# Investigating Information Search by People with Cognitive Disabilities

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The ability to gather information online has become increasingly important in the past decades. Previous research suggests that people with cognitive disabilities experience challenges when finding information on websites. Although a number of studies examined the impact of various design guidelines on information search by people with cognitive disabilities, our knowledge in this topic remains limited. To date, no study has been conducted to examine how people with cognitive disabilities navigate in different content structures. We completed an empirical study to investigate the impact of different search methods and content structures on the search behavior of people with cognitive disabilities. 23 participants with various cognitive disabilities completed 15 information search tasks under three conditions: browsing a website with a deep structure ($4 \times 4 \times 4 \times 4$), browsing a website with a broad structure ($16 \times 16$), and searching through a search engine. The results suggest that the participants overwhelmingly preferred the search engine method to the two browsing conditions. The broad structure resulted in significantly higher failure rates than the search engine condition and the deep structure condition. The causes of failed search tasks were analyzed in detail. Participants frequently visited incorrect categories in both the deep structure and the broad structure conditions. However, it was more difficult to recover from incorrect categories on the lower-level pages in the broad structure than in the deep structure. Under the search engine condition, failed tasks were mainly caused by difficulty in selecting the correct link from the returned list, misspellings, and difficulty in generating appropriate search keywords.

Categories and Subject Descriptors: H5.0 [**Information Interfaces and Presentation (e.g., HCI)**]: General; K 4.2 [**Computers and Society**]: Social issues—*Assistive technologies for persons with disabilities*

General Terms: Human Factors

Additional Key Words and Phrases: Cognitive disabilities, information search

**ACM Reference Format:**
Ruimin Hu and Jinjuan Heidi Feng. 2015. Investigating information search by people with cognitive disabilities. ACM Trans. Access. Comput. 7, 1, Article 1 (June 2015), 30 pages.
DOI: http://dx.doi.org/10.1145/2729981

## 1. INTRODUCTION

Information search is the process in which an individual gathers data with the use of a computing device. It can include a wide range of activities such as finding a document on a computer, checking email, and browsing the Web. In the past decades, the general public has become increasingly dependent on the Web to gather information. People with cognitive disabilities experience difficulty when navigating websites and searching for information (e.g., Small et al. [2005] and Kumin et al. [2012]). However, limited research has been conducted to examine how people with cognitive disabilities gather information online. Although there are promising studies (e.g., Freeman et al. [2005]

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DOI: http://dx.doi.org/10.1145/2729981

and Karrenman et al. [2006]) that employed adapted websites or pages to facilitate information search by people with cognitive disabilities, the websites investigated in those studies contained a limited number of pages and did not consider the support of a search engine. Since in reality, individuals with cognitive disabilities have to navigate among a large number of pages and may use search engines when searching for information online [Kumin et al. 2012], the findings of those studies are not closely representative of users' real life experience. To fill in this gap, we conducted an empirical study that aimed to examine the information search behavior of individuals with cognitive disabilities in a comparatively more realistic context. The website used in this study contained more than 270 pages and offered a search engine to assist in information search. We examined the impact of different content structures and compared the performance of information search with and without the search engine through tasks with different levels of difficulty. The results suggest that of the three conditions (deep structure, broad structure, and search engine), the search engine is the most effective and preferred method, while the broad structure is the least reliable method.

## 2. RELATED RESEARCH

Individuals with cognitive disabilities are the largest single disability group and account for over one billion people worldwide [World Health Organization 2011]. Loosely defined, individuals with cognitive disabilities can be those who have learning disabilities (e.g., Dyslexia and Dysgraphia), attention disorders (e.g., ADHD and ADD), developmental disabilities (e.g., Down Syndrome, Fragile X Syndrome, and Autism Spectrum Disorder), and neurological impairments (e.g., Alzheimer's Disease, Traumatic Brain Injury, and Dementia). Despite the fact that the causes, symptoms, and treatments concerning cognitive disabilities are yet to be fully explored and explained, existing efforts from a broad range of fields such as medical science, psychiatry, and clinical psychology have yielded some common knowledge about cognitive disabilities. In general, individuals with mild or severe cognitive disabilities have more difficulty concentrating on tasks (they tend to have a shorter attention span and get distracted more easily); they possess limited power of perception and logical reasoning (they often fail to function in an abstract environment); they demonstrate relatively poor problem-solving skills; and they experience short- and long-term memory problems (e.g., Cornish and Wilding [2010], Engle et al. [2005], Harris [2005], and Hogg and Langa [2005]).

It should be noted that the categorizations of cognitive disabilities can vary greatly, often requiring researchers' explanations and justifications at the outset that are aligned with the goals and objectives of the research. The different categories that are lumped under the family of individuals with cognitive disabilities are sometimes used for clinical classification and treatment. However, for the purposes of Web accessibility, scholars in general are more interested to know how diverse functional indicators impact user performance rather than the specific diagnosis of the user. For instance, to operationalize cognitive disabilities in the context of Web accessibility, Bohman [2004] focused on common functional limitations or "symptoms" of individuals with cognitive disabilities. Rowland [2004] argued that the most common challenges for individuals with cognitive disabilities on the Web included attention, memory, perception and processing, and problem solving. Similarly, Bohman and Anderson [2005] proposed a framework for researching cognitive impairments based on functional descriptors including memory, problem solving, attention, reading, linguistic and verbal comprehension, math comprehension, and visual comprehension. These findings motivated us to adopt a functionality-based approach when recruiting participants for the reported study.

The following sections offer a brief survey and analysis of the existing research on the use of websites by individuals with cognitive difficulties, including Web design, information search, as well as content structures and the use of search engines.

### 2.1. Web Design for People with Cognitive Disabilities

Researchers have conducted studies on general website design adaptations for people with cognitive disabilities. Holsapple et al. [2005], for example, introduced a theoretical framework consisting of four elements: navigation structure, knowledge acquisition, task and content compatibility, and their interplay. They also outlined a research agenda that identified important considerations on Web design for people with Alzheimer's disease. In line with universal design principles for individuals with disabilities, several studies made specific suggestions on how to design websites that facilitate information retrieval. Kirijian and Myers [2007] reported a participatory design case study on the development of a website specifically for individuals with Down syndrome. The website developed during the study was well received by the Down syndrome community. The site experimented with a host of Web components such as fonts, color, Web links, and searches. A set of design guidelines were proposed such as provide clear guidance, feedback, and rewards; use images to facilitate visual learning; and be careful with design details because every single variation will be interpreted by the user.

To better understand Web accessibility for individuals with cognitive disabilities, Sevilla et al. [2007] conducted a study that compared an existing commercial website and its cognitively accessible equivalent, concluding that the use of a simplified Web browser and an adequate Web design can facilitate people with cognitive disabilities to use the Internet. Friedman and Bryen [2007] reviewed Web design recommendations for people with cognitive disabilities from Web design experts and government and advocacy organizations. The top design recommendations for people with cognitive disabilities were found to be (1) use pictures, graphics, icons, and symbols along with text; (2) use clear and simple text; (3) use consistent navigation and design on every page; and (4) use headings, titles, and prompts.

All of these studies confirm that simplistic design, consistency in navigation and page design, and the use of images would improve the experience of people with cognitive disabilities when interacting with websites. We have adopted those guidelines when designing the "Mini-Library" website used for the information search study.

### 2.2. Information Search by People with Cognitive Disabilities

Broder [2002] suggested three classes of Web searchers according to their intent:

—Navigational: with the intent to reach a particular site.
—Informational: with the intent to acquire some information presented on one or more pages.
—Transactional: with the intent to perform some Web-mediated activities such as business transactions.

In this study, we focused on informational Web searches. A number of studies have been conducted to specifically investigate informational searches by people with cognitive disabilities. Harrysson et al. [2004] examined how people with developmental disabilities search for information on the Web. Seven participants with mild to moderate developmental disabilities took part in the study and completed search tasks on a few preselected websites. The websites selected all contained pages with clear-cut design and a maximum of seven to 10 information units. The amount of text on the pages was limited by using simple language combined with illustrations and pictures. It was found that participants were able to use the basic functions of the browser (e.g., close, back, forward, and side scroll). They could identify links and click them without difficulty. However, many participants had difficulty entering the URL of a website. In addition, when using the search engines, participants found it difficult to enter the query keyword into the search box. Making a selection from a large quantity of returned textual links was also a challenge.

Freeman et al. [2005] compared two websites containing similar information. The design of one website followed the general guidelines on usability and accessibility. The other website adopted design recommendations derived from the implications of dementia-related cognitive changes in addition to the general usability and accessibility guidelines. The recommendations for dementia-related changes include the following:

—use color and contrast cues to direct the user around the website;
—use visual cues such as pictures and icons in addition to verbal cues;
—use simple language; and
—minimize the number of choices on each page.

Five participants with early-stage dementia completed a number of semistructured search tasks on both websites. It was found that the website with the additional adaptation improved participants' sense of orientation. It was also suggested that limiting the choices and amount of information on Web pages could lead to fewer problems because many observed problems were related to scrolling. These findings help understand the difficulty in Web searching. However, given the same amount of information presented on a website, limiting the number of choices and amount of information on each page will inevitably result in a deeper structure and longer path (more pages) to reach specific information. The impact of a deep structure on performance was not examined in this study. Further, the participants only visited a very limited number of pages on both sites (an average of 5.2 and 5.6 pages, respectively).

In a similar study, Karreman et al. [2006] tested two websites that contained similar information. One of the two sites adopted the easy-to-read guidelines that consist of several categories including verbal content (e.g., use simple, straightforward language) and document layout (e.g., never use a picture as background for text). Each website contained a total of five pages. Participants with and without intellectual disabilities were asked to complete five search tasks on the websites. It was found that the adapted website did not significantly improve the efficiency of the search task. However, the adaptation helped participants in both groups comprehend the information.

In addition, there is one study that, although not directly investigating people with cognitive disabilities, does provide insights on the search behavior of people with cognitive disabilities. Trewin et al. [2012] studied the role of age and fluid intelligence on information searching. 14 young participants, 19 seniors with high fluid intelligence, and 22 seniors with low fluid intelligence participated in this study. It was found that age had a significant impact on efficiency with older users spending a longer time completing the searching tasks. Cognitive factors had significant impact on both performance and strategy. Compared to the senior group with high fluid intelligence, the senior group with low fluid intelligence made more use of the mouse prior to clicking, spent more time looking at the goal, conducted narrower searches, spent more time at lower levels in the hierarchy, and were less likely to return to the top-level pages when recovering from wrong initial selections. The difference in the likelihood of returning to the top-level pages was also observed between the young group and the senior group with high fluid intelligence, so further investigation is needed to differentiate the impact of aging from cognitive abilities. This finding is helpful in understanding the difficulties experienced by people with cognitive disabilities when conducting search tasks. If people with low cognitive abilities tend to perform narrower searches and are less likely to return to the top-level page, they may have greater commitment to the top-level category chosen and may be less likely to recover from wrong clicks.

### 2.3. Website Structure and the Use of a Search Engine

Customized presentation of information mainly involves the consideration of hierarchical menu design: broad/shallow versus narrow/deep. Researchers have examined the breadth versus depth trade-off in an effort to understand what kind of structure or combination of structures works better for a particular user group. The majority of studies have yielded consistent findings that a broad structure with fewer levels and more choices within each level performs better than a narrow structure with more levels and fewer choices within each level.

For example, when investigating menu design in general, Kiger [1984] found that a broad structure works better than a deep structure for neurotypical users. Larson and Czerwinski [1998] and Zaphiris and Mtei [2000] extended the study on menu design of websites and arrived at the same conclusion: users achieved better performance with a broad structure than with a deep structure. The authors found that a deep structure required higher cognitive load and that the users were more likely to be disoriented in a deep structure. Hochheiser and Lazar [2010] repeated Larson and Czerwinski's study for users who are blind using screen readers. They found that a broad structure also works better than a deep structure for users who are blind.

The massive amount of information available on the Web makes it hard for almost anyone to retrieve information, let alone people with cognitive disabilities. To find information, people often seek the assistance of a search engine. Kerkmann and Lewandowski [2012] discussed an effective methodology to conduct evaluation studies for Web search engines for people with disabilities. They structured the information seeking process into four steps: query formulation, selection, navigation (optional), and query modification. As mentioned earlier, in the study conducted by Harrysson et al. [2004], participants with developmental disabilities were asked to carry out a search using Google's image search box. It was found that the major problems in searching are the difficulty in correctly spelling the search words and selecting the correct link from the long list of returned links. In comparison, Aula et al. [2010] conducted a large-scale study to examine the search behavior of neurotypical users when using the "Google" search engine. The authors found that users tended to formulate more diverse queries, use advanced operators, and spend a longer amount of time on the search result pages when they have difficulty finding information.

Existing studies on information search have yielded important findings that inform the design of websites. The findings suggest that people with cognitive disabilities encounter various challenges when searching for information from the Web. It was also suggested that websites specifically tailored to people with cognitive disabilities regarding page design and structure can improve performance. However, to date, no study has been conducted to systematically examine the impact of website structure on the information search behavior of people with cognitive disabilities. In addition, most reported studies used websites containing a small number of pages with a limited amount of information and this is not representative of a typical searching environment. Therefore, those studies may not be able to provide comprehensive understanding about the performance level, challenges, and interaction strategies of people with cognitive disabilities when conducting a search in the Web environment. The study reported in this article is one attempt to narrow this gap in the existing literature. Through this study, we aimed to examine the impact of Web structure on search performance, and the use of search engines by people with cognitive disabilities in a more systematic and realistic approach than those adopted in previous studies.

## 3. RESEARCH QUESTIONS

To address the limitations in existing research, we conducted a user study that aims to answer the following questions:

—How do individuals with cognitive disabilities interact with different types of Web content structures? What are specific challenges do they experience when interacting with different Web structures?
—Can individuals with cognitive disabilities use a search engine effectively to find information? What are the specific challenges they experience when using a search engine?
—Do individuals with cognitive disabilities prefer browsing or the use of a search engine when searching for information online?

## 4. METHODOLOGY

### 4.1. Design and Development of the Website for the Study

*4.1.1. Web Content Structures.* A website called "Mini-Library" was specifically designed and developed for this study. The website contains descriptions of 256 books, all selected from the online catalog of a local public library. The books cover four main categories: "Animals," "Entertainment," "Places," and "Sports." The four categories were selected based on recommendations from both domain experts and parents of children with cognitive disabilities. They cover common themes that tend to intrigue people with cognitive disabilities so that the participants would be more engaged in the tasks. In addition, this type of content would also be more representative of the everyday search activities of the target population. This approach has been adopted in previous studies as well (e.g., Harrysson et al. [2004]). However, despite this effort, it is impossible to include all the topics that might be interesting to people with cognitive disabilities and present them in a way that fits each individual's personal preference. So the search performance may still be affected by each participant's interest and preference.

According to the studies on language acquisition of people with cognitive disabilities (see Buckley and Bird [2001] for an overview), the reading level of this population is quite diversified. However, the typical reading level is in the range of grade three to six. Therefore, the reading level of content used in this study is between grades 3 and 6. This is not related to the content of the books per se; rather, it is related to the textual information, mainly book descriptions, presented in the website.

The Web pages were organized into two different hierarchical structures: a narrow/deep structure, and a broad/shallow structure. Figure 1 demonstrates sample pages at different levels in the deep structure. This structure contains four levels, with four links at each level ($4 \times 4 \times 4 \times 4$). Users needed to navigate through a longer path and make more clicks to reach a target using this structure. In contrast, the broad structure (see Figure 2) contains two levels, with 16 links at each level ($16 \times 16$). This structure has more items in each page. The benefit is that the users need to navigate through a shorter path and make fewer clicks to reach a target as compared to the narrow/deep structure.

Although previous research suggested that images can help people with cognitive disabilities in Web search, we chose to include images only in the lowest level pages that present the content description of each book because including images in the higher level pages with 16 links would make the pages quite crowded. In those cases, we believe the negative impact of possible information overload would surpass the benefit of images. In order to keep the page design of the two conditions consistent, no images were included in the pages with four links either.

*4.1.2. Search Engine.* The website provides a customized "Google" search engine. Figure 3 demonstrates the search page with returned links and a corresponding book description page. The search engine is self-contained in the website and only returns results within the site. The returned results from a search include all pages containing


Fig. 1. Narrow/deep, $4 \times 4 \times 4 \times 4$ Web structure.

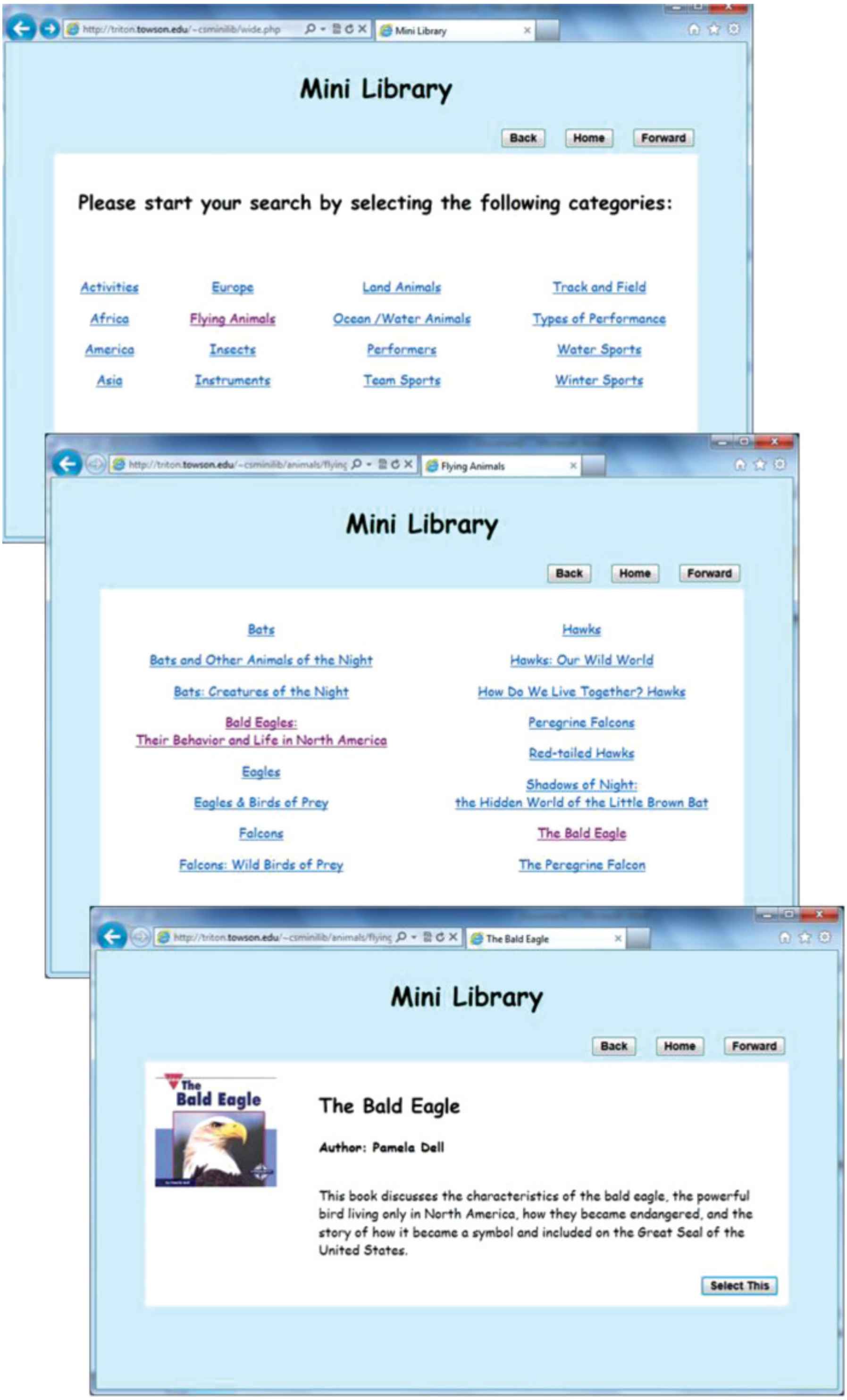


Fig. 2. Broad/shallow, 16 × 16 Web structure.

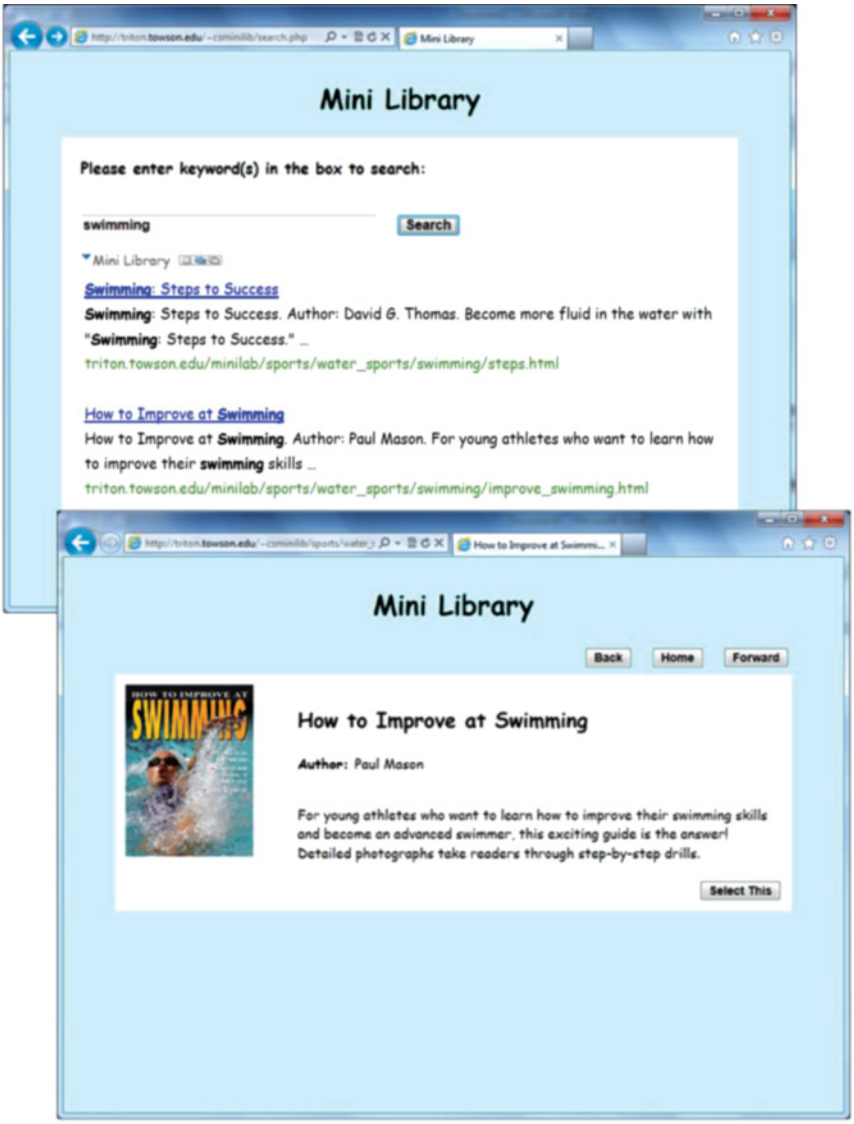


Fig. 3. Customized "Google" search engine.

the keyword(s).[1] For example, if a user wants to search for a book about swimming and enters "swimming" into the search box, the returned results will include all the pages of the books whose description page contains the word "swimming" as well as the categorical pages that contain the key word "swimming." Instructions were provided

[1]Difference in uppercase and lowercase letters is ignored by the search engine (e.g., pages containing either "Computer" or "computer"' are returned for the search term "computer"). Difference in standard single and plural words is also ignored (e.g., computer vs. computers). Variations of the search word that contain the exact search word are matched. For example, if the user enters "swim," pages containing "swimming" will be returned. Pages containing "swam" will not be returned. However, if the user enters "swimming," pages containing "swim" will not be returned.

Table I. Knowledge and Skills Required for Information Retrieval

| Browsing | Using a search engine |
|---|---|
| —Reading skills needed to find text combined with pictures<br>—Orientation skills needed to understand how to reach a specific page and how to navigate back and forth within the site<br>—Analytical, judgment/decision-making skills for determining the path and finding the items<br>—Problem-solving skills when encountering difficulties (e.g., not sure which path to take, or lost in the website) | —Typing/spelling skills needed for entering keywords<br>—Reading skills needed to understand text-based information and process retrieved items<br>—Analytical, judgment/decision-making skills for finding the most related items<br>—Problem-solving skills when the retrieved items do not fit or the page that the user selected does not fit (e.g., trying other items, or even refining the search keyword) |

when specific errors were detected. For example, when a term not found on any page or a misspelled word was entered, a message would appear stating "Sorry, no results were found. Please check your spelling and enter your keyword again." Users can click on the book link to reach the book description page.

*4.1.3. Page Design.* The website was designed following the guidelines and recommendations of WAI (W3C) and the previous research on cognitive disabilities (e.g., Engelen [2001], Karreman et al. [2006], Nielsen [1999], and Rotondi et al. [2007]). The website includes the following features:

—simplified contents, with both text and relevant, nontextual materials such as pictures of book covers;
—limited number of colors with high contrast;
—each line of text contains no more than 80 characters. Text is not justified (aligned to both the left and the right margins);
—font used for text is Comic Sans MS with font size 14;
—links change color whenever clicked;
—no scrolling needed except for pages that contain search results;
—consistent page layout, limited number of links and buttons for easy navigation; and
—reading level of the book descriptions is at grade three to six.

### 4.2. Participants

This study adopted the functionality-based approach (e.g., McGuire et al. [2006]) and examined individuals with cognitive impairments that affect the functionalities related to information search tasks. To recruit eligible participants, the researchers identified the knowledge and skills required for information search tasks and then associated that knowledge and those skills to the characteristics of cognitive disabilities. The knowledge and skills needed for information search tasks are listed in Table I.

Based on the summary of Table I, we specified the following participant recruitment criteria:

(1) Participants should have documented cognitive disabilities that result in difficulties or deficits in problem solving, attention, memory, reading, or writing. The disabilities include, but are not limited to, Down syndrome, Autism, Traumatic Brain Injury (TBI), Dementia, Dyslexia, Attention Deficit Disorder (ADD), Cerebral Palsy, and Fragile X Syndrome.
(2) Participants should have prior experience in computers and the Internet.
(3) Participants need to be 15 or older. At this age, many individuals with cognitive disabilities could master sufficient reading skills and could follow instructions easily.

Twenty-three participants (9 males and 14 females) who met the recruiting criteria took part in the study. The participants had different types of cognitive disabilities including Down syndrome (13), Cerebral Palsy (2), Neurological Impairment (1), Fragile X Syndrome (1), and other unspecified forms of intellectual disabilities (6). To make sure that the participants fit the profile required for the study, we gathered participants' disability information from their guardians, parents, and/or organizational supervisors. We gathered participants' computer experience information from both a questionnaire and an interview attended by both the participants and their caregiver(s). The ages of the participants range from 16 to 48, with an average age of 27.2 (SD = 7.98). Participants on average had 11.4 years of computer experience (SD = 5.6) and 7.1 years of Internet experience (SD = 5.5). All participants had previous experience finding information online through browsing and search engines.

### 4.3. Tasks

At the beginning of the study, each participant completed four training tasks. During the formal sessions, a within-group experiment design was adopted and each participant completed four tasks under each of the three conditions:

(1) browsing in the broad, $16 \times 16$ structure;
(2) browsing in the deep, $4 \times 4 \times 4 \times 4$ structure; and
(3) using a search engine.

After completing the search tasks under the three conditions, participants were asked to find three more books under whatever condition(s) that they preferred (free trials). Therefore, each participant completed a total of four tasks during the training session and 15 tasks during the formal sessions. Tasks were defined with four different levels of difficulty. The following factors were used as indicators of task difficulty:

—Whether or not multiple books in a category meet the task requirement. If any book in a category meets the requirement, the task is easier. If only one specific book meets the requirement, the task is more difficult.
—Whether or not the keyword(s) is in the book title. If the keyword is in the book title, the task is easier. If the keyword is not in the title, the task is more difficult.
—Whether or not a user has to read the book description to find the answer. If the user can find the book just by reading the category page or the book title, the task is easier. If the user has to read the book description, the task is more difficult.

Four groups of tasks were developed and used in the study:

—Easy tasks: Find any book in a category containing four books on the same topic. The tasks in this group include:
(1) Find any book about sharks. (used in training sessions)
(2) Find any book about China. (used in formal sessions)
(3) Find any book about lions. (used in formal sessions)
(4) Find any book about guitar. (used in formal sessions)
(5) Find any book about Wii games. (used in free trials)
—Medium tasks: Find a specific book with the book title provided in the search task. The tasks in this group include:
(1) Find a book about making drums. (used in training sessions)
(2) Find a book about red-tailed hawks. (used in formal sessions)
(3) Find a book about how to improve at swimming. (used in formal sessions)
(4) Find a book about piano method for children. (used in formal sessions)
(5) Find a book about teens in South Korea. (used in free trials)

—Difficult tasks: Find a specific book that the main task keywords are not in the book title. The tasks in this group include:
(1) Find a book about singer Miley Cyrus. (used in training sessions)
(2) Find a book about singers Jonas Brothers. (used in formal sessions)
(3) Find a book about Babe Ruth and other baseball players. (used in formal sessions)
(4) Find a book about Magic Johnson and other basketball players. (used in formal sessions)
For all four books, the name of the main character (e.g., Jonas Brothers) of the book is not in the book title.

—Most difficult tasks: Find a specific book to answer a question that requires information presented in the book description. The tasks in this group include:
(1) Find a book to answer this question: Who was introduced into the International Swimming Hall of Fame in 1988? (used in training sessions)
(2) Find a book to answer this question: What is the world famous historical site in Egypt? (used in formal sessions)
(3) Find a book to answer this question: What things originally came from Mexico? (used in formal sessions)
(4) Find a book to answer this question: Where do bald eagles live? (used in formal sessions)
(5) Find a book to answer this question: When was the first Marathon held? (used in free trials)

This group of tasks was designed to evaluate comparatively higher level reading and problem-solving skills than those needed in the previous three groups of tasks. The participants were told that they had to read the book description in order to answer the questions. The titles of multiple books might be relevant to the question. They needed to read the book description to find and confirm the best answer.

For easy tasks, the task succeeded when the participant found any book in the correct category. So there were four correct answers. For the other three groups, there was only one correct answer that best fit each task.

### 4.4. Procedure

The study was conducted at participants' homes or work places. Participants completed the tasks using any computer with a network connection that they preferred. At the beginning of the study, a researcher interviewed participants and their parent(s), and asked them to fill in a questionnaire to collect demographic data including health conditions, educational background, cognitive ability, and computer and Internet experience.

Following the interview, a training session was offered to introduce the website and the search tasks. Participants were shown each of the three search conditions and tried to find one book under each condition under the researcher's guidance. During the formal study sessions, participants completed 15 search tasks (four tasks under each search condition, plus three tasks during the free trials at the end). The search tasks were blocked by conditions. In other words, each participant completed four tasks under one condition, then four tasks under the second condition, followed by another four tasks under the third condition. The order of the three search conditions was randomized to control the learning effect. The four tasks completed under each condition included one easy task, one medium-level task, one difficult task, and one most difficult task. The three tasks from each of the four groups (easy, medium, difficult, and most difficult) were randomly assigned to each of the three conditions. In this way, each condition was randomly assigned an easy task, a medium task, a difficult task, and a most difficult task. Within each condition, the order of the four tasks was also randomized. With a limited number of participants, this design did not result in a

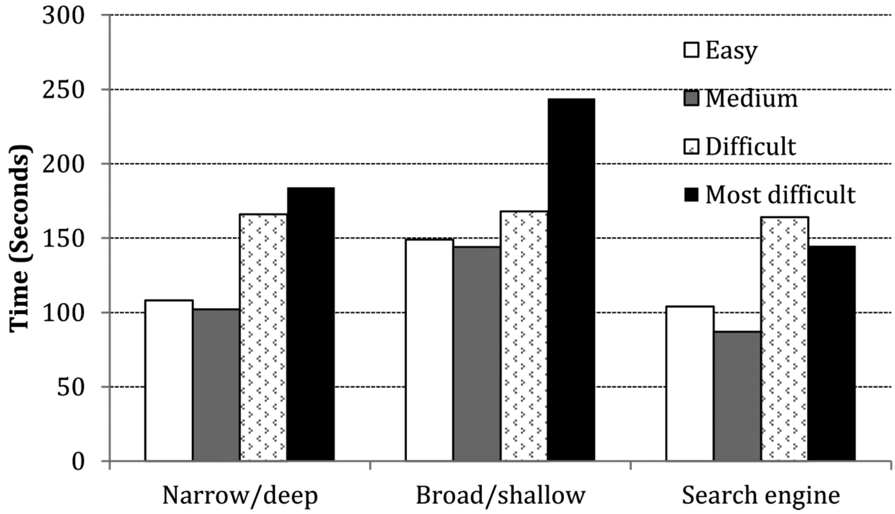


Fig. 4. Average task completion time under each difficulty level and task condition.

completely counterbalanced design. However, it did result in relative balance in the condition orders of the study.

After completing the tasks under the three conditions, participants completed three free trials in which they tried to find a book under whatever condition(s) they preferred. During the free trials, participants were presented a top-level page containing three links, each leading to the home page of one of the three conditions. Participants could switch between conditions by moving back to the top-level page and visiting the link to another condition.

Each task was typed and presented to participants on a piece of paper. The entire session took approximately 60 to 90 minutes. In order to reduce fatigue, participants were asked to take a break between conditions. Upon the completion of all 15 tasks, participants were asked to answer a questionnaire regarding their subjective satisfaction, frustrations, and problem-solving strategies.

## 5. RESULTS

For each task, we logged and analyzed the following measurements: the time that each participant spent finding a book, whether the participant successfully found the book, and the total number of pages that the participant visited during the task. We also documented and analyzed data regarding user preference and satisfaction.

### 5.1. Task Completion Time

A task began when participants finished reading the task instruction and started to view the “Home” page of the specific condition. A task ended when participants verbally indicated that they had found the book or they gave up the task. Figure 4 demonstrates the average task completion time under each difficulty level and task condition. Since the task completion time data is not normally distributed, a Friedman Repeated Samples test was used for the analysis. A Friedman test using the task completion time as the dependent variable and condition as the independent variable suggests that there is no significant difference in task completion time among the three conditions ($X^2(2) = 1.13$, n.s.). A Friedman test using the task completion time as the dependent variable and task difficulty level as the independent variable suggests that there is a significant difference in task time among tasks with different difficulty levels

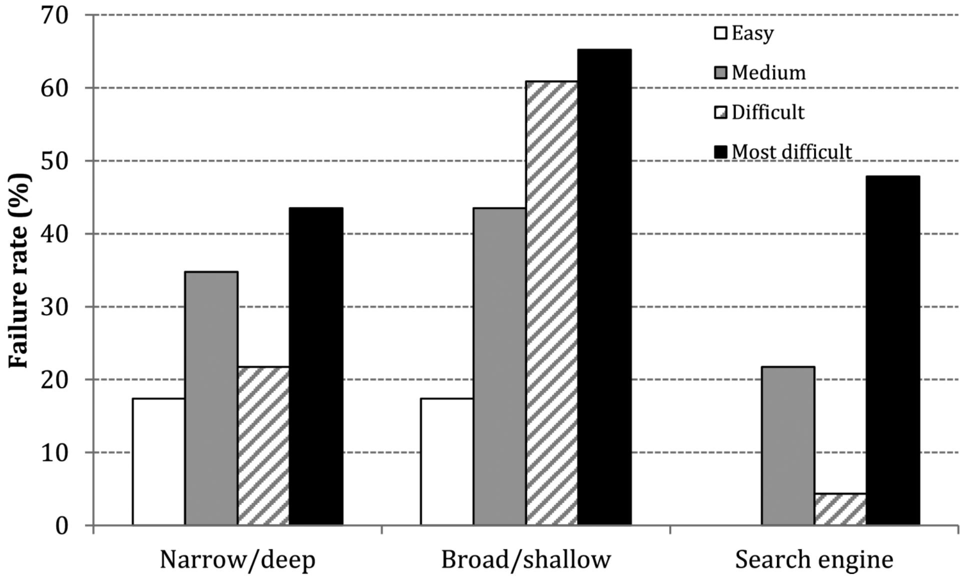


Fig. 5. Failure rate under each difficulty level and task condition.

($X^2(3) = 25.38$, $p < 0.001$). A Friedman Repeated Samples test using task completion time as the dependent variable and task order as the independent variable suggests no learning effect throughout the three conditions and 12 tasks ($X^2(11) = 13.84$, n.s.).

### 5.2. Failed Tasks

There are three possible outcomes for each task: success (meaning participants found the right book), failure (meaning participants found the wrong book), and incompletion (meaning participant gave up the task before finding any book). Both failure and incompletion were counted as failed tasks and failure rates were calculated as a ratio between the number of failed tasks and the total number of tasks under each condition. The failure rates for the deep, broad, and search engine conditions are 29.3%, 46.7%, and 18.5%, respectively.

Figure 5 demonstrates the average failure rate under each difficulty level and task condition. P-P plots suggest that the number of failed tasks under different conditions and task difficulty levels are normally distributed. A Repeated Measures ANOVA test using the number of failed tasks as the dependent variable and condition as the independent variable suggests that there is a significant difference in the number of failed tasks among the three conditions ($F(2, 44) = 9.76$, $p < 0.001$; effect size = 0.16). The LSD post hoc test suggests that participants were more likely to fail under the broad condition than the deep condition ($p < 0.05$) or the search engine condition ($p < 0.005$). There is no significant difference between the deep condition and the search engine condition.

We also counted the total number of failed tasks under each difficulty level. A Repeated Measures ANOVA test using the number of failed tasks as the dependent variable and difficulty level as the independent variable suggests that there is a significant difference in the number of failed tasks among tasks with different levels of difficulty ($F(3, 66) = 13.80$, $p < 0.001$; effect size = 0.22). The LSD post hoc test suggests that participants were significantly less likely to fail with the easy tasks than the other three types of tasks ($p < 0.005$, $p < 0.05$, $p < 0.001$). Participants were more likely to

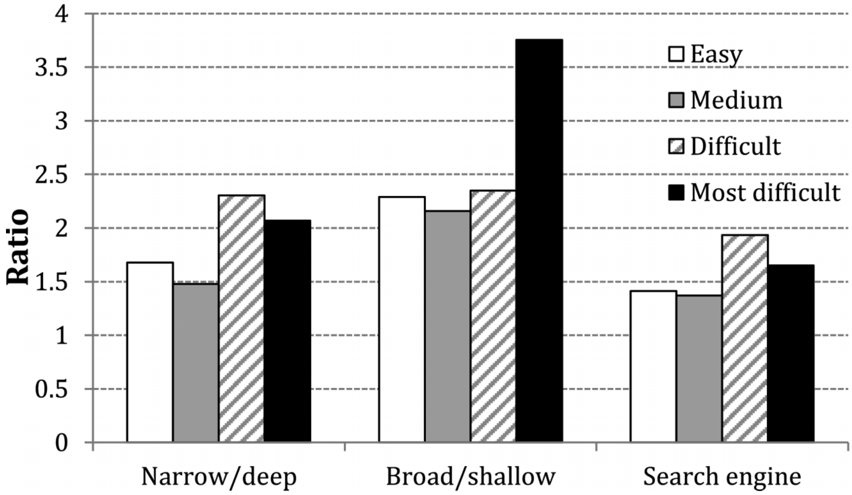


Fig. 6. Ratio between the number of actual pages visited and the number of pages on the optimal path under each difficulty level and task condition.

fail with the most difficult tasks than either the medium tasks ($p < 0.05$) or the difficult tasks ($p < 0.005$) (Figure 5). There was no significant difference in failure rates between the medium tasks and the difficult tasks. As suggested in Figure 5 the failure rate of the most difficult tasks were quite high, especially under the broad condition (65%).

A Repeated Measures ANOVA test using the task outcome (whether it succeeded or failed) as the dependent variable and task order as the independent variable suggests no learning effect throughout the three conditions and 12 tasks (F(11, 242) = 0.91, n.s.).

### 5.3. Path Analysis

For information search tasks, it is important to understand the "lostness" of the user [Smith 1996]. There are various metrics to measure the "lostness" in hyperspace [Otter and Johnson 2000]. In this study, we used a simple metric to evaluate the extent to which the participants deviated from the optimal path: the ratio between the number of Actual Pages visited (AP) and the number of pages on the Optimal Path (OP). The number of pages on the OP for the three conditions are five (deep), three (broad), and two (search engine), respectively. Higher ratios suggest that the user visited a higher percentage of pages that are not on the OP and took a longer detour to reach the target page.

P-P plots suggest that the page ratio is normally distributed. A Repeated Measures ANOVA test using the page ratio as the dependent variable and condition and difficulty level as the independent variables suggests that there is a significant difference in the ratio among the three conditions ($F(2, 44) = 3, 78$, $p < 0.05$; effect size = 0.08). The LSD post hoc test suggests that the search engine condition resulted in a significantly lower ratio (1.59 on average) than the broad condition (2.64 on average) ($p < 0.05$). No significant difference exists between other conditions (Figure 6). There is also a significant difference in the ratios between tasks with different difficulty levels ($F(3, 66) = 4.40$, $p < 0.01$; effect size = 0.06). The LSD post hoc test suggests that the most difficult tasks resulted in significantly higher ratios than the easy tasks ($p < 0.05$) and the tasks with medium-level difficulty ($p < 0.05$) (Figure 6). There is no significant difference between other groups.

Table II. Causes for Failed Attempts Under the Two Browsing Conditions

| | Content structure | | | Recognition | | | Total |
|---|---|---|---|---|---|---|---|
| | Wrong book | Incompletion | Total | Wrong book | Incompletion | Total | |
| Narrow/deep | 9 | 4 | 13 (48%) | 14 | 0 | 14 (52%) | 27 |
| Broad/shallow | 12 | 9 | 21 (49%) | 19 | 3 | 22 (51%) | 43 |

A Repeated Measures ANOVA test using the page ratio as the dependent variable and task order as the independent variable suggests no learning effect throughout the three conditions and 12 tasks ($F(11, 242) = 0.37$, n.s.).

### 5.4. Causes for Failure and "Lostness" for Browsing Tasks

*5.4.1. Causes for Failed Browsing Tasks.* Two authors of the article analyzed the data to identify the major causes for failed browsing tasks. The failed attempts can be grouped into two categories: (1) difficulty in understanding the content structure or identifying the correct category and (2) difficulty in recognizing the correct book. The key criterion for the classification is whether the participants had ever reached the correct bottom category page. The two categories were defined as follows:

(1) Difficulty due to understanding the content structure or identifying the correct category: Participants usually started from an incorrect category and struggled between multiple categories throughout the task. With the exception of only one instance,[2] participants never reached the correct bottom-level categorical page that contained the link to the page of the target book. In this group, there are also several cases where the participant might have misunderstood the task or failed to understand the key term in the task description. However, separating those cases from the rest of the cases would require considerable subjective interpretation by the coders. Therefore, we chose to keep those cases in this group.
(2) Difficulty due to recognition: Participants reached the bottom categorical page that contained the title link to the book, but selected the wrong book in the correct category, or moved away and selected a book from an incorrect category, or gave up the task. In many cases, they even reached the page of the target book but moved away.

Table II summarizes the counts of the two groups and the final task status (selecting the wrong book or giving up the task (Incompletion)).

A Chi-square test suggests that under both the deep condition and the broad condition, the participants were significantly more likely to give up a task when they had difficulty in understanding the structure than when they had difficulty recognizing the correct book ($X^2(1) = 5.06$, $p < 0.05$; $X^2(1) = 4.56$, $p < 0.05$).

*5.4.2. Examples of Failed Browsing Tasks.* We selected a number of representative failed tasks to demonstrate how and why the participants failed to find the target book. Table III lists several failed tasks under the deep structure. During those tasks, the participants completed the task but chose an incorrect book.

In the first example (D1), the participant started with the correct category, but selected "Types of performance" instead of "Performers" at the second level. There are several other cases that either failed or detoured due to the confusion between the two categories. Some participants continued exploring the other categories after visiting the

[2]In this special case, the participant did reach the correct bottom categorical page, but quickly moved away from the page to view other categories. The participant visited 17 pages before reaching the correct categorical page and 22 pages afterward. The dominant cause for failing the task is difficulty with content structure and categories rather than recognizing the correct book.

Table III. Samples of Completed Failed Tasks Under the Deep Structure
"Optimal path" lists the four pages on the optimal path to find the book. "Pages visited" lists the pages that participants actually visited. Causes for failed tasks are listed after the "Pages visited" label. "SC" stands for difficulty understanding the content structure or identifying the correct category; "R" stands for difficulty recognizing the target book. The "Deep" page refers to the home page of the deep structure with four top-level categories. Because some categorical pages and book pages share the same name (e.g., the categorical page for "Egypt" vs. the page for the book titled "Egypt"), the actual book pages are marked with (B).

| | |
|---|---|
| Task | Find a book about singers Jonas Brothers (Medium) |
| Optimal path | Entertainment > Performers > Singers > Burning Up (B) |
| D1. Pages visited (SC) | Entertainment > Types of performance > Singing > How to Sing (B) |
| Task | Find a book about piano method for children (Medium) |
| Optimal path | Entertainment > Instruments > Piano > Piano Method for Children (B) |
| D2. Pages visited (SC) | Places > Deep > Places > Europe > Places > Deep > Entertainment > Performers > Composers > Mozart (B) |
| Task | Find a book about how to improve at swimming (Medium) |
| Optimal path | Sports > Water sports > Swimming > How to Improve at Swimming (B) |
| D3. Pages visited (SC) | Entertainment > Types of performance > Singing > Types of performance > Entertainment > Deep > Sports > Winter sports > Ice skating > Figure Skating School (B) > Ice skating > Ice Skating: Steps to Success (B) > Ice skating > The Complete Book of Figure Skating (B) > Ice skating > Ice Skating (B) |
| Task | Find a book to answer this question: Where do bald eagles live? (Most difficult) |
| Optimal path | Animals > Flying animals > Eagle > The Bald Eagle (B) |
| D4. Pages visited (R) | Animals > Flying animals > Eagle > Eagles and Birds of Prey (B) |
| Task | Find a book to answer this question: What is the world famous historical site in Egypt? (Most difficult) |
| Optimal path | Places > Africa > Egypt > Egypt (B) |
| D5. Pages visited (R) | Entertainment > Performers > Entertainment > Types of performance > Entertainment > Deep > Places > Europe > Places > Deep > Places > Europe > Italy > Europe > Places > America > Places > Africa > Egypt > Egypt: Cultures of the World (B) |

bottom-level pages and found the right book eventually. In this example, the participant chose a book that contained no information about Jonas Brothers. In the next two examples (D2 and D3), the participants selected an incorrect category at the second level and failed to recover from that error by exploring other categories at the same level.

The fourth example (D4) demonstrates a typical failed task due to difficulty in recognizing the correct book. The participant followed the optimal path at all three top levels but selected an incorrect book at the bottom level. In the fifth example (D5), the participant was able to recover from multiple incorrect categories by getting back to the higher level and exploring other subcategories. The participant reached the correct bottom-level category "Egypt," but selected the incorrect book, which is relevant but does not contain information about the question. Clearly, the participant in this example demonstrated a higher level of browsing skills than those in the first three examples.

In Table IV,the first three examples demonstrate difficulty in content structure or confusion between specific categories. In the first example (B1), the participant selected the "Types of performance" category instead of the "Instruments" category. In the second example (B2), the participant's later choices (Insects, Water sports, Winter sports, Track and Field) seemed to be even less relevant than the earlier choices. Similarly, the third example also demonstrates the difficulty in identifying the correct category. The category that the participant chose was relevant to sports, but did not contain the needed book. Instead of exploring other categories, the participant just chose the first book that he viewed in this category. In the next two examples, the participants reached the correct category page but did not recognize the correct book. In the last example, the participant visited a totally irrelevant category and selected an

Table IV. Samples of Completed Failed Tasks Under the Broad Structure
"Optimal path" lists the two pages on the optimal path to find the book. "Pages visited" lists the pages that participants actually visited. Causes for failed tasks are listed right after the "Pages visited" label. "SC" stands for difficulty understanding the content structure or identifying the correct category; "R" stands for difficulty recognizing the target book. "Broad" page refers to the home page of the broad structure with 16 top-level categories. Actual book pages are marked with (B).

| | |
|---|---|
| Task | Find a book about piano method for children (Medium) |
| Optimal path | Instruments > Piano method for children (B) |
| B1. Pages visited (SC) | Types of performance > Jazz Dance Class (B) |
| B2. Pages visited (SC) | Performers > Ludwig Van Beethoven (B) > Performers > Broad > Activities > Broad > Insect > Broad > Water sports > Broad > Winter sports > Broad > Track and Field > The First Marathon (B) |
| Task | Find a book about Babe Ruth and other baseball players (Difficult) |
| Optimal path | Team sports > Baseball's Greatest Hitters (B) |
| B3. Pages visited(SC) | Track and Field > Marathon: You Can Do It (B) |
| B4. Pages visited (R) | Team sports > Baseball and Softball (B) |
| B5. Pages visited (R) | Track and field > Broad > Team sports > Baseball Now! (B) > Team sports > Basketball Greats (B) |
| Task | Find a book about how to improve at swimming (Medium) |
| Optimal path | Water sports > How to Improve at Swimming (B) |
| B6. Pages visited (SC) | Types of performance > The Act of Singing (B) |

Table V. Samples of Incomplete Browsing Tasks Under the Deep Structure
"Optimal path" lists the four pages on the optimal path to find the book. "Pages visited" lists the pages that the participants actually visited. Causes for failed tasks are listed right after the "Pages visited" label. "SC" stands for difficulty understanding the content structure or identifying the correct category; "R" stands for difficulty recognizing the target book. The Deep" page refers to the home page of the deep structure with four top-level categories. Actual book pages are marked with (B).

| | |
|---|---|
| Task | Find any book about lions (Easy) |
| Optimal path | Animals > Land animals > Lions > any book (B) |
| D6. Pages visited (SC) | Animals > Flying animals > Eagles > Flying animals > Animals > Insects > Animals > Deep > Entertainment > Activities |
| Task | Find a book about Babe Ruth and other baseball players (Difficult) |
| Optimal path | Sports > Team sports > Baseball > Baseball's Greatest Hitters (B) |
| D7. Pages visited (SC) | Entertainment > Activities > Gaming > Activities > Entertainment > Activities > Gaming > Wii Player (B) > Gaming > Activities > Deep > Sports > Team sports > Basketball > Michael Jordan (B) > Basketball > Team sports > ***Baseball*** > Team sports > Football > Team sports > Soccer > Soccer (B) > Soccer > Mia Hamm (B) > Soccer > Team sports > Football > All about Football (B) > Football > Sports Heroes: Football (B) > Football > NFL Power Players (B) > Football > Peyton Manning (B) > Deep > Sports > Winter sports > Sledding >Sledding (B) |

irrelevant book without viewing any other categories. We suspect that the participant confused the word "swimming" with "singing" when completing this task.

All incomplete tasks under the deep condition were caused by difficulty in content structure or the identification of specific categories. In example D7, the word "baseball" in the task instruction is an important clue. In addition, the participant had to read the book description on the book page to confirm that the book contains information about Babe Ruth. The participant had difficulty identifying the correct category at the beginning of the task. Later, she was able to focus on the "Team sports" category but failed to identify the "Baseball" category. This example is also the only special case under the "SC" category. Usually, during the failed tasks under the "SC" category, participants never reached the bottom categorical pages that contained the book title link to the correct book. However, in D7, the participant did reach the correct bottom categorical page "Baseball" (bolded and italicized in Table V) after viewing 17 pages. However, she quickly left the page and went back to the higher category to view other

Table VI. Samples of Incomplete Browsing Tasks Under the Broad Structure
"Optimal path" lists the two pages on the optimal path to find the book. "Pages visited" lists the pages that the participants actually visited. Causes for failed tasks are listed right after the "Pages visited" label. "SC" stands for difficulty understanding the content structure or identifying the correct category; "R" stands for difficulty recognizing the target book. The "Broad" page refers to the home page of the broad structure with 16 categories. Actual book pages are marked with (B).

| | |
|---|---|
| Task | Find any book about Guitar (Easy) |
| Optimal path | Instruments > any book about Guitar (B) |
| B8. Pages visited (SC) | Performers > Broad > Track and Field > Broad > Land animals > Broad |
| Task | Find any book about China (Easy) |
| Optimal path | Asia > any book about China (B) |
| B9. Pages visited (SC) | Types of performance > Broad > Flying animals > Broad > Land animals > Broad > Ocean/water animals > Broad |
| Task | Find a book to answer this question: Where do bald eagles live? (Most difficult) |
| Optimal path | Flying animals > The Bald Eagle (B) |
| B10. Pages visited (SC) | America > The 50 States (B) > America > The United States of America (B) > America > The United States: A State-By-State Guide (B) > America > Brazil: Enhancement of the World (B) > America > Destination Detectives: Brazil (B) > America > Destination Detectives: Mexico (B) > America > Broad > Europe > England (B) > Europe > Broad > Land animals > Elephants (B) > Land animals > Elephant (B) > Land animals > Broad > Land animals > Black Bear (B) > Land animals > Bears for Kids (B) > Land animals > Broad > Land animals > Broad > America > Broad > Ocean/Water animals > Broad > Track and Field > Broad > Water sports > Broad > Land animals > Broad > Land animals > Broad > Land animals > Broad |

Table VII. Number of Searches in the Broad Condition that Started Deviating at Two Levels of Pages

| Level of pages | 1 | 2 | Total |
|---|---|---|---|
| Success with detour | 17 | 3 | 20 |
| Failed | 21 | 14 | 35 |
| Total | 38 | 17 | 55 |

Table VIII. Number of Searches in the Deep Condition that Started Deviating at Four Levels of Pages

| Level of pages | 1 | 2 | 3 | 4 | Total |
|---|---|---|---|---|---|
| Success with detour | 4 | 15 | 4 | 6 | 29 |
| Failed | 7 | 10 | 0 | 5 | 22 |
| Total | 11 | 25 | 4 | 11 | 51 |

types of team sports. The participant gave up the task after viewing another 22 pages (Table VI).

*5.4.3. Analysis for "Lostness".* We examined the level at which participants started to deviate from the optimal path for both the failed searches and the successful searches that involved "lostness" (one or more pages not on the optimal path were visited). Data about the specific pages visited was incomplete for four participants due to a technical failure. So this analysis was only conducted for 19 participants. Tables VII and Table VIII summarize the results for the broad and deep conditions, respectively.

A Chi-square test suggests that there is no significant difference between the two conditions regarding the possibility of selecting the wrong category ($X^2(1) = 0.50$, n.s.). We combined the searches that started detouring at the first- and second-level pages in the deep condition, which contain equivalent amounts of information as the first-level pages in the broad condition. This group includes the searches that started detouring

Table IX. Number of Search Tasks that Succeeded or Failed with One or Multiple Queries under Each of the Four Task Conditions

| | Success | Failure | Success with one query | Success with multiple queries | Failure with one query | Failure with multiple queries |
|---|---|---|---|---|---|---|
| Easy | 23 | 0 | 19 | 4 | 0 | 0 |
| Medium | 18 | 5 | 17 | 1 | 5 | 0 |
| Difficult | 22 | 1 | 14 | 8 | 0 | 1 |
| Most difficult | 12 | 11 | 10 | 2 | 10* | 1 |
| Total | 75 | 17 | 60 | 15 | 15 | 2 |

*In one of the 10 cases, the participant gave up the task (Incompletion).

at higher level pages. Similarly, we combined the searches that started detouring at the third level and fourth level in the deep condition. This group includes searches that started detouring at lower-level pages. No significant difference is observed between the two conditions regarding the higher level group. However, for searches that started detouring at lower levels, 10 out of the 15 searches in the deep condition succeeded eventually, while only three succeeded out of the 17 searches in the broad condition. A Chi-square test suggests that there is a significant difference in the success rate between the two groups ($X^2(1) = 7.94$, $p < 0.005$). This finding helps explain the difference in failure rates between the broad condition and the deep condition.

### 5.5. Causes for Failed Search Queries

The study suggests that participants with cognitive disabilities were able to use a search engine to find information online in a reasonable amount of time. More specifically, they were capable of extracting a keyword or keywords from a search question and entering the keyword(s) into the search engine. However, there is still a need for improvement in both efficiency and reliability. On average, the participants spent 2 minutes finding each book and the failure rate was nearly 20%.

As shown in Table IX, participants completed a total of 92 searches using the search engine, of which 17 failed. A search task could contain multiple queries. A query was coded as a failed query in one of the following three cases:

—the participant chose an incorrect book for a task;
—the participant gave up a task; and
—the participant did not choose any book and entered another query for the same task.

When completing the 92 search tasks, the participants entered a total of 114 queries, of which 39 failed. We reviewed each of the 39 queries to investigate why the queries failed and whether the participant detected the failure (see the second column in Table X). Further, we would like to find out how the participant modified the search terms in the subsequent query once a failed query had been detected (see the "modification strategy" and the "modified search terms in the subsequent query" columns in Table X).

Two authors of the article worked separately to identify the major causes for failed queries and coded each query. Afterwards, the authors reviewed the coding results together to resolve any discrepancies. Four major causes were identified:

(1) Typo: The search term(s) contained one or more typos and the correct book was not returned (e.g., "Gutier" for "Guitar").
(2) Recognition Failure (RF): Participants entered appropriate keyword(s) but failed to recognize the correct book in the returned list.

Table X. Summary of Failed Search Queries

The "P#" column represents the number assigned to the participant. The "Failure detection" column shows whether the participant detected the failure. The "Search terms" column lists the keywords entered by the participant. The "Reasons for failure" column lists the corresponding code (Typo, RF, BK). For failed queries that were detected and modified, the "Modification strategy" column lists the code for the strategy adopted in the subsequent query (FT, ND, RRK). The "Modified search" column lists the modified search terms entered in the subsequent query. Queries belonging to the same task are listed in the order that they occurred and italicized.

| P# | Failure detection (Y/N) | Search terms | Reason for failure | Modification strategy | Modified search terms in subsequent query |
|---|---|---|---|---|---|
| Easy condition: Failed queries that were modified and all four tasks eventually succeeded | | | | | |
| P3 | Yes | Gutier | Typo | FT | guitar |
| P9 | Yes | books about lions | RK | RRK | Lions |
| *P15-1* | *Yes* | *Books* | *BK* | *ND* | *Chiua* |
| *P15-2* | *Yes* | *Chiua* | *Typo* | *FT* | *China* |
| P19 | Yes | Ions | Typo | FT | Lions |
| Medium difficult condition: Failed queries that were modified and the task eventually succeeded | | | | | |
| P14 | Yes | Pino | Typo | FT | piano method |
| Medium difficult condition: Failed tasks with one query | | | | | |
| P10 | No | Hawks | RF | | |
| P15 | No | Swimming | RF | | |
| P17 | No | Hawks | RF | | |
| P18 | No | tailed hawks | RF | | |
| P23 | No | Swimming | RF | | |
| Difficult condition: Failed queries that were modified and the task eventually succeeded | | | | | |
| P2 | Yes | Basketball | BK | ND | magic johnson |
| P4 | Yes | Basketball | BK | ND | Basketball Players |
| P5 | Yes | baseball players | BK | ND | babe ruth |
| P9 | Yes | baseball players | BK | ND | Babe Ruth |
| P13 | Yes | babe ruth and other baseball players | RK | RRK | babe ruth |
| *P14-1* | *Yes* | *bab ruth and other base ball players* | *Typo/RK* | *RRK* | *bab ruth and other* |
| *P14-2* | *Yes* | *bab ruth and other* | *Typo/RK* | *FT/RRK* | *babe ruth* |
| *P15-1* | *Yes* | *Pout* | *Typo* | *ND* | *Bape* |
| *P15-2* | *Yes* | *Bape* | *Typo* | *FT* | *Bad* |
| *P15-3* | *Yes* | *Bad* | *Typo* | *FT* | *Babe* |
| P23 | Yes | Singer | BK | ND | jonas brothers |
| Difficult condition: First query modified, but task still failed | | | | | |
| *P18-1* | *Yes* | *Basekeball* | *Typo* | *FT* | *basketball* |
| *P18-2* | *No* | *Basketball* | *BK* | | |
| Most difficult condition: Failed queries that were modified and the task eventually succeeded | | | | | |
| *P14-1* | *Yes* | *site in egypt* | *RK* | RRK | *sie egypt* |
| *P14-2* | *Yes* | *sie egypt* | *Typo/RK* | *FT/RRK* | *egypt* |
| P16 | Yes | would famous historical sate in Egypt | Typo/RK | RRK | famous Egypt |

Continued

Table X. Continued

| P# | Failure detection (Y/N) | Search terms | Reason for failure | Modification strategy | Modified search terms in subsequent query |
|---|---|---|---|---|---|
| Most difficult condition: Failed tasks with one query | | | | | |
| P2 | No | bald eagles | RF | | |
| P3 | No | Mexico | RF | | |
| P4 | No | Bald Eagles | RF | | |
| P5 | No | Mexico | RF | | |
| P10 | No | Egypt | RF | | |
| P12 | No | Mexico | RF | | |
| P13 | No | Bald Eagles | RF | | |
| P15 | Yes | Iving | Typo | | |
| P17 | No | Egypt | RF | | |
| P22 | No | Eygpt | RF | | |
| Most difficult condition: Failed queries that were modified, but task still failed | | | | | |
| *P1-1* | *Yes* | *eagles living* | *RF* | *ND* | *bald eagles* |
| *P1-2* | *No* | *bald eagles* | *RF* | | |

(3) Broad Keyword (BK): The search term(s) were too broad, in which case the correct book would be returned but the participants did not recognize the book because it was buried in a comparatively long list of search results (e.g., entering "books" when trying to find a book about China; entering "basketball" when trying to find the book about Magic Johnson). Note that these cases actually belong to a special group of "recognition failure." In addition, it is possible that word(s) included in the broad search terms are not on the description page of the correct book, in which case the book would not be returned. In this study, it happened that the correct book was in the returned list for all the cases.
(4) Redundant Keyword (RK): A search might also fail when the search terms contained redundant word(s) not presented on the description page of the book, in which case the correct book would not be returned. For example, P9 entered "books about lions" instead of "lions." Since none of the description pages of the correct books contained both the word "books" and "about," no book was returned. Other examples in this category include the word "other" in "babe ruth and other baseball players" and the word "site" in "site in Egypt."

Among the 39 failed queries, 23 were detected by the participants. The participants adopted three strategies when modifying the search terms in the failed queries:

(1) Fix Typo (FT): In this case, participants tried to enter the same search term(s) correctly (e.g., change "Gutier" to "Guitar").
(2) Narrow Down (ND): In this case, participants tried to use different search term(s) that were more relevant to the question (e.g., change "basketball" to "magic johnson").
(3) Remove Redundant Keywords (RRK): In this case, participants tried to shorten the search terms by removing redundant or irrelevant words (e.g., change "books about lions" to "lions").

As demonstrated in Tables X and XI, among the 39 failed queries, the primary cause for failure was difficulty in recognizing the correct book in the returned list. This type of failure was also the most difficult to detect, both by the user and by the system. The second most frequent cause was typos, which counted for 33% of all the failed queries. In addition, 18% of the failed queries were due to redundant search keyword(s). In contrast to the recognition failure, all failed queries due to typos and redundant keywords were

Table XI. Summary of Causes for Failed Queries

| | RF | | Typo | | RK | | BK | | Total | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Detected | Yes | No | Yes | No | Yes | No | Yes | No | Yes | No | Detection rate |
| Easy | 0 | 0 | 3 | 0 | 1 | 0 | 1 | 0 | 5 | 0 | 100% |
| Medium | 0 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | 16.70% |
| Difficult | 0 | 0 | 6 | 0 | 3 | 0 | 5 | 1 | 12* | 1 | 92.31% |
| Most difficult | 1 | 10 | 3 | 0 | 3 | 0 | 0 | 0 | 5* | 10 | 33.33% |
| Total | 1 | 15 | 13 | 0 | 7 | 0 | 6 | 1 | 23* | 16 | |
| Detection rate | 6.25% | | 100% | | 100% | | 85.71% | | 58.97% | | |
| Percentage | 41.03% | | 33.33% | | 17.95% | | 17.95% | | | | |

*The total number does not equal to the sum of the breakdown conditions because four queries failed due to two reasons.

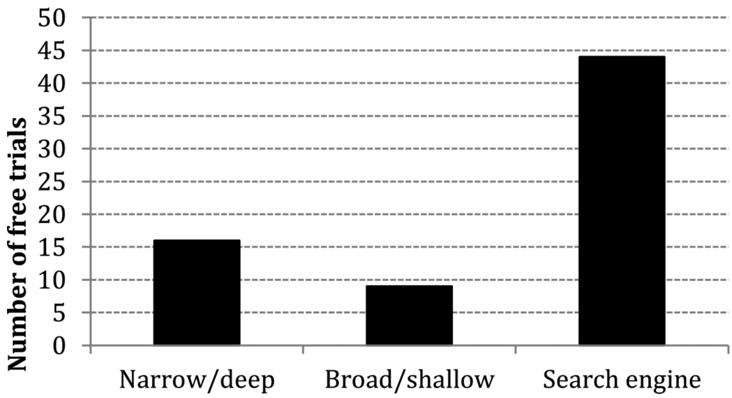


Fig. 7. Number of free trials under each condition.

detected by the participants. Finally, 18% of the queries failed due to broad keyword(s) and 86% of those cases were successfully detected.

### 5.6. Preference

*5.6.1. Preference Based on Three Free Trials.* The participants completed a total of 69 tasks during free trials (23×3). We counted the number of times that each method was used during the 69 trials. During 18 of the trials, the participants started with one method and switched to other methods. In those cases, we counted the last method that the participant used as the preferred method. Among the 69 trials, the deep method was preferred in 16 trials; the broad method was preferred in nine trials; the search engine method was preferred in 44 trials (see Figure 7). A Chi-square test shows that there is a significant difference in user preference among the three methods ($X^2(2) = 29.83, p < 0.001$). The participants overwhelmingly preferred the search engine method over the browsing methods.

As to the 18 trials in which participants used two methods, seven started with the deep method, 10 started with the broad method, and one started with the search engine method. Eventually, four ended with the deep method, two ended with the broad method, and 12 ended with the search engine method. Furthermore, there were seven trials in which participants switched methods more than once. Among those seven trials, six ended with the search engine method. The result further confirmed that the search engine method was preferable to the other two methods.

*5.6.2. Preference Based on Survey Ranking.* 14 out of the 23 participants chose the search engine method as their top choice, eight chose the deep structure method, and only one

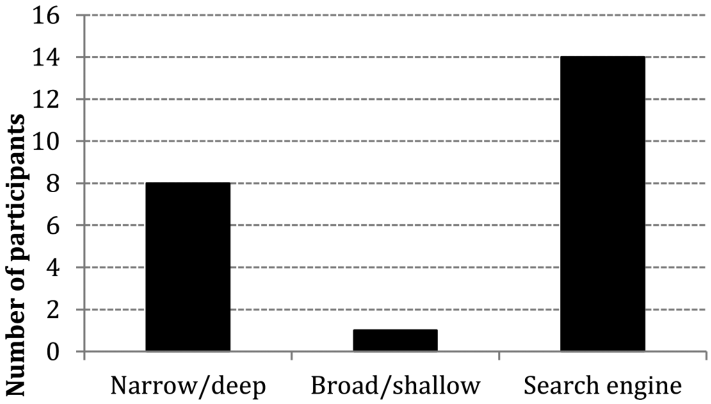


Fig. 8. Top preference on each condition.

chose the broad structure method (Figure 8). A Chi-square test shows that there is a significant difference among the three methods ($X^2(2) = 11.05$, $p < 0.005$). Participants preferred the search engine method more than the other two methods.

We also examined whether the preferred method chosen in the survey is consistent with the method that participants actually adopted during the free trials. We counted the last method used during each free trial as the preferred method. A Pearson product-moment correlation test was conducted between the participants' top ranked method and the preferred method in the free trials. The user ranking was highly correlated with the preferred method used in the free trials ($r(23) = 0.652$, $p < 0.001$).

## 6. DISCUSSION

This study shows that it is possible for people with cognitive disabilities to master Web search skills. However, not all people with cognitive disabilities should be expected to perform a Web search. In this study, all participants had previous experience using computers and the Internet, which indicates that they are comparatively high functioning. Even with previous experience using computers and the Internet, two participants failed 10 tasks (failure rate = 67%) and one participant failed 12 tasks (failure rate = 75%), suggesting that Web search was quite challenging for them. In addition, because more than half of the participants had Down syndrome, the results might be more representative of individuals with Down syndrome than other conditions of cognitive disabilities.

### 6.1. Impact of Search Methods on Performance

The result suggests that, for people with cognitive disabilities, the search engine method is more reliable than browsing. Under the search condition, participants took an average of about 2 minutes to find a book and the average failure rate was 18%. This result is consistent with the findings of Kumin et al. [2012] that people with Down syndrome tended to rely on search functions to find information online. Both studies suggest that many people with cognitive disabilities are capable of conducting successful searches using a keyword or a list of keywords. The two primary problems observed in this study when using search engines are consistent with those reported in Harrysson et al. [2004]: misspellings and difficulty in selecting the correct link from the returned list. However, although no specific failure rate was reported for the Harrysson study, the search capability demonstrated in our study (82% success rate) seems to exceed that of the Harrysson study. The difference might be due to computer and Internet experiences. In the Harrysson study, none of the seven participants had previous Internet experience except emails. In contrast, all participants in our study had previous experience searching for information online through both browsing and search engines. The difference observed in these two studies suggests that sufficient training and experience may substantially improve the searching performance of people with cognitive disabilities.

The deep structure yielded better performance than the broad structure. Using the deep structure, the participants took an average of 2 minutes and 20 seconds to find a book and the failure rate was 30%. No statistically significant difference was found between the deep structure method and the search engine method. This result indicates that the participants were capable of finding information by following the links and browsing Web pages.

Using the broad structure, the participants took an average of approximately 3 minutes to find a book and the failure rate was as high as 47%, meaning that they only found half of the books. The failure rate under the broad condition was significantly higher than that of the search condition and the deep condition. This suggests that presenting a page with numerous links (16 in this case) may not be a good choice for people with cognitive disabilities due to information overload. People with cognitive disabilities tend to be slow in reading the links. They are more likely to forget the pages that they have already visited and often make repetitive visits. In addition, more links on the same page may cause more confusion, especially when the links share similar words or terms. For example, one participant confused "Basketball Greats" with "Baseball's Greatest Hitters." This result is consistent with the Freeman [2005] study that strongly recommended limiting the number of content elements on each page. However, limiting the amount of information presented on each page will lead to deeper structures. The websites used in the Freeman study only contained five pages, which was not sufficient to examine whether the users could navigate through a comparatively deep structure. Our study answered that question and showed that people with cognitive disabilities were capable of browsing through a four-level structure to find information.

However, it was reported that deaf users, who also experience information overload problems with broad structures, could improve their performance with practice. In contrast, no improvement was observed for the deep structure as the deaf users gained more experience in that structure [Fajardo et al. 2009]. Although deaf users and people with cognitive disabilities are two substantially different user groups, it is still worth exploring whether people with cognitive disabilities have different learning patterns between the deep structure and the broad structure.

### 6.2. Causes for Failure

Two major causes were observed for failed tasks under the two browsing conditions: (1) confusion over content structure and categories, and (2) difficulty in recognizing the target book. These causes can be linked to the clinical/functional diagnosis about individuals with cognitive disabilities. Many participants lacked the perceptual and logical skills needed for search tasks, making it difficult to detect the connection between a category and its subcategories and further hindering the understanding of the content structure. When an incorrect category was selected, participants who understood the content structure could move back to the higher level and explore other categories. In contrast, participants with difficulty in the content structure were more likely to stay in the incorrect category or drastically change the search path and move further away from the correct path. In several cases, the participant might not understand what to look for because the categories visited were completely irrelevant to the search task.

Because this study was the first controlled experiment to examine the impact of content structure by people with cognitive disabilities, we had very limited knowledge regarding how participants would respond to the content categories and the tasks. The categories and subcategories were chosen based on recommendations from domain experts and parents of children with cognitive disabilities. They cover topics that are generally intriguing to people with cognitive disabilities so that the participants could be more engaged in the tasks. The result suggests that specific categories might be more confusing than the others due to the nature of the topics, such as “performers” and “types of performance” under the “entertainment” category. However, the subcategories and books listed under each category were chosen to be substantially distinctive from those under other categories. In online Web searching tasks, there are always categories that are more likely to be confused with each other. When visiting an incorrect category, neurotypical users can usually detect that the content is not what they want and move on to explore other categories. Some participants in the study demonstrated such types of error recovery ability, while others experienced challenges. The result suggests that people with cognitive disabilities are vulnerable to confusing categories due to their limited error recovery ability. So when designing websites specifically targeted to people with cognitive disabilities, it is important to get the target audience actively involved in the architecture design process through activities such as card sorting games.

The recognition difficulty can be attributed to challenges in reading and comprehension. It should be noted that sometimes the book chosen, although incorrect according to the researchers’ coding criteria, may be highly relevant to the search task. For example, multiple participants chose “Eagles and Birds of Prey” for the task that required the participant to answer the question “Where do bald eagles live?” Because the answer to the question was not included in the book description, “Eagles and Birds of Prey” was not the correct book for the task. However, this book might help the participant understand the habitat and behavior of bald eagles. Therefore, this task, although coded as “failed,” still demonstrated that the participant was able to perform a Web search.

Interestingly, although participants were equally likely to visit incorrect categories in the two browsing conditions, it was more difficult to recover from an incorrect category in the broad condition than the deep condition if the deviation started at a lower level. Only 18% of such searches succeeded in the broad condition, while 67% of those searches succeeded in the deep condition. Having fewer choices on each page seemed to help the participants in making the final decision once they reached the lower-level pages. During six searching tasks under the deep condition, the participants were able to determine that the specific book that they found was not the correct one, and navigate back to a higher level to explore other categories until they found the right book. Similar cases only occurred three times under the broad condition. Overall, deeper structure with fewer choices at each level worked more effectively in this study.

Regarding the use of search, recognition failure counted for 41% of the failed tasks under the search condition. Furthermore, 94% of the queries involving recognition failure remained undetected by the participants, suggesting that the participants ended up with incorrect information and were unaware of it. Further research is needed to investigate how to help people with cognitive disabilities detect and address recognition failures. In addition, personalized search methods could be explored that enhances the search result by considering a variety of information about the user and the context [Pitkow et al. 2002]. Typos were the second frequent cause for failed queries (33%). In contrast to recognition failures, typos were much easier to detect and address. 36% of queries failed due to the use of broad keyword(s) or redundant keyword(s), suggesting that the participants needed assistance in identifying appropriate keyword(s).

### 6.3. Interaction Strategy

As mentioned earlier, the process of information search involves trial and error, meaning that individuals use different strategies to correct mistakes during a search. For example, it is very common to navigate a wrong path, enter a misspelled word in a search engine, or get lost at a certain point. Neurotypical users tend to try a variety of strategies to get back on track (Aula et al. [2010]). For example, they may choose the "Back" button to adjust the search; they may click the "Home" button to start all over; they may do a new search in the search engine; and in many cases, they may spend time trying to figure out the logical relationship between the pages and links.

In contrast, participants with cognitive disabilities seemed to stick to a limited number of interaction strategies as observed in our study. When browsing the Web pages, participants almost exclusively relied on the "Back" button to get back to the home page when they got lost or clicked a wrong link. Of all the trials, only two participants used the "Home" button to restart the browsing task. Consistent with the free-browsing condition, the participants also heavily relied on the "Back" button when using the search engine.

The reliance on the "Back" button is further confirmed by the parents during the interviews. This strategy had a negative impact on efficiency, especially when some participants spent time reading every page on the way back to the home page. A number of participants stated that they preferred this strategy because it showed a clear and continuous path of navigation history, which seemed more "logical" and "safe." Design considerations are needed to encourage people with cognitive disabilities to use the "Home" button in a more effective way. For example, the designers can make the "Home" button highly visible using larger sizes, bright colors, and appealing icons. The use of breadcrumbs may help because it provides users a clear path of the navigation history. In addition, training activities that teach effective interaction strategies could also help in addressing the overuse of the "Back" button.

### 6.4. Design Implications

Numerous studies have examined the effect of content structure on performance, and the results consistently favor the broad structure over the deep structure. Our study extends the investigation in this research question to individuals with cognitive disabilities. In this case, our findings suggest otherwise: for individuals with cognitive disabilities, the deep structure outperforms the broad structure. Individuals with cognitive disabilities can be easily overwhelmed by pages with numerous links or content items. It seems that they are more effective in solving tasks that are broken down to multiple steps than tasks that involve numerous choices. Actually, this problem-solving approach has been recommended by existing literature (e.g., Buckley and Bird [2001]) and was frequently mentioned by parents of the participants during our interviews.

The finding of this study provides insight on the design of search engines for people with cognitive disabilities. One challenge that designers should consider is how to help people with cognitive disabilities detect errors or failures. The three major causes for failed tasks using the search engine are recognition failure, typos, and broad or redundant keywords. Designers can address the problems caused by typos by implementing a spell-check function and present a simple and clear message to inform the user whenever a typo is detected. Although some typos that happen to be other correctly spelled words (e.g., two for too) could not be detected by this feature, most of the typos could be effectively captured. The recognition failures are not easy to detect. However, designers may be able to reduce recognition failures by presenting the search results in a way that is more accommodating to people with cognitive disabilities. In general, we found busy pages with long lists of links overwhelming for people with cognitive disabilities. Designers may consider providing an easy customization function that allows people with disabilities to set the number of links on each page and modify the way those links are presented (e.g., different font sizes, the amount of information presented for each link, etc.). It should be noted that some of these features are already commonly implemented in many websites. In the meanwhile, more advanced search features that take into consideration the user and contextual information could also be explored.

The result suggests that people with cognitive disabilities tend to adopt one navigation or interaction strategy and stick to it, which often results in low efficiency. One notable example is the reliance on the “Back” button as a “safe harbor” when navigating through pages. Designers should consider how to encourage users with cognitive disabilities to explore other functions and strategies. A simple habit of using the “Home” button to restart a browsing or search task may substantially improve search efficiency. Providing a clear and continuous navigation path such as a breadcrumb may also be beneficial.

### 6.5. Limitations and Future Research

Due to the complexity of the three-level design, we had difficulty finding a way to completely counterbalance the order of three conditions, four levels of task difficulty, and the assignment of tasks to conditions. So we decided to present the condition and task orders randomly. Therefore, the condition orders and assignment of tasks among conditions were not completely counterbalanced. However, the difference in condition order and task assignment is quite limited. In addition, the order analysis using task completion time, number of failed tasks, and page ratio found no learning effect across the 12 tasks (Sections 5.1, 5.2, and 5.3). So we do not believe that the difference in condition order would significantly affect the result.

The study only examined two different information organization structures: the two-level structure with 16 links on each page, and the four-level structure with four links on each page. In reality, many websites use a structure that is much deeper than four levels. Future studies are needed to investigate structures with more levels and how effective users can navigate in those structures.

The website used in this study contains substantially more pages than websites used in previous studies involving users with cognitive disabilities. Therefore, the setting is comparatively more realistic than those studies. However, the website is still not fully representative of the typical settings of a realistic website, which may offer functions such as sitemap, breadcrumbs, and faceted navigation, to facilitate information search. A series of focused studies are needed to examine how people with cognitive disabilities interact with various navigation mechanisms.

Like the majority of empirical studies, this study only examined the initial interaction with the website by individuals with cognitive disabilities. The participants were given a limited amount of time to get acquainted with the website. It is possible that, with more practice, the performance might improve and the interaction strategies may evolve. So future longitudinal studies will be helpful to understand how people with cognitive disabilities learn to navigate within a new website and how their interaction strategies evolve. A longitudinal study can also provide insight regarding whether there is any difference in the learning effect between the deep structure and the broad structure, as has been observed among deaf users.

A controlled condition of neurotypical users without any disabilities was not included in this study. So we do not have data regarding how people without disabilities would perform under the three search conditions. We plan to include neurotypical users in the longitudinal study to observe how the two groups of users differ in performance and interaction strategies.

In this study, the links on pages were listed according to alphabetic order. We chose to list the items alphabetically in order to keep the design consistent between the deep and broad conditions. It would be interesting to replicate the study with the links listed categorically in the broad structure.

Finally, in order to eliminate potential bias and maintain consistency across conditions, all search tasks in this study were presented to the participants in writing, which means that the participants could have copied the search term(s) from the instructions. More typos and other difficulties related to keyword entry might be observed if the tasks were presented verbally. We will consider using prerecorded task instructions in the longitudinal study.

## 7. CONCLUSION

This study examined the impact of different Web content structures and the use of search engines on information search tasks performed by individuals with cognitive disabilities who possess similar characteristics as specified in Section 4.2. The result of this study in some cases confirms and in other cases challenges the findings of existing literature. It suggests that the broad structure currently adopted by many websites may not work well for people with cognitive disabilities. Given their specific characteristics, people with cognitive disabilities may prefer well-structured tasks broken down to simple steps, which fit better for the deep structure. The result also suggests that, with sufficient experience, many people with cognitive disabilities may be able to use search engines effectively to find information online. Participants in this study have shown an overwhelming preference for the search engine method, with data presenting evidence that they can achieve comparatively high efficiency and satisfaction using this method. In this regard, more efforts and resources should be devoted to developing and designing search engines that accommodate the special needs of people with cognitive disabilities. In the meanwhile, we would like to mention that, given the limited participant sample size and length of this study, the result needs to be interpreted with caution and further studies are needed to validate the finding.

## ACKNOWLEDGMENTS

We would like to thank The Jess and Mildred Fisher College of Science and Mathematics for partially funding this work through the Fisher College General Endowment Grant.

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Received January 2014; revised January 2015; accepted January 2015