the scores as predictors of the HIR performance in a regression analysis.

In summary, our first prediction was that the increase of the content familiarity will reduce the disadvantage (especially in terms of disorientation, number of revisited pages and response time) of Graphical Interface with regard to Verbal Interface during HIR. The second prediction was that the visuospatial abilities of users will predict the efficient performance mainly in the Graphical Interface.

6.1. Method

Participants

Sixty five volunteer subjects participated in this experiment in exchange for experimental credits or an economical remuneration. All participants were hearing students of introductory courses from the University Granada and University of Basque Country (Spain).

Material, Task and Design

The Material and the Search Task were similar to Experiment 2. A Mix Multifactorial Desing 2 (Hypertext Format: Graphical vs. Verbal) x (3) (Path Length: Sort vs. Medium vs. Long) x 2 (Number of Search Sessions: 1 vs. 2 vs. 3) was used. The variable *Sessions* was introduced to manipulate the familiarity of users with the icons and words of each hypertext format condition. The dependent variables were the percentage of correct answers, the response time, the disorientation and the repeated visits to the same node. The last variable was measure comparing *N* (number of different nodes visited) with *S* (number of total nodes visited) by means of the indicator N/S. Although this measure is part of the Smith's disorientation measure, we though that its independent analysis could be interesting because the resulting value shows if the users are revisiting the same nodes (values close to 0) or visiting new ones (values close to 1).

Unlike in Experiment 2, participants did not complete the relatedness judgment tasks but fulfilled three tests of visuospatial abilities of the *Kit of Factor-Referenced Cognitive Test* (Ekstrom et al., 1976). The selected tests were the Identical Pictures Test, the Card Rotation Test and the Paper Folding Test. Each test measures different visuospatial factors (perceptive speed, spatial orientation and visualization respectively) which may influence hypertext interaction. The Identical Picture test measures the speed to compare and scan figures or symbols or to perform other simple tasks which involve visual perception. This ability may be important to perform visual searches between the elements of a hypertext node, especially, when the time to complete the task is limited (Figure 6.1).

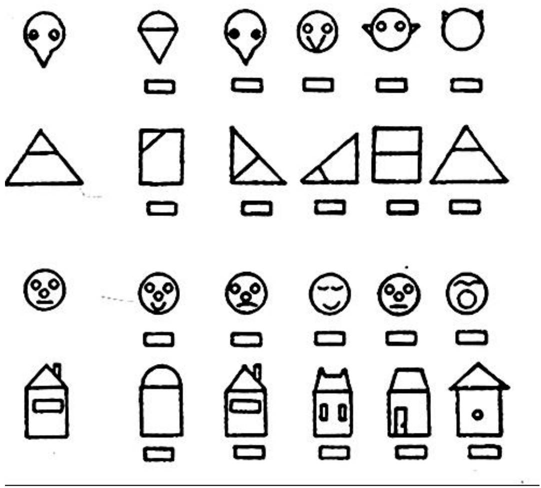

Figure 6.1. Examples of the Identical Picture Test. Subjects were shown a series of pictures rows. The picture on the left of each file was identical to one of the five pictures on the right. Subjects were asked to identify as many pictures matches as they could in one minute.

The Card Rotation test measures the ability to perceive spatial patterns or to maintain the orientation with regard to the objects in the space. The orientation process may be important during HIR to maintain in memory knowledge on paths between nodes (route knowledge) or the full map of the hypertext structure (survey knowledge).

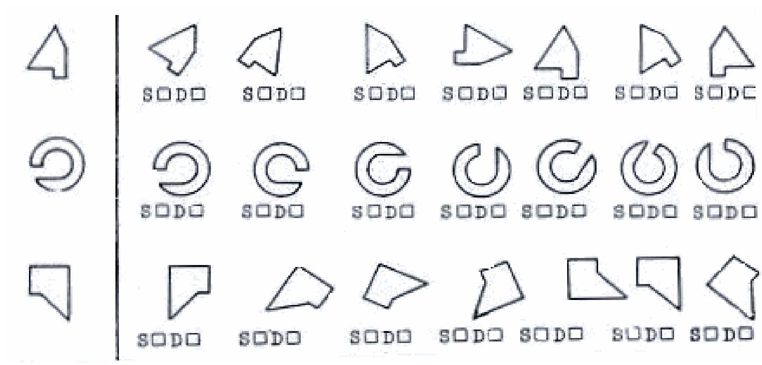

Figure 6.2. Examples of the Card Rotation Test. The subjects were asked to determine which of a set of 8 two-dimensional shapes were rotated versions of the target shape on the left. They have 3 minutes to complete 20 trials.

Finally, the Card Rotation test measures the ability to manipulate or transform pictures of spatial patterns. It could be important to follow paths in reverse order during HIR (from terminal nodes to the main node of the hypertext) (see figure 6.3).

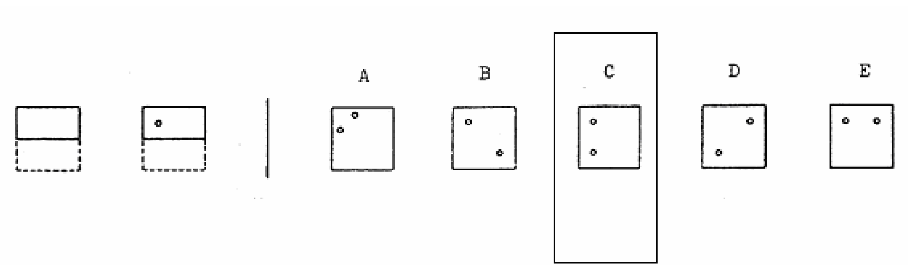

Figure 6.3. Example of the Paper Folding Test. The two figures on the left represent a square piece of paper being folded. In the second figure a small circle shows where a hole has been punched through all of the thicknesses of paper. Subjects were asked to choose the drawing on the right that shows where the holes are after the paper has been unfolded. They have 3 minutes to complete 20 trials.

Procedure

As in Experiment 2, participants read the general instructions and performed a practice session of the search task. In the experimental session, the number of targets was augmented to 27 targets per session (9 targets per level of paths length) except in the third session which was composed of 12 targets (3 targets per level of paths length). The order of presentation was different for each session of search and users rested several minutes between sessions. In both Graphical and Verbal Interface the targets were presented in textual format (contrary to experiment 2, where targets were presented in the same format as the corresponding condition of interface type). After the three sessions of search, participants fulfilled the three visuospatial tests which were presented always in the same order (Identical Picture test, Card Rotation test and Paper Folding Test).

6.2. Results

In order to compare the results of this experiment with those of Experiment 2, we performed three ANOVAs by item with the data of Session 1 (one ANOVA for each dependent variable). Path Length was introduced as between items variable and Interface Format as within-item variable. We found a replication of Interface Format Effect and Path Length

Effect in the Session 1. The main effect of interface format was significant for correct answer, F (1,24)=10,02; MS_e= 58,7; p=0.0042, response time, F (1,24)=19,26; MS_e= 11.3; p=0.0002, and disorientation, F (1,24)=42,75; MS_e= 0.005; p=0.00. Replicating the results of hearing in Experiment 2, users found more targets in the verbal interface than in the graphical interface (94.8% [7.4] vs. 88.2% [15.7]). In addition, they were faster (10” [5.6] vs. 14” [7.3]) and became less disoriented (0.1 [0.1] vs. 0.23 [0.1]).

The main effect of path length was significant for correct answers, F (2,24)=9,03; MS_e= 139; p=0.0012; and response time, F (2,24)=11,05; MS_e= 40.5; p=0.0004. Again, the pattern of results replicated such results found in experiment 2. The longer the path is, the fewer targets were found (Short= 82% [3], Medium= 94.5% [7.2] and Long=98 % [14.3]) and the slower the users were (Short= 7.3” [3.5], Medium= 11.8” [5.7] and Long=17.2” [11.4]).

Finally, the interaction between Interface Format and Path Length was significant for correct answers (F (2, 24)=4,80; MS_e= 58.7; p=0.0177), though the difference between the graphical and the verbal interface was only significant in long paths (F (1, 24) = 18.8; MS_e= 58.7; p= 0.00) and not in medium paths as in experiment 2.

In general terms, the main effects of experiment 2 for hearing users were replicated in experiment 3 even though the averages between both experiments seem to vary. With the aim of contrasting the results between experiments, we performed an ANOVA by subjects for each dependent variable with Experiment (Experiment 2 vs. Experiment 3) and Interface format (graphical vs. verbal) as between group independent variables. The difference between experiments was significant for correct answers, F (1,9)=40,68; MSe = 77; p=0.0001, and response time, F (1,9)=40,68; MSe = 13.3; p=0.0001. In experiment 3, users found more targets and were faster than in experiment 2. In the case of correct answers, the interaction between type of interface and experiment was significant, F (1,85)=18,08; MS_e= 333.9; p=0.0001. Users of experiment 3 found more targets than users of experiment 2 when searching in the graphical interface (E1=62.8 % vs. E2= 88.2%), F81, 85)= 52.9; MS_e= 333.9; p= 0.000, while the difference in verbal interface (91% vs. 94.8%) was not significant. One possible explanation is that in experiment 3, the number of trials was higher than in experiment 2 (27 vs. 12), which augmented the experience of users and facilitated the search.

Effect of Experience

To test our main hypothesis, that is, that the experience with the hypertext will reduce the disadvantage of the graphical hypertext interface, we performed one ANOVA by Item with Interface format and Sessions (Session 1 vs. Session 3) as within-item independent variables for each dependent variable (see Table 6.1). The main effect of Sessions was significant for response time, F (1,11)=22,16; MS_e= 25,9; p=0.0006 (see Figure 6.1) and disorientation, F (1,11)=33,68; MS_e= 0,0036; p=0.0001 (see Figure 6.2); however, not for correct answers, F (1,11)=2,74; MS_e= 154,5; p=,1261 (see Figure 6.3). Users were faster and became less disoriented in Session 3 than in Session 1. The interaction Sessions x Interface Format was significant for response time, F (1,11)=11,31; MS_e= 3,36; p=0.0063, and disorientation, F (1,11)=16,82; MS_e= 0,0013; p=0.0018 but not for correct answers, F (1,11)=,31; MS_e= 42,14; p=,5861. In Session 3, the difference in response time and disorientation between Graphical and Verbal Interfaces disappeared and decreased respectively (the difference between type of interface was higher in Session 1 than in Session 3 for disorientation, F (1, 11)=16,8; MS_e= 0,0013; p= 0,0017). That is, as we predicted, the disadvantage of the graphical hypertext interface was reduced with the increase of experience.

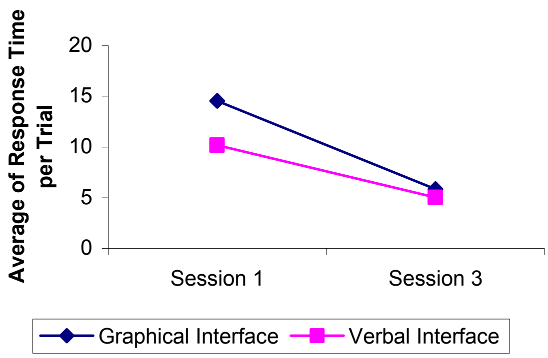

Figure 6.1. Average of Response Time per users in the Graphical and Verbal Interface in Sessions 1 and 3.

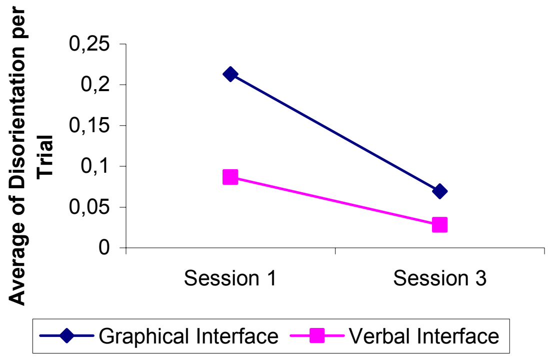

Figure 6.2. Average of Disorientation users in the Graphical and Verbal Interface in Sessions 1 and 3.

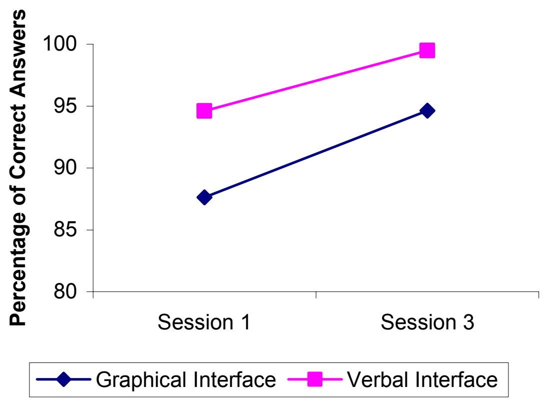

Figure 6.3. Percentage of Correct Answers users in the Graphical and Verbal Interface in Sessions 1 and 3.

Although the percentage of correct answers for the Graphical Interface augmented in Session 3, the disadvantage with regard to the Verbal Interface remains significant, $F\,(1, 9) = 44.25$; $MS_e = 3.22$; $p = 0.001$.

In addition, we analysed the number of pages revisited per search (N/S). We found a main effect of Sessions, $F\,(1,11)=15{,}99$; $MS_e = 0{,}005$; $p=0.002$. As we described in the design session, the values close to 0 meant many revisited pages and values close to 1 meant that every node seen was a new one. As we predicted, users revisited fewer pages in Session 3 (0,94) than in Session 1 (0,86). The main effect of Type of Interface was also significant, $F\,(1,11)=44{,}31$; $MS_e = 0{,}002$; $p=0.000$; with the users revisiting fewer pages with the Verbal (0,94) than with the Graphical Interface (0,86). The interaction Session x Interface Format was significant, F (1,11)=13,59; 0,001; MS_e= p=0.004. The difference between interfaces in number of revisited pages was larger in Session 1 than in Session 3, F (1, 11)= 13,6; MS_e= 0,001; p= 0,004.

		Session 1		Session 3	
Measure	Type of Interface	Means	Standard Deviations	Means	Standard Deviations
Correct Answers	Graphical	88	22	95	4
	Verbal	95	10	99	1
Response Time	Graphical	14,5	8,3	5,9	3,1
	Verbal	10,2	6,2	5	2,1
Disorientation	Graphical	0,21	0,11	0,07	0,05
	Verbal	0,09	0,06	0,03	0,04
Repeated Pages (N/S)	Graphical	0,79	0,09	0,92	0,06
	Verbal	0,92	0,06	0,96	0,05

Table 6.1. Means and Standard Deviation for Graphical and Verbal Interface Conditions for each dependent variable.

Visuospatial abilities

In order to contrast whether visuospatial abilities of users predicted HIR performance, we perform a Standard Regression Analysis for each dependent variable (correct answers, time and disorientation) at each level of path length. The scores in the 3 visuospatial tests were introduced as predictors.

The only user visuospatial ability which predicted HIR was perceptual speed and only in the case of Graphical Interface. Specifically, the scores in the Identical Picture Test, which measured this ability, predicted the response time in short and long paths (see table 6.2). The more perceptual speed, the faster users found the targets in short and long paths.

Predictor	Dependent Variable	R^2	BETA	t(24)	p-level
Identical Picture (IP) scores	Response Time in Short Path	0,327	-,43	-2,27	0,03
	Response Time in Long Path	0,147	-,47	-2,32	0,03

Table 6.2. The Regression summary shows the significant R^2 values for Identical Picture (IP) scores as predictor and Response Time for Short and Long Paths as dependent variable.

We performed an ANCOVA by subjects with interface format as independent variable between-groups, identical picture scores as covariate variable and response time as dependent variable with the aim of testing whether perceptual speed differences among the users could be causing the effect of interface format in response time. The main effect of interface format was significant, F (1,58)=30,31; MS_e= 8,3; p=0.0000 (as in the case of the ANOVA by subjects, F (1,87)=15,16; MS_e= 19; p=0.0002). The users were faster in the verbal (adjusted mean=10, SD =3,6) than in the graphical interface (adjusted mean =13,8; SD = 2,6). The adjusted means showed that the difference between interfaces was even bigger when the perceptual speed of users is controlled (see table 6.1).

6.3. Discussion and Conclusion

According to our main prediction, the disadvantage of the graphical hypertext interface was reduced with the increase of users' experience, especially in the case of total response time, disorientation and number of repeated pages per search. Although the effect was no statistically significant, the disadvantage of the Graphical Interface, with regard to the percentage of correct answers in Session 3, was also reduced. Our results generally agree with those of Wiedenbeck (1999), who found that the disadvantage for the icon-only interface of an e-mail software compared to the label-only and icon label interfaces was reduced after two Sessions of trials (especially for time).

A plausible interpretation of these results is based on the familiarity with the icons and words which compose each type of interface that users acquire after three sessions of trials, that is, even though they do not exactly know the meaning of the interface elements (especially in the case of icons), they are able to use familiarity with them to guide the selection process. However, the recollection of episodic information may be necessary to determine the source of the familiarity: *if the source is the current trial then the operator* [icon or word] *should be rejected, if it is a previous trial, then perhaps it should be selected* (Howes and Payne, 2001, p. 1). In Experiment 3, even though users continue to visit more nodes than needed, they revisit less nodes within-search in Session 3 than in Session 1 (especially with the Graphical Interface). This result may be interpreted as users recollecting certain episodic information from the previous searches about when and where they found a familiar link and which the consequence of clicking in it was. Therefore, as in the case of frequency constraint in the CoLiDeS model, frequently accessed or familiar objects do not ensure that they are the correct choices. That is, frequency and familiarity, though helpful, are not enough and users must also retrieve where and when the information was encountered. This interpretation is coherent with the dual-process model of recognition (Mandler, 1980) which states that recognition memory is based on two processes: familiarity and recollection. The first process provides individuals with the necessary information to say if an object has been seen before or not. The recollection process provides information on where and when such an object was seen or studied. We found in the literature some attempts to take into account such distinction in models of interactive search based on cognitive architectures (e.g. Howes & Payne, 2001; Howes, et al., 2002).

An alternative explanation to the effect of augmenting the number of trials is that the users simply acquired experience in the search task itself. However, we think that the practice trials which the users preformed before the experimental session should have ensured that they knew perfectly the system environment and the task procedure. Therefore, the probability of a practice effect seems to be low.

Another possibility to explain the effect of experience, which would be alternative or compatible to this of recognition memory, is that users may be producing knowledge on the choices when attempting to explain why a sequence of moves led to a resulting state (Johnson, Zhang & Wag, 1994). For example, if clicking on the link *Classifieds* led to a node with job vacancies, apartment vacancies, etc., users may infer that all information related to *Vacancies* in general can be found in this section, even though they do not recognise the link as leading to their current goal the last time. Actually, in Experiment 1, we found that users showed a better mental model after they performed the search, which means that the hypothesis of a knowledge acquisition effect must be also considered in future research.

Other important result of Experiment 3 is the replication of interface and path effects of Experiment 2. That is, as we observe in Session 1, users find more targets, are faster and become less disoriented in the verbal interface than in the graphical interface. They also find more targets and are faster in short than in medium and long paths. In addition, the interaction between the two variables is replicated for correct answers, that is, the disadvantage of the graphic interface during the HIR task happens especially in long paths when the semantic processing demands augment.

Finally, the hypothesis about the involvement of visuospatial abilities is only partially supported. There is only one visuospatial ability (perceptual speed), which is able to predict response time in short and long paths (only for the Graphical Interface). Users with a higher ability to compare and scan figures or symbols may perform the visual search and match processing faster between the choices, especially in the case of icons, where the semantic information may not be available. The rest of the visuospatial abilities do not predict the performance in the HIR task designed. The absence of prediction of card rotation scores contrasts with the results of Dahlbäck et al. (1996) and Cribbin and Chen (2001), who observed that mental rotation correlated with the efficiency search for one piece of information in a hypermedia system. The same contradiction occurs with regard to the paper folding scores and the data of Nilsson and Mayer (2002) who have observed that participants with a high ability to manipulate and create spatial images (measured by the Paper Folding test) were better navigating in hypertext. Perhaps, the hypertext system used in Experiment 3 is not as complex as in the cited experiments, which could explain the absence of correlation.

Therefore, according to the results of experiment 1, 2 and 3, interacting with hypertext would not be similar to navigate in a physical space as semantic information seems to be more important than visuospatial information, at least in the first steps of the interaction. However, as our objective is to design accessible web site to deaf signer users and such users may have advantages in visuospatial processing (Arnolds, and Mills, 2001), we considered necessary to explore the involvement of this processing in HIR more deeply. The ability to scan and compare figures and symbols seem to be related to the capacity of visuospatial WM. Miyake et al. (2001) used the 3 visuospatial tests used in this experiment and found that they all implicated some degree of the visuospatial store of WM, although differed in the degree of the executive functioning (highest for spatial visualization and lowest for perceptual speed). This means that this store of WM store may be involved in hypertext interaction with graphical interface. Until now, most of the cited studies which explored the involvement of this structure in interactive search tasks used the correlation o regression analysis. The problem of these approaches is that they are not able to established cause-effect relations among the manipulated variables (visuospatial WM) and the measured variable (HIR performance). The dual task paradigm which is able to provide this kind of evidence had, to our knowledge, not yet been used in HIR research in spite of being acknowledged as a definitive methodology (Boechler, 2001; Nilson & Mayer, 2002). The objective of experiment 4 was to test the hypothesis of the involvement of WM in hypertext by means of the dual tasks paradigm.

7

Experiment 4. The Role of Visuospatial Working Memory

Most of researchers and web designers use terms related to environmental navigation such as “orientation”, “navigation” or “route” to make reference to the users’ behaviour in hypertext. In these occasions, they seem to be assuming a spatial metaphor of hypertext. However, several questions arise regarding the spatial metaphor. As Boechler (2001) stated, does *spatial metaphor* mean that hypertext has the same spatial features of a physical space or is it only a useful metaphor in Human Computer Interaction (HCI) which helps users to understand the system? Do users require the same cognitive processes used in a physical environment such as spatial processing? In this sense, Boechler emphasizes the necessity of empirical research in Cognitive Psychology and related fields to answer these questions.

As the WM is a process highly related to the orientation process in real environment (e.g. Garden, Cornoldi & Logie, 2002), it is a good candidate to be involved in the hypertext navigation. The objective of Experiment 4 was to explore the involvement of the visuospatial sketchpad and the phonological loop in HIR tasks by means of the dual-task paradigm. In addition, the interface format (graphical or verbal) and the length of path to find a target were manipulated to observe the interaction with the type of interference task. Before presenting the experimental results, a brief revision of the literature on the visuospatial processing in hypertext is presented.

7. 1. Visuospatial Processing in Hypertext

As Boechler (2001) suggests, spatial metaphor of hypertext may simply be a metaphor which helps users to understand the system. With the aim of discarding this hypothesis it is necessary to investigate if physical and information spaces (hypertext) have similar characteristics regarding cognitive processing. In the previous experiments, we have found evidence supporting both verbal (e.g. reading abilities in Experiment 1) and visuospatial processing (e.g. perceptual speed in Experiment 3) during HIR. Other authors have also observed evidence for the involvement of both types of abilities in interactive search task. In the case of verbal abilities, reading comprehension and vocabulary (e.g. Niederhauser et al., 2000; Vicente & Williges, 1987) or verbal WM (Juvina & van Oostendorp, 2004; Larson & Czerwinski, 1998) seem to be relevant processes when searching information in hypertext and menu systems.

With regard to visuospatial abilities, the literature is rather abundant. The classical studies of Vicente and Williges (1987) and Campagnoni and Erlich (1989) are two of the most cited examples. In both studies, the users with high spatial abilities were more efficient (in terms of completion time and table of content re-visitation, respectively) during information search than the users with low spatial abilities. Dahlbäck et al. (1996) observed that mental rotation ability, related to spatial orientation factor, positively correlated with the efficiency of searching for one piece of information in a hypermedia system. Zhang and Salvendy (2001) tested the effect of presence/absence of a *preview* during hypertext information search and its interaction with the visualization abilities of the users. The researchers found that without preview, low visualization users were outperformed by high visualization users. Cribbin and Chen (2001) found that the disorientation (LOST) and the orientation time (Tno) was predicted by the spatial orientation ability of users in database searches aided with graphical overviews. More recently, Nilsson and Mayer (2002) have observed that participants with a high ability to manipulate and create spatial images (measured by the Paper Folding test) were better navigating in hypertext. Finally, in the Experiment 3, perceptual speed ability (measured with the Identical Picture test) was a valid predictor of users' response time in the HIR task.

As it was introduced in Experiment 3, the Card Rotation test, which was used by Cribbin and Chen and Dahlbäck et al. in their experiments to measure the spatial orientation, seems to require the participation of visuospatial sketchpad and central executive (Miyake et al., 2001). On the other hand, a strong relation between the orientation process and visuospatial WM has been found in other fields of research (e.g. path learning from maps, Garden et al., 2002). Therefore, it is possible to infer from this previous data that the visuospatial WM is involved in HIR.

The objective of Experiment 4 was to test the involvement of the visuospatial sketchpad and the phonological loop in HIR tasks by means of the dual task paradigm. If searching information in hypertext involves visuospatial working memory, then a concurrent visuospatial task should interfere with the performance of such a task (percentage of targets found, response time and disorientation). In addition, the interface format (graphical or verbal) and the length of path to find a target were manipulated to observe the interaction with the type of interference task.

Although only hearing non signer people participated in this experiment, the establishment of both the participation of visuospatial WM during HIR and their interaction with the abilities of users are especially relevant for a sample of users with particular cognitive characteristics as in deaf signer users. For that reason, this experiment should be repeated in the future counting with the participation of this kind of users. As it was explained above, some domains of visuospatial spatial cognition may have especially developed in deaf people. The key point is to discover if such domains coincide with the visuospatial domains involved in HIR in such a way that they may be exploited to facilitate performance in the task.

7. 2. Method

Participant

Thirty four students of the Faculty of Computer Science of Basque Country University (Spain) participated in this experiment. There were twenty three men and eleven women (average age 20.3 and 21.2 respectively). They received experimental credits for their participation.

Design, Material and Procedure

We used a Mixed Multi-factorial Design (3) x (2) x 2. *Concurrent Task* (Visuospatial-VS, Verbal-V and Control-C) and *Path length* (Short and Long) were the within subject independent variables. *Interface Format* (Graphical and Verbal) was the between groups independent variable. In this occasion, we only used two levels of path length with the aim of reducing the total time of the experimental session. The dependent variables of the HIR task were the number of targets found, the time spent to find a target and disorientation.

The hypertext system was the same used in experiments 2 and 3. The concurrent tasks, similar to the tasks used by Kruley et al. (1994), were composed of two sets of elements, a *memory set* (or) and a *recognition set*. Before presenting each set, the participants looked at a fixation point in the centre of the screen during 500 milliseconds.

In the case of the VS task, the memory set consisted of a sequence of 5 coloured dots in an 8 x 8 matrix (Figure 7.1.) which was presented for 667 milliseconds (Kruley et al., 1994). The same matrix was presented in the recognition set; however, in half of the trials, the sequence of coloured dots appeared in the same position than in the memory set and, in the other half, the position of the coloured dots varied (identical and different trials were presented randomly). The dot sequence conserved its configuration but each dot was displaced to an adjacent dot (to the right or to the left). The participants were asked to click on the button "yes" if they though that the memory and recognition sets were identical and to click on the button "no" if they were different. The recognition set remained visible until participants responded.

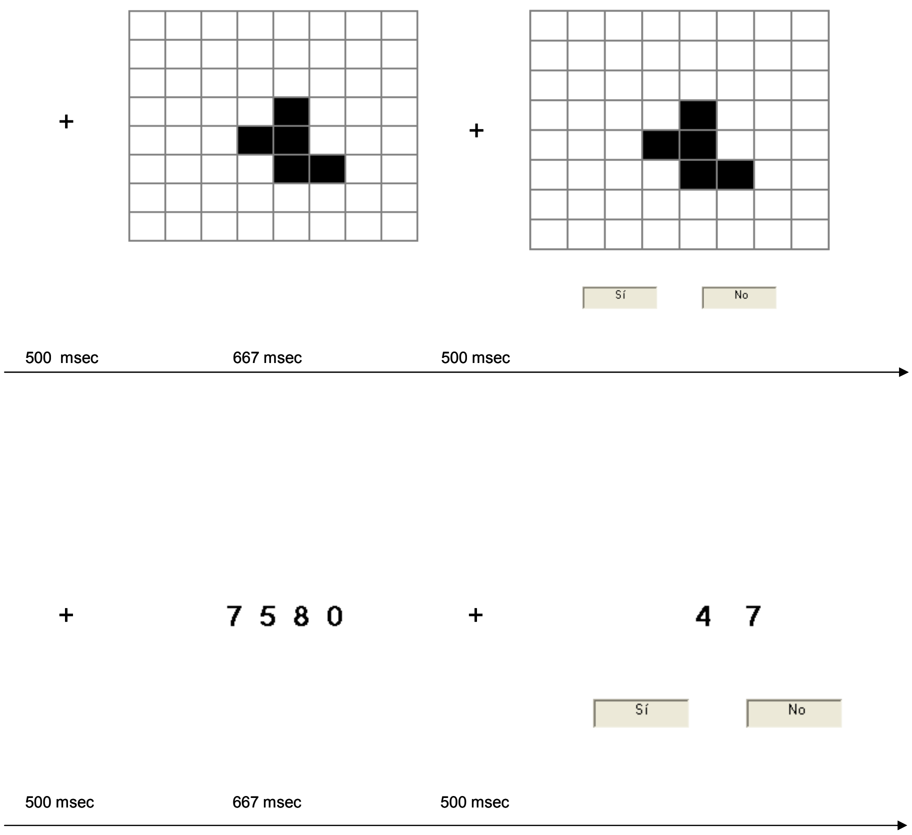

Figure 7.1 Memory and Recognition sets of the Concurrent Visuospatial Task (top) and the Concurrent Verbal Task (bottom).

In the case of the V task, the memory and recognition sets consisted of a sequence of 4 digits. In the recognition sets, only 2 digits of the memory sets were presented. In half of the trials, the order of the two digits was different to the recognition test. The participants were asked to click on the button “yes” if the order of digits was identical in memory and recognition sets and to click the button “no” if they were different. For example, if the memory set was 5 - 7 - 3 - 4 and the recognition test was 7 - 4, the correct answer was “yes”. If the recognition test was 4 - 3, the correct answer was “no”.

There were 18 trials, 12 with concurrent tasks (6 with the V task, 6 with the VS task) and 6 without concurrent tasks (control trials). The order of trials was fixed at the beginning of the experiment for all subjects. In the concurrent trials (see figure 7.2.), participants were presented with a fixation point (500 milliseconds) followed by the memory set for 667 milliseconds followed by a screen with the target to be searched.

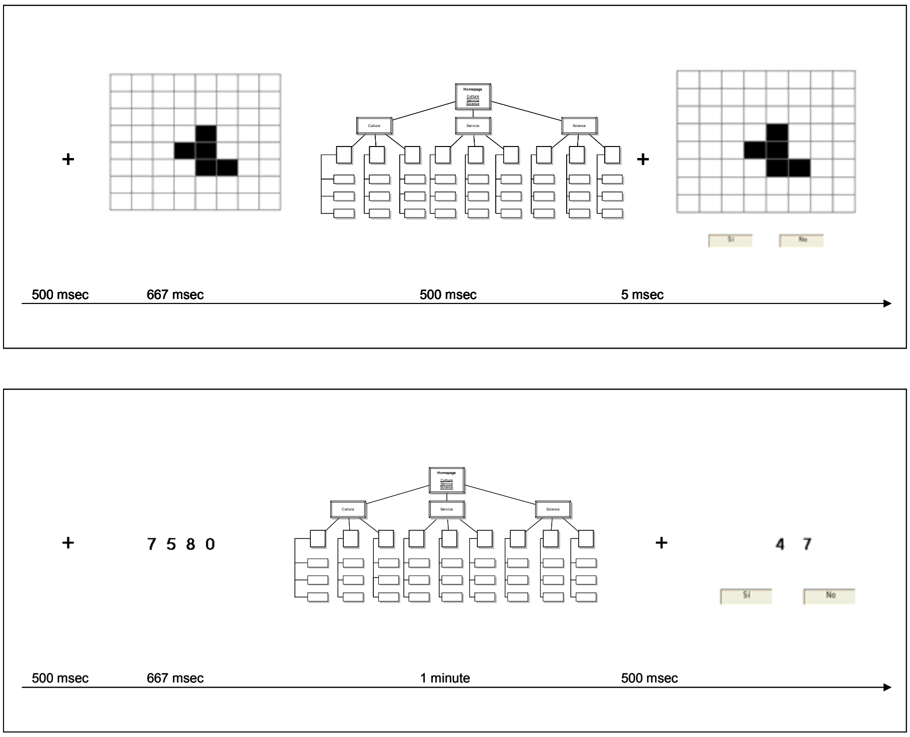

Figure 7.2. Procedure summary of a search trial in the visuospatial concurrent condition (top) and in the verbal concurrent condition (bottom) of Experiment 4

When participants clicked “ok” in the target screen, they were returned to the home page of the hypertext (in the graphical or verbal interface depending on the experimental condition of the participant). Participants had 1 minute to find the target (which was visible during the search trial). When they found the target or when time minute finished, the recognition set (preceded by a fixation point during 500 milliseconds) was presented without a time limit to answer. In the control trials, the procedure of the search task was the same as in the previous experiments with the difference that at the end of the trial the V or VS task was presented (see figure 7.3.). In this way, the control trials served as control for both the search and concurrent tasks. Half of the 6 control trials were followed by the VS task and the other half by the V task. The order of presentation of the concurrent and control trials were counterbalanced between subjects. Half of the participants (17) performed the task in the Graphical Interface condition and the other half (17) in the Verbal Interface condition.

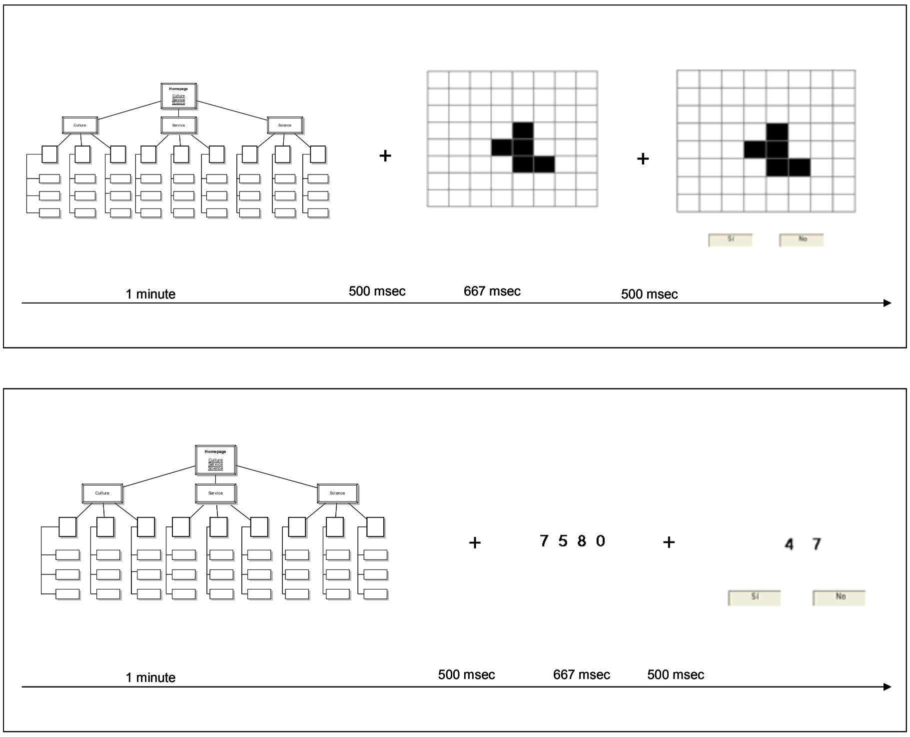

Figure 7.3. Procedure summary of a search trial in the visuospatial control condition (top) and in the verbal control condition (bottom) of Experiment 4.

Finally, the users completed two tests of memory span, one spatial and one verbal. The spatial span test was a computerized version of the Corsi Block-Tapping Task (Berch, Krikorian & Huha, 1998) and the verbal span task was the Forward Digit Span Test of WAIS-III (Wechsler, 1999). In the Corsi Block-Tapping Task, an increasing sequence of blocks (from 3 to 9 blocks) arranged in a board was displayed in a computer monitor. After the presentation of each sequence, the individuals had to reproduce the sequence in the correct order. In the Forward Digit Span Test, the individuals were given an increasing sequence of digits, which they had to reproduce.

7. 3. Results

Effects of Interface Format and Path Length

With the aim of testing the robustness of the results of Experiments 2 and 3, we analyzed the effect of interface and path length in the control condition (only search task). We performed one ANOVA by item with Interface Format and Path Length as independent variables (within-item and between items respectively) for each dependent variable (see means and standard deviations in Table 7.1).

		Short Path		**Long Path**	
	Type of Interface	Means	Standard Deviations	Means	Standard Deviations
Correct Answers	Graphical I.	100	20	85	26
	Verbal I.	93	0	91	9
Response Time	Graphical I.	5,8	6	18,8	9
	Verbal I.	8,1	5	10	4
Lostness	Graphical I.	0,2	0,2	0,36	0,2
	Verbal I.	0,1	0,1	0,1	0,1

Table 7.1. Means and Standard Deviation for Graphical and Verbal Interface in Long and Short paths for each dependent variable.

The effect of Interface Format was replicated in the case of response time, F (1,16)=7,15; MS_e= 38.9; $p=0.02$; and disorientation, F (1,16)=17,80; MS_e= 0,03; p=0.001. Users were slower (13” vs. 8”) and became more disoriented (0.28 vs. 0.1) in the Graphical Interface than in the Verbal Interface. In the case of correct answers, though the main effect was not significant, F (1,16)=1,69; MS_e= 212,6; p=0,2; the pattern of results was replicated, that is, users found more targets in the Verbal (95.4%) than in the Graphical structure (89%).

The main effect of path length was also replicated for Response Time, F (1,16)=12,13; MS_e= 41.4; p=0.0031 and Disorientation , F (1,16)=1,80; MS_e= 0.03; p=,1988). As in the previous variable, the difference between path lengths was not significant for correct answers, F (1,16)=1,81; MS_e= 391,1; p=0,2, although the tendency was similar to the tendency of the Experiments 2 and 3 (97% vs. 88%). That is, in short paths, users found more targets (96% vs. 88%), were faster (6.9” vs. 14.4”) and became less disorientated (0.15 vs. 0.23) than in long paths.

The interaction between the Interface Format and Path Length was nearly significant in the case of disorientation, F (1, 16) =3,76; MS_e= 0.02; $p=0.07$, but not in the rest of the dependent variables. However, the analysis of simple effects showed that the results of our previous experiments were replicated, that is, users became more disoriented and were slower, in the Graphical interface than in the Verbal interface but only in the case of long paths, F (1,16) = 9; MS_e= 39; p= 0,01 and F (1,16)=19; MS_e= 0.02; p=0.001, respectively. Perhaps, the absence of significance was due to the low number of control trials per item and subject (6 in total).

Verbal and Visuospatial involvement in HIR task

Firstly, we analysed the correlation between verbal and spatial span and the dependent variables of HIR performance (correct answers, total search time, and disorientation). The average verbal span was 6,4 (SD = 1,04) and the average spatial span was 5,9 (SD = 0,9). There were no significant correlations between the verbal and spatial span and any dependent variable (see table 7.2.).

In order to analyse whether the V and VS concurrent tasks produced interference in the search task performance, we contrasted the concurrent conditions of the search task with the control condition of the search task (ANOVA by subject for each dependent variable).

	Correct Answers	**Total Response Time**	**Disorientation**
Verbal Span	-0,10	-0,02	0,13
Spatial Span	0,21	0,05	0,01

Table 7.1. Correlations values between verbal spatial spans and the percentage of correct answers, the total response time and the disorientation en the search task.

There were no significant differences in performance between searches with concurrent tasks and the control condition. As users were instructed to do their best in the two tasks (Rende et al., 2002), it is possible that they considered the search task more important or interesting and invested more resources when carrying the task out. In this case, the interference may have occurred in the concurrent tasks.

With the objective of testing this possibility, we first analysed the base line of performance in the control conditions of V and VS tasks. The average for correct answers (true positives plus true negatives) was 92.2 % (SD =18.4) for the V task and 95.1 % (SD =12) for the VS task. The average response time was 3.9" (1.6) for the V task and 2.4" (1.3) for the VS task. The VS task was significantly faster than the V task, F (1, 33)=23.07; MS_e= 1665E; p=0.00.

Secondly, we contrasted the V and VS tasks performance in control and concurrent conditions. In order to do this, we performed several ANOVAs for each concurrent task (V and VS) and each dependent variable (response time and percentage of correct answers) with Condition as within subject variable (control vs. concurrent + search in short paths vs. concurrent + search in long paths) and Interface Format as between-groups variables. The differences between control and concurrent conditions were not significant in the case of V task (see means in Table 7.3) for any dependent variable. However, in the case of VS, the effect of condition was significant for correct answers, F (2, 64) = 7.30; MS_e= 457.9; p=0.0014 and for F (2,64)=7.94; MSe = 2770E; p=0.001 (see Table 7.2 and Figure 7.1). The simple effect analysis showed that, in the concurrent conditions considered together (see Figures 7.1 and 7.2), users obtained fewer correct answers, F (1, 32)= 15.3; MS_e= 435.5; p= 0.0004; and a higher response time, F (1,32)= 19.6; MS_e= 2233541, p=0.0001, than in the control condition (see means in Table 7.3). The interaction between condition and interface format was not significant.

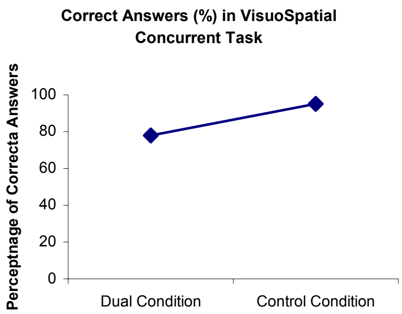

Figure 7.1. Percentage of correct answers in the Visuospatial Task for control and dual condition.

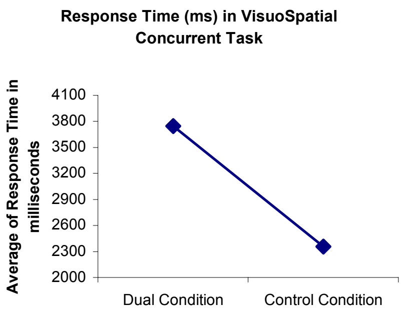

Figure 7.2. Response time in milliseconds in the Visuospatial Task for control and dual condition.

		Visuospatial Concurrent task		**Verbal Concurrent Task**	
Measures	Conditions	Means	Standard Deviations	Means	Standard Deviations
Correct Answers	Dual Condition	78	25	85,5	27
	Control condition	95	12	92,2	18,5
Response Time (seconds)	Dual Condition	3,7	2,4	3,5	1,5
	Control condition	2,4	2,2	4	1,6

Table 7.3. Means and Standard Deviations of percentage of correct answers and response time in the Visuospatial and Verbal Tasks for control and dual condition.

7. 4. Discussion and Conclusion

The main objective of Experiment 4 was to test the involvement of Visuospatial and Verbal WM in a HIR task by means of the dual task paradigm. Only the performance in the concurrent VS task is interfered by the search task, which seems to confirm that the visuospatial store is involved in the HIR task.

This result may constitute a support to the second possibility on the use of spatial metaphor proposed by Boechler (2001), that is, hypertext interaction has spatial components as in the physical world due to the fact that users seem to use the same kind of processing (spatial memory) used in such environment.

However, we do not find support for the participation of the phonological loop in HIR. This null result is probably due to methodological artefacts as all users obtain high scores in the verbal span test. In this experiment, users have enough verbal WM capacity to perform two V tasks concurrently but not to perform two VS tasks concurrently (despite the fact that the V concurrent task is more difficult than the VS task, as revealed by the analysis). That is, we can not strongly conclude that the phonological loop is not involved in HIR tasks contrarily to the data obtained by other authors in correlation and regression analysis (Juvina & van Oostendorp, 2004; Larson & Czerwinski, 1998). To prevent ceiling effects, it is necessary to perform further research, in which samples of users with individual differences in verbal and spatial span participate, or where more difficult verbal and spatial concurrent tasks are used than those used in Experiment 4.

In addition, as it is intended that deaf signer users are the main final beneficiaries of this research, it is fundamental to replicate this study with such kind of users. Garden et al. (2002), suggest that complex environments, as hypertext, may provide a large variety of cues for interaction (e.g. semantic, visual, etc). If deaf signer people are efficient in certain areas of visuospatial cognition, for example, memory for spatial locations, visual or spatial cues may aid their performance.

On the other hand, we replicate the negative effect of graphic interface when users have to find a target in deep nodes of the hypertext structure. However, we do not find any interaction of this variable with the effect of the visuospatial concurrent task. Therefore, the absence of such interaction suggests that the effects of interface format and path length are more dependent on semantic factors or even on recognition memory than on visuospatial factors. As we have explained along this document, this semantic relevance is defended by most of the researchers, for example, by Pirolli (2004) who developed SNIF-ACT model (cited in the introduction) to simulate how users make use of proximal information scent to forage for distal content on the WWW.

To our knowledge, in spite of their acknowledged utility (Boechler, 2001; Nilson & Mayer, 2002), no researcher has previously used the Dual Task methodology in the area of HIR before us. Apart from the methodological shortcomings of this experiment mainly related to lack of a heterogenic sample of users with regard to spatial memory, the dual task methodology has proved to be valid and useful in order to explore the involvement of WM stores in HIR allowing to establish cause-effect relations because the availability of WM resources are directly manipulated within subjects and their effect measured.

From the applied point of view, the involvement of certain spatial processing in HIR supports the guideline that spatial clues such as maps or visual landmarks may be useful to improve hypertext navigation. However, theses cues may also interact with the spatial and verbal abilities of users. Maps, previews or graphical overviews may only enhance the performance of users with low spatial abilities (e.g. Zhang & Salvendy, 2001). For this reason, further research to increase the support of this guideline is necessary.

8
General Conclusion

8.1. Theoretical Conclusion

This thesis arose from the necessity of finding solutions to a pragmatic problem: hypertext accessibility of deaf signer people. Such a problem led to the formulation of theoretical and basic questions on cognitive processing which were explored by means of empirical research. The general cognitive questions that we formulated were: *Which are the cognitive accessibility problems of deaf people to the web?* ; *Which cognitive processes are involved in web interaction?* and *Which capabilities or abilities of users may be limiting or, contrarily, favouring web interaction?*

By means of the 4 experiments which composed the thesis, we have tried to answer these questions constrained to the HIR task. A range of cognitive processes have resulted in being relevant to deaf signer users and/or hearing users in HIR: reading comprehension, semantic memory, episodic memory (recognition) and visuospatial working memory. The results of Experiment 1 showed that reading comprehension is one of the processes highly involved in HIR text-based. This process is severely restricted in Deaf Signer people, a fact which is often ignored or simply unknown for web designers. In this experiment, we observed that the low reading comprehension abilities contributed to make deaf signers users to not successfully complete some of the components of the HIR (e.g. comprehension or selection process in terms of CoLiDeS model). For example, with the aim of selecting an item of a set of items by evaluating the degree of relatedness (scent) between them and their goal, users should previously read such items (words). If the reading process is not automatic and consumes a great amount of resources, users may suffer a lot of interference (Foltz, 1996).

In addition, Experiment 1 revealed that the type of hypertext structure may reduce the influence of the reading difficulties in deaf signer users (although it was only a non significant tendency). Concretely, this type of users find more targets, are faster and get less disoriented in narrow/deep than in wide structures (their scores were below the hearing users scores in any case). A possible explanation may be that the number of items which must be read each time is reduced in the narrow/deep structure (8 items) compared to the wide structure (62 items). In this way, they would not be overloaded. On the contrary, hearing users with good reading abilities are more efficient in the wide than in the narrow/deep structures. This pattern of results is the most frequently found in the literature (e.g. Norman, 1991; Lee and Tedder, 2004). According to Norman (1991), depth structures augment the uncertainty about the location of a target, increasing consequently the semantic processing demands between nodes and interfering with the performance. This variable, in spite of being also affecting deaf signers, would not overloading their capacity as in the case of the number of items to be read in the deep structure.

According to the hypothesis of Norman (1991), in Experiment 2, we observed that both type of users found fewer targets, were slower and got less disoriented when the length of the path to find the targets increased in deep structures. Furthermore, contrary to the PSE, the semantic processing implicated in the selection of links seems to be more interfered by icons than by words, above all, for Deaf signer users. Experiment 2 showed that the interface format is not relevant when the targets are in the first layers of nodes. However, this variable becomes more important with the augmenting of semantic demands when the targets are in deeper layers of the hypertext structure. In those cases, graphical interfaces interferes users performance. They find fewer targets and are less efficient (in terms of response time and disorientation).

This data calls for the reconsideration of the models of hypertext interaction that only have into account the visual search process. On the contrary, the results support the hypothesis of a number of theoretical models of hypertext search which consider the semantic processing a core process of the task (e.g. CoLiDeS, SNIF-ACT). However, not only visual and semantic information may be guiding the information search in hypertext. Users may be using the familiarity, the recollection or the frequency of successful paths to make selections among choices (Kitajima et al., 2000; Payne et al., 2000). In absence of semantic clues, the recognition of successful paths may be helpful and reduce the disadvantage of graphical interfaces compared to the verbal interfaces. In fact, in Experiment 3, the disadvantage of the Graphical Interface was reduced in terms of response time, disorientation and number of repeated pages per successful trial after three sessions of search. We assumed that this effect was due to the fact that the users, after repeated sessions of search, may recollect if a choice was correct for the current goal in previous trials, which in absence of semantic cues or plausibility may be used in the selection process.

The second finding of Experiment 3 may be more related to the literal matching, another of the ColiDeS model constraints which users try to satisfy during HIR. Literal matching occurs *whether the representation of the unelaborated current goal has a literal matching with the actual object* (Kitajima et al., 2000, p. 6). To satisfy this constraint, several abilities of the users related with the visual search may be relevant. In Experiment 3 we found that users who were faster scanning and comparing symbols (perceptual speed ability) were also faster completing the searching tasks.

Considering this data, even though in the precedent experiments the verbal abilities and the semantic processing showed a high involvement, to contemplate the spatial metaphor of hypertext is appropriate. This metaphor states that if hypertext presents similar characteristics to physical environment, the same cognitive processes which are involved in real navigation should be present in hypertext navigation (e.g. visuospatial WM). In Experiment 4, we used the dual task methodology to explore the involvement of the two subsystems of the WM process. We found that the spatial concurrent task was interfered by the search task, which means that the resources of visuospatial sketch pad are being used in HIR. Although it is necessary to overcome various methodological shortcomings of Experiment 4 with further research, this result seems to agree with the previous results of the studies of regression and correlation supporting that physical space and informational space has similar cognitive characteristics (e.g. Zhang & Salvendy, 2001; Nilsson & Mayer, 2002). If so, as we will discuss in next section, the aids used to enhance navigation in physical spaces must be tested in the context of hypertext navigation for deaf signer users.

In short, we observed that there are a wide range of cognitive processes involved in the HIR, mainly the semantic processing and the reading abilities. In this sense, the extent to which the hypertext format or structure do not facilitate to the users reading or the access to their semantic knowledge, the performance should be interfered. This reasoning may even be more relevant if the users, due to the peculiarities of their cognitive systems, process the information in a different way (Experiments 1 and 2). On the other hand, the manipulations performed in Experiments 3 and 4 show that visuospatial abilities and the capacity of the visuospatial working memory have a repercussion in the efficiency of the hypertext search task.

These effects are possibly related to the literal matching and orientation processes.

However, the manipulations performed in Experiments 3 and 4 must be replicated in deaf signers users and it is necessary to focus not only on these cognitive characteristics that limits their performance in HIR (such as reading comprehension and organization of knowledge in semantic memory) but also on these characteristics that may enhance it (such as spatial memory). In that sense, we think that this thesis opens a great amount of future research lines, signalling a range of possible aspects that should be considered in the research of cognitive accessibility of deaf people.

Another conclusion derived from the observation of a range of cognitive processes involved in hypertext interaction (semantic processing, recognition and working memory) is that it is important to formulate models of HIR which account for how all these processes interact. As suggested by Wright (1993), these models would mean a challenge to Cognitive Psychology and especially to Cognitive Ergonomic. Perhaps, one of the approaches more directed related to this goal is formulated by the CoLiDeS model, which proposes a diversity of processes such as attention (in the parsing phase) and comprehension. Other interesting approaches are the SNIF-ACT model (Pirolli, 2004) and the model of interactive search by Howes and Payne (2001). One of the values of these models is that they are based on cognitive architectures which play an important role in user modelling (Howes & Young, 1996). On the other hand, according to Pirolli (2004), the most significant problem of the computational models of information scent concerns the *analysis of non-text information scent cues, such as graphical icons, animations and so on…*(Pirolli, 2004, p. 36). Taking into account the results of the last three experiments of this thesis, this analysis will be a non trivial issue, especially when this kind of cues is considered as a potential alternative to text in order to find solutions to enhance the performance of users with web cognitive accessibility problems as deaf signer users.

8.2. Applied Conclusion

Although this thesis open many questions for the further research, we think that we may present a set of guidelines derived from our results which may be useful to enhance the performance of deaf signer people and all users in general in HIR:

6) Not to overload each hypertext node with too much verbal content. If it is not possible or desirable to remove the verbal information, one possible solution is to distribute it along other layers of nodes through a hypertext structure. However, this solution implies certain risk as the increase of the uncertainty on the location of a target (Norman, 1991). Therefore, it is necessary to find a trade-off between breath and depth in the hypertext designs.
7) It is important to take into account that the path length augments the number of semantic judgments and the ambiguity of top-level choices which may mainly affect unknown icons. For this reason, a reasonable solution may be to locate the most important icons in the shallower layers of the hypertext or to explicitly teach users the meaning and function of icons in the specific hypertext.
8) To provide users with aids that support the comprehension of the content or to obtain information scents from proximal cues. Several researchers measure the semantic distance between distal and proximal cues by means of LSA cosines (Soto, 1999; Tamborello and Byrne, 2005). A possible solution to design useful and accessible hypertext may be to select the set of labels for related links with less semantic distance among them.
9) The use of pictures and icons instead of words and sentences is not recommended without a previous study of the semantic distance of icons, the complexity of the pictures, and the familiarity of users with such graphic representations (see McDougall et al., 1999, for a revision).
10) The involvement of certain visuospatial processing in HIR supports the use of spatial clues such as maps or visual landmarks to help users to be oriented, especially in users with low spatial abilities or those who can not use verbal semantic cues.

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Appendix A

Example of the structure of the Music section in the Mid Wide Structure		
Main Page	Level 1 of depth	Level 2 of depth
CULTURE	Cinema	
	Horror	Headline1,Headline2,Headline3
	Drama	Headline1,Headline2,Headline3
	Comedy	Headline1,Headline2,Headline3
	Music	
	Singles	Headline1,Headline2,Headline3
	Concerts	Headline1,Headline2,Headline3
	Bands	Headline1,Headline2,Headline3
	Expositions	
	Painting	Headline1,Headline2,Headline3
	Sculpture	Headline1,Headline2,Headline3
	Photography	Headline1,Headline2,Headline3

Example of the structure of the *Music* section in the Narrow and Deep Structure			
Main Page	Level 1 of depth	Level 2 of depth	Level 3 of depth
CULTURE	Cinema	Horror	Headline1,Headline2,Headline3
		Drama	Headline1,Headline2,Headline3
		Comedy	Headline1,Headline2,Headline3
	Music	Singles	Headline1,Headline2,Headline3
		Concerts	Headline1,Headline2,Headline3
		Bands	Headline1,Headline2,Headline3
	Expositions	Painting	Headline1,Headline2,Headline3
		Sculpture	Headline1,Headline2,Headline3
		Photography	Headline1,Headline2,Headline3

Appendix B

Pairs of concepts (related and unrelated) used in Experiment 2 and degree of relatedness judged by Deaf and Hearing users. The values in bold indicate the significant differences between types of user.

Pairs of Concepts		**Type of User**	
Related Pairs		Deaf	Hearing
Informática	Medicina	2,47	2,63
Inmobiliaria	Hostelería	2,76	3,00
Música	Exposiciones	3,53	3,25
Nutrición	Informática	2,94	2,08
Medicina	Nutrición	3,41	4,33
Música	Pintura	3,12	4,21
Ciencia	Nutrición	5,71	5,79
Ciencia	**Medicina**	**3,71**	**4,63**
Exposiciones	Pintura	4,35	4,42
Exposiciones	Cultura	3,76	4,08
Informática	Ciencia	3,82	4,63
Música	Cultura	2,24	4,29
Pintura	Cultura	4,12	4,13
Servicios	**Hostelería**	**3,76**	**3,50**
Servicios	Inmobiliaria	3,82	3,79

Pairs of Concepts		**Type of User**	
Unrelated Pairs		Deaf	Hearing
Ciencia	Exposiciones	3,65	3,92
Ciencia	Música	3,00	3,04
Ciencia	Servicios	2,24	1,88
Cultura	**Inmobiliaria**	**3,88**	**2,67**
Cultura	Informática	4,24	3,71
Cultura	Ciencia	3,59	4,25
Cultura	**Medicina**	**1,88**	**3,38**
Exposiciones	Servicios	2,24	2,33
Exposiciones	Hostelería	1,82	2,33
Exposiciones	**Inmobiliaria**	**4,29**	**3,17**
Hostelería	Ciencia	2,00	2,08
Hostelería	Medicina	2,35	2,50
Hostelería	**Cultura**	**2,12**	**3,46**
Hostelería	Nutrición	3,94	4,54
Hostelería	Informática	2,12	2,00
Informática	Música	3,24	3,83
Informática	Exposiciones	2,71	3,21
Informática	**Servicios**	**4,47**	**3,21**
Inmobiliaria	Informática	4,35	3,63
Inmobiliaria	Pintura	2,59	2,96
Inmobiliaria	Ciencia	2,18	1,67
Medicina	Exposiciones	1,65	1,96
Medicina	Música	1,59	2,00
Medicina	Inmobiliaria	2,88	2,54
Medicina	Pintura	2,24	2,00
Música	Inmobiliaria	2,82	2,75
Música	Servicios	2,29	2,21
Música	Hostelería	2,76	2,13
Nutrición	Exposiciones	2,18	2,54
Nutrición	Servicios	2,47	2,54
Nutrición	Inmobiliaria	2,00	2,38
Nutrición	Música	1,41	1,50
Pintura	Nutrición	1,71	1,67
Pintura	Hostelería	1,71	1,67
Pintura	Informática	3,06	2,75
Pintura	Ciencia	2,82	3,13
Servicios	Medicina	4,06	3,83
Servicios	Pintura	2,12	1,96
Servicios	Cultura	2,82	2,96
Cultura	Nutrición	2,94	4,00