A Comparative Analysis of the Information-Seeking Behavior of Visually Impaired and Sighted Searchers

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Understanding search behavior is important and leads to more effective interfaces that support searchers throughout the search process. In this article, through an observational user study, we investigate the search behavior of 15 visually impaired and 15 sighted searchers while they complete complex search tasks online. We study complex search tasks because they are challenging, cognitively intensive and affect performance of searchers. We compare the behavior of the two groups of searchers at four stages of the information-seeking process namely, *Query Formulation*, *Search Results Exploration*, *Query Reformulation*, and *Search Results Management*. For each stage, we identify research questions to investigate the impact of speech-based screen readers on the information-seeking behavior of visually impaired users. Significant differences were observed during query formulation and in the use of query-level support features such as query suggestions and spelling suggestions. In addition, screen-reader users submitted a lower number of queries and displayed comparatively limited exploratory behavior during search results exploration. We investigate how a lack of visual cues affected visually impaired searchers' approach towards query reformulation and observed different strategies to manage and use information encountered during the search process. We discuss the implications that our findings have for the design of search interfaces and propose a set of design guidelines to consider when designing interfaces that are usable and accessible with screen readers. This work also enhances our understanding of search behavior when using an auditory interface and could be useful when designing audio-based information retrieval systems.

Introduction

As the web allows access to a large amount of information, searching has become a daily activity for many people who now turn to the web for a diverse range of tasks (Kellar, Watters, & Shepherd, 2006). This ease of access to information has benefited most people, but has particularly been a blessing for people with disabilities, for example, visually impaired people, as they have access to much of the same information available to sighted people. Therefore, the web has empowered visually impaired users (Berry, 1999) and has played a significant role in combating social exclusion (Craven, 2004).

Visually impaired people usually access the web using screen-reader software that processes web pages sequentially from top to bottom and reads their content out in computer-synthesized speech. This sequential access imposes numerous challenges on visually impaired users (Andronico, Buzzi, Castillo, & Leporini, 2006; Borodin, Bigham, Dausch, & Ramakrishnan, 2010), for example, lack of context and information overload. The screen-reader interface, like all auditory interfaces, suffers from a lack of persistence and in a search environment, it requires the user to increasingly depend on their memory to keep track of encountered information.

Given the challenges imposed by the screen reader, searching can be considered to be a challenging problem for visually impaired users. The type of search task also impacts the search process as it represents the searcher's information needs and drives the information-seeking process (Marchionini, 1995). Previous research such as Kellar et al. (2006) shows that people perform a diverse range of search tasks on the web ranging from simple tasks like finding the capital city of a country to more complex tasks like planning travel or finding medical advice.

Search tasks represent an information problem for the searcher and hence, they drive the search process (Marchionini, 1997). Search tasks are goal-oriented as searchers usually aim to find information to satisfy an information need. When defining their information problem, searchers use their prior knowledge to identify concepts and relationships to formulate a search task. Kuhlthau (1991) argued that the affective and cognitive states of searchers also impacted their perception of tasks. Therefore, different

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searchers conceptualize information problems differently and these varying conceptualizations determine the perceived complexity of the search task.

Simple search tasks are easy to complete effectively; searchers have a well-defined mental model for simple tasks and they know which path to follow to solve their information problem. However, search tasks that are perceived by users as complex are more difficult to complete effectively as they affect performance and search effectiveness (Bell & Ruthven, 2004). User's mental models for the information problem are ill-defined or incomplete (Marchionini, 1989). This may result from a lack of domain knowledge or a lack of understanding of the task itself. Therefore, complex tasks place high cognitive demands on users (Campbell, 1988). In this article, we focus on complex search tasks as we believe an understanding of searchers' behavior for such tasks is fundamental to design appropriate search support.

For decades, researchers have been trying to understand the online searching behavior of web users which has led to numerous theories such as berry-picking (Bates, 1989), information foraging (Pirolli & Card, 1999), and orienteering (O'Day & Jeffries, 1993). These theories have increased our understanding about the ways people search and thus have informed the design of search interfaces. For example, Bates (1989) observed that searchers are unlikely to expect to find all relevant information in one place and used the berry-picking analogy to describe searchers' expectation of finding relevant bits of information throughout the search process. This was confirmed by others (Pirolli & Card, 1999; O'Day & Jeffries, 1993), and have provided much insight into how people make decisions about relevant information while searching.

Motivation and Research Questions

Despite visually impaired searchers' increasing dependency on the web for their information-seeking activities, to the best of our knowledge, no studies on information-seeking behavior have focussed on the visually impaired population. In this article, we address this gap in the literature by carrying out a comparative observational study between 15 visually impaired and 15 sighted participants to investigate their information-seeking behavior for complex search tasks. Given the additional cognitive efforts required from screen-reader users (Chandrashekar, Stockman, Fels, & Benedyk, 2006), we reasonably assume that the information-seeking behavior of visually impaired searchers is impacted by the speech-based interaction imposed by screen readers. Hence, we investigate the differences between visually impaired and sighted users at four stages of the information-seeking process, namely, *Query Formulation*, *Search Results Exploration*, *Query Reformulation*, and *Search Results Management*. In the following, we describe these stages and formulate our research questions for each of them:

1. *Query Formulation*. Query formulation is an important and critical stage (Marchionini & White, 2007) as it has the potential to shape the entire search process. In this respect, Kuhlthau (1991) described this stage as the "turning point" of the information search process. Searchers often find it difficult to successfully translate their information need into a query and employ different strategies to do so. For example, searchers can adopt an *orienteering* approach (using a series of short queries to reach the information of interest) (Marchionini, 1995; O'Day & Jeffries, 1993), or a *teleporting* approach, described by Teevan, Alvarado, Ackerman, and Karger (2004) as a more directed behavior in which a longer, more precise query is submitted (Hearst, 2009).

   In addition, there have been numerous efforts to address the challenging problem of query formulation; query-level support features such as interactive query suggestions (White & Marchionini, 2006) and search assistants (Anick & Kantamneni, 2008) have been designed and created to assist searchers in formulating their information need. However, most of these support features have been evaluated with sighted users who interact with search engines differently from visually impaired users. Therefore, we focussed on the following research questions:

   RQ1: Which strategies do visually impaired searchers employ when formulating their initial queries?

   RQ2: How useful are query-level support features for screen-reader users?

2. *Search Results Exploration*. Searchers spend most of their time at this stage of the information-seeking process (Marchionini & White, 2007) to review retrieved results and to determine whether their queries have been successful. This is an important stage of the process as it plays a significant role in determining the future direction of the search task. The linear processing imposed by screen readers make this stage of the information-seeking process challenging and time consuming (Craven & Brophy, 2003) for visually impaired searchers and therefore, we ask the following questions:

   RQ3: What are the navigation strategies used by visually impaired searchers on the search results page?

   RQ4: How does the sequential access of screen readers affect the number of search results viewed and the number of queries submitted by visually impaired searchers?

   RQ5: How does the screen reader affect the number of external pages (beyond the search results list) visited by visually impaired searchers?

3. *Query Reformulation*. The process of query reformulation is common during information seeking as searchers' state of knowledge about their search tasks changes. Query reformulations can be a result of a change in the searcher's state of knowledge or in the searcher's mental model of the problem at hand, that is, their information need. Jansen, Spink, and Pedersen (2005) observed that a large portion of search sessions contain query reformulations. Hearst (2009) attributes this behavior to the ability of search engines to retrieve the results in a fraction of a second which makes the strategy of "testing the water" well suited for sighted users. Linear processing of the retrieved results

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page by screen readers means that access to search results is slower and hence we investigate the following:

> *RQ6:* What effect does the linear access of screen readers have on the query reformulation strategies of visually impaired searchers?

4. *Search Results Management*. This stage of the information-seeking process is closely related to how searchers collect, analyze (Pirolli & Card, 2005), and use the information (Marchionini & White, 2007) encountered during the search process. For example, a person aiming to book flights online needs to search which airlines travel to their destination, compare the prices and only after doing so, they can use the information they found to complete their intended task. Hearst (2009) described this part of information seeking as the broader process of information access and related it to sensemaking (Pirolli & Card, 2005; Russell, Stefik, Pirolli, & Card, 1993). Information use, part of sensemaking, is the stage in the information-seeking process when searchers understand the results and decide that the information collected is relevant and as complete as necessary to satisfy their information need (Marchionini & White, 2007).

For our study, we view search results management as an intermediate step between exploration and information use and sensemaking. As the search sessions with our users were relatively short, we did not always reach the stage in the information-seeking process when they would use the information found. However, as we are studying complex search tasks which may require information gathering from multiple sources, we focus on search results management to investigate the differences in the way visually impaired and sighted searchers manage encountered information that they feel could be useful at a later stage in their information-seeking process. We were, therefore, interested in the following:

> *RQ7:* How does the lack of persistence of the auditory screen-reader interface affect visually impaired searchers' strategies to remembering and managing encountered information?

The remainder of the article is structured as follows: In the Related Work section, we describe the information-seeking process as well as existing work on search task complexity. We also survey the literature on visually impaired users' access to the web including challenges posed by screen readers during navigation. In the Methods section, we discuss the experimental procedure and present data from our observations in Results. We conclude the article by discussing the implication of our findings and provide guidelines for the design of accessible search interfaces.

Related Work

In this section, we review the previous research in areas related to the work we present in this article. We first describe the information-seeking process, with particular emphasis on the work by (Marchionini & White, 2007). We then provide an overview of the challenges posed by screen readers and discuss how these have been addressed by the existing work. Lastly, we define task complexity and outline the criteria used in this study to validate complex search tasks.

Information-Seeking Process

Information seeking is defined by Marchionini (1995, p. 5) as "a process in which humans purposefully engage in order to change their state of knowledge" and "a fundamental and high-level cognitive process often part of learning or problem solving" (p. 6). During the information-seeking process, which is usually a human activity that is part of a larger life activity, people carry out a set of activities in a progressive and iterative way (Marchionini & White, 2007). The information-seeking process can be very diverse, however, previous information-seeking frameworks (Bates, 1989; Ellis, 1989; Kuhlthau, 1991) show that the sub-activities of the process are very similar. While Bates (1989) described a berry-picking approach to information seeking, Kuhlthau (1991) proposed a six-stage model of the information search process incorporating the affective and cognitive differences displayed by searchers.

In this article, we use the work of Marchionini and White (2007) to significantly structure our findings and discussions. However, the authors did not propose a new theory or framework for information seeking. Instead, they defined the information-seeking process and organized the process as different sub-activities to discuss the state of existing support for each stage. We briefly summarize the information-seeking process as defined by Marchionini and White (2007).

First, the information seeker *recognises* a need for information and *accepts* the challenge to do something to fulfill that information need. Once the challenge has been accepted, the information seeker *formulates* the problem during which the mental model for the information need is conceptualized, that is, the sources of information and the type of information that will satisfy the need, etc. are imagined. The information need is then *expressed* using a search system, following which, the information seeker engages in search results *exploration*. The exploration stage may not yield the expected outcomes leading to the problem being *reformulated*. At some point, the information seeker decides to stop searching and *use* the information found.

Screen Readers and Navigational Support

Information-seeking behavior is impacted by the way the searcher interacts with the search system. For visually impaired searchers, the screen reader, which is the most popular assistive technology, plays a significant role in how webpages and interfaces are perceived (Andronico et al., 2006; Stockman & Metatla, 2008). While sighted users place a strong emphasis on layout and aesthetics, screen-reader users' impressions of webpages are largely dependent on content. As most visually impaired users use keyboards, after memorizing their layout, it is the output of information that remains most challenging. When dealing with web content, screen readers process the page source, parse the HTML code,

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and arrange the content in the same order as it appears in the source. As a result, users perceive the page content as an augmented text document that screen readers process sequentially, from left to right and from top to bottom, presenting the content word by word and line by line until the end of the page is reached.

Therefore, visually impaired users receive the content of the page in small portions and have to make connections between these pieces of information to construct their mental model and to get an overview of the page. This requires high-cognitive effort from screen-reader users (Chandrashekar et al., 2006), because it often involves hearing repeating webpage features such as banners and copyright information as well as meta information that screen readers present about webpages such as the presence of lists, headings, and edit fields. However, years of development have resulted in improved navigation functions with screen readers and users typically have the options to navigate by link, heading, frame, form field, etc. and can also use page markers to identify and return to specific points on a page (WebAim, Accessed May 2011).

The lack of previous work on the information-seeking behavior of visually impaired searchers has also been highlighted in the NoVA (Non-Visual Access to Digital Libraries) report (Craven & Brophy, 2003), which compared how visually impaired and sighted searchers completed four tasks using online resources. One of the tasks was a search engine task and for this task, the authors reported that navigation on the search engine was frustrating (Craven, 2004) for visually impaired participants and their mean task completion time was close to 16.5 min compared with 6.4 min for sighted searchers. In the NoVa report, the authors focussed on low-level aspects of the search process, reporting extensively on aspects such as keystrokes and number of clicks. This was helpful to understand the navigation procedure and the accessibility challenges that webpages pose to visually impaired users. However, it did not focus on *why* visually impaired participants perform certain actions and thus, could not provide a high-level perspective on the decision-making process of visually impaired users during information seeking.

There have been considerable research initiatives to address web accessibility challenges of the visually impaired community: Leporini, Andronico, and Buzzi (2004) proposed a set of guidelines for designing accessible search interfaces that were based on preliminary testing with automatic validation tools and a survey questionnaire (Buzzi, Andronico, & Leporini, 2004). Despite the questionnaires not allowing the researchers to capture real-time interaction with search engines, they highlighted numerous issues faced by visually impaired users when searching online, for example, 46% of visually impaired searchers had difficulties in reading results retrieved by search engines.

Andronico, Buzzi, Leporini, and Castillo (2006) adapted the Google interface to improve accessibility while ensuring that the visual appearance of the pages was the same as the original page. The authors tested the modified interface with 12 visually impaired participants and data collected through pre and post questionnaires showed that a majority found the interaction with the search interface simpler. The search process was also considerably less time consuming with a clearer and easier to use interface.

Contrary to Andronico et al. (2006), Bigham, Cavender, Brudvik, Wobbrock, and Lander (2007) adopted an *in situ* approach to compare the real-time browsing behavior of sighted and visually impaired users. A tracking proxy was used to record the browsing behavior of participants over a week from their homes, ensuring that participants were in a familiar environment using their own equipment. The authors defined *probing* as the behavior observed when a user leaves a page and quickly returns to it (Bigham et al., 2007), for example, a user clicks on a link on the search engine results page and then quickly returns to the list of retrieved results. More probing was observed among the visually impaired searchers as they have limited contextual information available to them as a result of their use of screen readers. Therefore, Bigham et al. (2007) argued for links to be associated with more contextual clues. This remote usability study, conducted in participants' homes, allowed the authors to record what their participants did, for example, visually impaired searchers did not shy away from webpages with inaccessible content. However, the tracking proxy did not provide insights into the decision-making process of the participants to understand why certain actions were performed.

Complex Search Tasks

The definition of task complexity has varied in the previous work: Campbell (1988) argued that task complexity results from the task's objective attributes and places high-cognitive demands on the user, whereas Byström and Järvelin (1995) defined a complex task from a subjective perspective. They showed that the user's perception of the complexity of a task is impacted by how certain the user is about the task.

However, researchers agree that the complexity of tasks significantly affects the search process. Fowkes and Beaulieu (2000) found that complex topics required a higher level of engagement from users and in Shiri and Revie (2003, 2006), the number of physical and cognitive moves was high for complex tasks as they required users to interact more with the system's features (Marchionini et al., 1991).

Numerous factors contribute to task complexity: A lack of structure in the task definition results in the user having an ill-defined mental model of the search task. This model can become more incomplete if the searcher lacks domain knowledge (Marchionini, 1989). When faced with complex tasks, users may not be able to establish a goal hierarchy, that is, they may not be able to identify which goals need to be accomplished to reach a solution (Paas & Van Merrinboer, 1994). Thus, intrinsic task characteristics such as uncertainty and vagueness can further impact on the cognitive load associated with the search task (Sweller, Merrienboer, & Paas, 1998).

Complex tasks may also require searchers to perform multiple searches to gather information from different sources.

Therefore, searchers have to analyze and compare the information found to make a decision on how to use relevant information. These steps, also part of general problem solving activities, require cognitive efforts from the searcher. All these factors contribute to task complexity and in turn affect performance and effectiveness (Bell & Ruthven, 2004). For this article, we used the above-mentioned research and described a set of criteria to define complex search tasks. We used these criteria to construct examples of complex tasks (described in Methods) as well as to validate the tasks chosen by participants in our study. We present the criteria for describing complex search tasks in the following:

- Lack of structure in search task definition.
- Include task characteristics such as uncertainty and vagueness.
- Lack of prior knowledge on search domain.
- Require several search iterations.
- Information from multiple sources has to be aggregated.
- Involve a decision-making stage after relevant information has been compared and analyzed.

In the study presented in this article, we focus on complex search tasks as they are challenging and cognitive-intensive. We compare the information-seeking behavior of visually impaired and sighted searchers and investigate the impact that speech-based screen readers have on the information-seeking process of visually impaired searchers. Despite several works addressing the browsing and navigation behavior of screen-reader users, our literature review showed that there is no previous work on the information-seeking behavior of visually impaired searchers that is comparable to the wealth of existing information-seeking theories and frameworks available for sighted searchers. Therefore, in this article, we focus on the information-seeking process of visually impaired searchers and compare their behavior with that of sighted searchers at four stages of the process namely, *Query Formulation*, *Search Results Exploration*, *Query Reformulation*, and *Search Results Management*.

Methods

We carried out an observational study with 15 visually impaired and 15 sighted participants to compare their information-seeking behavior for complex search tasks. During the study, users were observed while they performed a task of their choice using their own equipment at home or in their workplace. In this section, we further describe the user study focussing on the recruitment strategy, the participants, and the search tasks that were used. We also outline our experimental set up and explain the strategy for data collection and analysis. Lastly, we highlight the limitations that could have resulted from the design of our study.

Participants

We recruited 15 visually impaired and 15 sighted searchers for this study. Given the known difficulties in recruiting participants with disabilities, we first carried our experiment with a random sample of 15 visually impaired participants, who were very diverse in terms of age, search experience, and profession. Therefore, to ensure that our comparative analysis is valid, we recruited a purposive sample of sighted participants with almost the same diversity. The similarities between the samples are shown in Table 1, where we provide information about the demographics and the search experience of the two groups of participants.

TABLE 1. Demographics of all participants.

	Visually impaired searchers	Sighted searchers
Age	32.6 years [22–50]	27.6 years [22–54]
Gender	11 Male, 4 female	7 Male, 8 female
Search experience	10.3 years	10.9 years
Frequency of computer use	Daily	Daily
Use of online search engine	Daily(12) Weekly(3)	Daily(15)

We recruited the visually impaired participants mostly via dedicated e-mail lists. Despite our sample consisting of 13 users with no vision and 2 users with very low-level vision, in the remainder of this article, we refer to this group of participants as "visually impaired" mainly for political correctness. However, there were no differences in the data we collected for participants with different vision levels as they all depended exclusively on the speech output of screen readers to access the web.

The screen reader, Jaws,[1] was used by 12 visually impaired participants, VoiceOver[2] was used by two participants and only one participant used Window-Eyes.[3] None of the participants used Braille during the observation and a majority (10) rated themselves as having advanced proficiency with their assistive technology, while five rated themselves as intermediate users. As far as browsing proficiency was concerned, nine visually impaired participants thought they were advanced, five were intermediate, and only one participant rated themselves as beginner. Our sighted participants were recruited mainly through word of mouth. In browsing proficiency, 11 sighted participants rated themselves as advanced, while 4 believed they were intermediate. In Table 1, we provide additional demographic information about both samples of participants.

Tasks

Prior to the experiment, we sent participants an information sheet which contained guidelines for choosing a complex task which they would perform during the observation. Those guidelines were derived from the set of criteria presented in section Complex Search Tasks. Along with those guidelines, we also included examples of complex tasks to further help those who were struggling to come up with their own search task.

[1] http://www.freedomscientific.com/products/fs/jaws-product-page.asp
[2] http://www.apple.com/accessibility/voiceover/
[3] http://www.gwmicro.com/

TABLE 2. Example tasks provided to participants.

Topic	Task
Travel	You will soon be on leave from work and you would like to travel to X. You want to find out the best ways of getting to X and the different places to stay. You are also interested in the places to visit, the different things to do while you are on vacation, the places to eat etc. Use your favorite online search engine to help you plan your vacation to X
E-books	Your friends have been talking a lot about e-books recently and you realize you do not know much about them. You decide to find out more about e-books online using an online search engine. You are particularly interested in ways to read e-books, the formats in which they are published and the devices/software you would need to use them. Gather the information on e-books and decide which one you would prefer

We constructed four categories of example tasks and ensured that they were complex by validating them against the criteria presented previously. For example, as shown in Table 2, we constructed a *travel* task which would require the user to make a decision by comparing and analyzing information found from different travel web sites. The user is also likely to perform multiple searches and for an unvisited country, the task would involve a level of uncertainty. These factors contributed to making the *travel* task complex and as shown in Table 2, we did not fully define our example tasks so that participants use them only as triggers for defining their own information need. For example, every participant who performed a *travel* task defined it individually, according to where they would like to go, how to get there, and what they like to do on holidays.

A few days before the observation, we reminded participants that they needed to think of a complex search task to complete and for those who did not use the provided examples, on the day of the observation, we validated their choice of tasks according to the criteria described in section Complex Search Tasks. On some occasions, we did request participants to choose an alternative task as their chosen task did not match our definition of task complexity. In this way, we ensured that search tasks were similarly complex across all participants in the study.

Given that our examples were broad and vague, participants who used them still contributed to designing and shaping the task description and thus, we ensured that tasks were interesting for the participants and were as close as possible to real information needs. For visually impaired participants, our examples included one task from four different topics, namely, *travel*, *relocation*, *audio books*, and *e-books*. In Table 2, we describe the *travel* task and the *e-books* task. For sighted participants, we replaced the *audio books* task with a *Postgraduate Education* task as we felt that such a task is more likely to be relevant to their interests. Among the 15 participants who used the example tasks as guidelines, nine performed a *travel*-related task, three chose a *relocation*-related task, and three searched about *e-books*.

Experimental Procedure

For each session, participants chose their own search task and used their own equipment to ensure that we observed them in settings close to those in which they perform their daily search activities. Each session was structured as follows:

- Prior to the observation session, participants were asked to sign a consent form and had to fill a pre-experiment questionnaire. This questionnaire collected demographic information, including data about their search experience. For the visually impaired participants, we also collected data about their proficiency with assistive technologies.
- Participants were then observed while they completed their chosen complex search task. We visited only two of the visually impaired participants at their place of work and recorded their interaction with the search interfaces using an external video camera. For the remaining participants, we carried out the observation remotely using Skype[4] via the screen-sharing functionality. In those cases, we recorded the participants' interaction with the search interface using screen capture software on the experimenter's machine. This type of remote usability study is common in HCI (see Andreasen, Nielsen, Schroder, & Stage, 2007, for a review) and is known to be as effective as traditional testing (Thompson, Rozanski, & Haake, 2004).
- During the last part of the session, we carried out a semi-structured interview with our participants. This provided an opportunity to follow-up issues identified during the observation. We recorded this interview for the later analysis.

Data Analysis

The main source of data for analysis was the video recordings of searchers' interaction with the search engine. We transcribed the recording for each participant and analyzed the transcriptions to identify emerging patterns. Similar to the Open and Axial coding phase of Grounded Theory (Strauss & Corbin, 1998), we identified concepts from the recordings and devised a coding scheme according to the commonalities across different participants. The Grounded Theory methodology is useful for exploring complex relationships between concepts, such as the relationship between search interfaces, search tasks, and searchers and has been used for data analysis in the previous information-seeking studies (Blandford & Adams, 2005; Kuhlthau, 1988).

The videos were annotated using a video annotation tool, ELAN,[5] and the observed behaviors were categorized according to the coding scheme, for example, whether participants used search support mechanisms or advanced query operators. We also transcribed the video recordings into a search log format to derive quantitative data. We complemented the data analysis by using the experimenter's notes and by summarising responses from the semi-structured interviews.

[4] http://www.skype.com

[5] http://www.lat-mpi.eu/tools/elan

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The video recordings combined with data from the questionnaires and the semi-structured interviews allowed us to appropriately capture the searching behavior of the participants in our study. On the quantitative data, we carried out statistical testing at $p < 0.05$ with a two-tailed unpaired t-test using R statistical package.[6]

Limitations

The type of tasks used in our study rely heavily on our definition of task complexity. Taking into consideration the subjectivity of the concept, despite providing guidelines, participants' understanding of complex tasks might not have been similar to ours. However, to mitigate the impact of this limitation, we validated participants' choice of task at the beginning of each session using the criteria described in section Complex Search Tasks. In addition, we also tried our best to ensure that participants chose tasks that they had not carried out before. We explained the purpose of our work and explicitly required them to choose a complex task that they have not previously completed. However, it was beyond our control if any participant performed a task which they were familiar with.

Another limitation of our work is that we did not choose a random sample for the sighted searchers, as we tried to ensure that the diversity among the visually impaired searchers was replicated in the sample of sighted searchers. Statistical testing on small samples such as those in our study, has its limitations. However, we used the t-test and Chi-square only to validate our findings on the significant differences that we observed between visually impaired and sighted searchers.

In this usability study, we studied the differences in the information-seeking behavior among visually impaired and sighted searchers. However, several factors can impact the information-seeking behavior and differences can be caused by different technologies or interaction medium, affective and cognitive aspect of participants (Kuhlthau, 1991). Therefore, it is difficult to identify the exact causes of the differences, but as our focus was on understanding what searchers did during information seeking and why they perform certain actions, we believe the cause of the difference did not significantly affect our findings.

Results

In this section, we present and compare findings on the search behavior of our participants at the *Query Formulation*, *Search Results Exploration*, *Query Reformulation*, and *Search Results Management* stages of the information-seeking process. We structure the presentation of our findings according to the research questions (RQ1 to RQ7) identified in section Motivation and Research Questions.

Query Formulation

In this section, we focus on how the two groups of participants formulate their queries to express their information needs and we also study the awareness and use of query-level search support mechanisms.

TABLE 3. Mean length of queries [SD] (Minimum to Maximum).

	Visually impaired searchers	Sighted searchers
No. of terms in queries	4.61 [2.76] (1 to 18)	3.86 [0.67] (1 to 10)

RQ1: Which strategies do visually impaired searchers employ when formulating their initial queries?

We observed an orienteering approach (O'Day & Jeffries, 1993) among the sighted searchers who issued quick, broad queries to get to the relevant part of the information space. Once the first set of results were retrieved, sighted searchers easily picked up clues and hints to iteratively refine their queries to get to the information they were interested in. This type of behavior is common among sighted searchers and has previously been observed and defined in O'Day & Jeffries (1993).

We observed a different strategy among visually impaired users who submitted long-complex queries representing the complete information need in an attempt to find what they were looking for in one step. Therefore, at the beginning of their search, most visually impaired searchers felt the need to be precise and specific with their search terms. When probed on this strategy, they explained that if they submitted specific queries, it would bring relevant results close to the top of the page, making access easier and quicker.

As a result, as shown in Table 3, the average query length for the visually impaired searchers was close to five keywords, significantly higher compared with the sighted searchers ($t(28) = -2.41$, $p = 0.023$). However, despite queries from visually impaired searchers being longer and more expressive than sighted searchers, only four of them used advanced query operators such as "double quotes" or "plus" to be more specific in their queries and to restrict the results retrieved by the system.

In light of this observed importance of the query formulation process, it would be reasonable to believe that visually impaired searchers will find assistance provided by search interfaces helpful and use query-level support mechanisms to support their query formulation process. However, this was not the case as our observations in the next section demonstrate.

RQ2: How useful are query-level support features for screen-reader users?

In this section, we investigate the use and awareness of the query-level support features under study. We describe each of the support mechanisms in the following and explain how they can be accessed with screen readers.

- *Query Suggestions* are alternative queries that appear in a drop down list in real time as the user types their query. Screen-reader users can access search suggestions by using navigation arrows to move down the list; however, they have

[6]http://www.r-project.org/

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TABLE 4. Awareness of search support features.

Support features	Visually impaired searchers (%)	Sighted searchers (%)
Query suggestions	66.7	100
Spelling suggestions	66.7	100
Related searches	60	40

TABLE 5. Use of search support features.

Support features	Visually impaired searchers	Sighted searchers
Query suggestions	2	23
Spelling suggestions	2	12
Related searches	0	2

to be typing at a relatively slow pace to be able to hear this option.

- *Spelling Suggestions* appear at the top of the search results page when keywords are misspelt and they are accessible by screen readers.
- *Related Searches* are similar to query suggestions but are presented to the user on the results page after the first set of results is retrieved. They are queries that are related to the user's search request and are accessible by screen readers.

Our findings about query-level search support features were surprising as they revealed a lack of awareness and use of these features by visually impaired searchers. Only one of the visually impaired participants used any of the search support features while completing their complex search tasks during the observation. The primary search engine used by all participants during the observation was Google whose interface provides all of the above-mentioned query-level search support features. Therefore, we asked screen-reader users about their awareness and use of support features in the semi-structured interviews.

Forty percent of visually impaired participants were not aware of at least one of the search support features on the interface and in Table 4, we describe the awareness of both groups of participants about each of the three support mechanisms. We tested the differences in awareness using a Chi-square test at $p < 0.05$. Significant differences in the awareness of both *Query Suggestions* and *Spelling Suggestions* were observed among visually impaired and sighted users ($x^2(1, 30) = 6$, $p = 0.014$).

The *Query Suggestion* feature was known to two-third of all visually impaired participants, but as shown in Table 5, the feature was used two times by only one visually impaired searcher during the observation. During the semi-structured interviews, we probed the group of screen-reader users who were aware of the feature about their reasons for not using it. They agreed that while the suggested queries were accessible with their screen readers, interacting with them was not intuitive and could be difficult, time consuming and cumbersome. As for the sighted searchers in our study, they were more familiar with query suggestions and used it significantly more (23 times, $t(28) = -2.59$, $p = 0.015$) while they completed their complex search tasks.

One-third of the visually impaired participants ignored the presence of *Spelling Suggestions* and most of those who did notice the feature were often confused by it. When using the Google interface and having misspelt a keyword, 1 of our participants remarked: "*Why does it ask me what I mean if that is exactly what I wrote?*" One of the reasons for this kind of confusion is where misspelt terms sound the same or very similar to the correct spelling when pronounced by the screen reader. In these cases, visually impaired searchers sometimes fail to perceive the difference in spelling and therefore fail to understand why the system provides them with spelling suggestions. During the observations, 47% of visually impaired participants were presented with spelling suggestions at least once (16 times in total), but they were used by only two participants.

As far as the *Related Searches* feature was concerned, 60% of the visually impaired participants were aware of their presence on the search interface. Those who were aware of the feature did know how to use it as the related searches appear as links at the bottom of the page. In general, screen-reader users confused those with the links for search results and claimed they would rather "*go back to the part of the interface where there is a description of the results.*" 60% of the sighted searchers had never noticed the related searches on the Google interface before because as two sighted participants claimed "*It would be great if they had been at the top of the screen.*"

Search Results Exploration

As discussed previously, the fact that screen readers process web pages sequentially from top to bottom poses numerous challenges, such as information overload and lack of context (Andronico et al., 2006). This problem is more acute when it comes to searching, as users of screen readers are looking for specific pieces of information. As one of our participants said: "*While searching, I spend most of the time listening to irrelevant information than accessing information that could potentially be of use to me.*" Therefore, in this section, we discuss findings about searchers' browsing strategies when it comes to search results exploration.

RQ3: What are the navigation strategies used by visually impaired searchers on the search results page?

The most popular navigation strategies among the visually impaired searchers were *heading-to-heading* navigation (93%) followed by *link-to-link* navigation (40%), reading the full content of the page (46%) and searching for keywords (46%). A majority of the visually impaired participants stated that they would try multiple strategies to get a better idea about the content and layout of the page. For example, in the absence of headings, a participant who typically navigates using headings will browse the page through the links or will search for specific keywords on the page. Despite improving the effectiveness of navigation, these strategies are

TABLE 6. Mean number of search results viewed [SD] (Minimum to Maximum).

	Visually impaired searchers	Sighted searchers
No. of search results viewed	4.27 [2.15] (1 to 9)	13.40 [7.39] (3 to 29)

TABLE 7. Mean number of external links viewed [SD] (Minimum to Maximum).

	Visually impaired searchers	Sighted searchers
No. of external links viewed	0.40 [0.83] (0 to 3)	2.27 [2.60] (0 to 9)

still sequential and remain time consuming for the users of screen readers. The visually impaired searchers in our study were aware of this and as a result, we observed only 13% of the screen-reader users visiting more than one search engine results page compared with 43% among sighted searchers.

RQ4: How does the sequential access of screen readers affect the number of search results viewed and the number of queries submitted by visually impaired searchers?

Results exploration is the stage where searchers spend most of their time (Hearst, 2009), making it a critical stage for visually impaired searchers who according to the previous research (Craven & Brophy, 2003; Ivory, Yu, & Gronemyer, 2004), typically spend between 2 to 5 times longer to browse the results than sighted users. Therefore, we studied the number of retrieved pages that all participants viewed when completing their complex task and we present our findings in Table 6. The average number of results viewed by sighted participants was significantly higher (13.40) than visually impaired participants (4.27) at ($t(28) = -4.60$, $p = 0.00008$). After submitting their queries, sighted searchers quickly scan the list of retrieved results to decide whether their search terms have been successful. If they believe the results retrieved are not satisfactory, they change their search terms to better match their information need.

Hence, as shown in Table 6, sighted participants submitted significantly more queries (10.93) than visually impaired participants (4.47) at ($t(28) = -3.70$, $p = 0.0009$). Before they could determine whether a query has been successful, visually impaired searchers had to depend on their screen readers to sequentially process the list of results and in the same amount of time, sighted searchers are able to make better progress with their search tasks and visit more webpages than visually impaired searchers.

Ten of the sighted participants opened multiple tabs or windows during the search process, either to view more than one results at a time or to submit multiple queries. This behavior was observed among only two visually impaired participants. Managing multiple sources of information requires a high level of cognitive effort and users of screen readers have to increasingly depend on their memory during their search task. Therefore, it is harder to keep track and remember the contents of multiple pages at the same time.

RQ5: How does the screen reader affect the number of external pages (beyond the search results list) visited by visually impaired searchers?

While exploring the search results retrieved by the search engine is an important stage of the information-seeking process, previous research (Bates, 1989) showed that searchers do not expect to find all required information in one place. Instead, they expect to find bits of information throughout the search process to meet their information needs. This behavior is often observed when searchers visit a webpage retrieved by search systems and then visit other external links on that page. The decision to do so can reflect the searchers' evolving information need that changes in line with encountered information. For example, a searcher completing a travel task may visit the wikipedia page for the place of interest and then follow the external link for the tourism office or transport facilities.

In our study, we observed this behavior among sighted participants (11) who visited external links 34 times. However, this behavior was limited among visually impaired searchers: 4 visually impaired participants visited a total of 6 external links and this was significantly lower than sighted searchers at ($t(28) = -2.65$, $p = 0.013$). The mean number of external links visited by both groups of searchers is shown in Table 7.

Query Reformulation

The query reformulation stage of the search process often represents a change in the state of knowledge of the searcher and Marchionini and White (2007) discuss that the set of documents retrieved for a query often serves as feedback. This means that depending on what was retrieved for a query, the searcher is in a position to judge whether their query has been effective or whether the system has been effective at responding to their query. When searchers are not satisfied with the results, they can choose to reformulate their queries or submit new queries. There are several approaches to query reformulation, for example, searchers can decide to reformulate their queries using terms from their own knowledge or terms that can be found in the set of documents retrieved for the existing query.

RQ6: What effect does the linear access of screen readers have on the query reformulation strategies of visually impaired searchers?

In this section, we investigate participants' strategies for reformulating queries and in Table 8, we present data on the average number of reformulations from both groups of participants. We define query reformulations as the instances where the searcher refines an existing query by adding or removing terms from it. However, a substantial part of the existing query should be included in the new query for it to count as query reformulation.

TABLE 8. Mean number of queries and query reformulations [SD] (Minimum to Maximum).

	Visually impaired searchers	Sighted searchers
No. of queries	4.47 [1.77] (1 to 8)	10.93 [6.54] (4 to 23)
No. of query reformulations	1.27 [1.16] (0 to 4)	3.40 [3.44] (0 to 13)

The number of visually impaired searchers' attempts at query reformulations was significantly lower than sighted searchers ($t(28) = -2.28,\ p = 0.031$). When prompted on this behavior, visually impaired searchers reported that they trusted the search engines and that if they did not find satisfactory results, they "*would start from scratch with a new query because it is not the system's fault*". The number of query reformulations was higher among sighted searchers. In fact, we observed most sighted searchers reformulating their queries with search terms that they picked from documents retrieved for their existing queries. Therefore, sighted searchers' query reformulation strategies were more iterative and inline with the orienteering behavior reported in O'Day and Jeffries (1993), where searchers use information in their current state to influence the future directions of their search.

Search Results Management

Given the challenges faced by visually impaired searchers, we investigate how the participants in our study managed the information they found during the search process. We were particularly interested in this stage as we chose to study search behavior for complex tasks which are known to be challenging and cognitively intensive.

RQ7: How does the lack of persistence of the auditory screen-reader interface affect visually impaired searchers' approaches to remembering and managing encountered information?

We observed that 73% of visually impaired participants relied on some form of note taking to keep track of their search results either through word processors such as Notepad or using Braille note taking devices. Notes taken by the screen-reader users varied in the level of structure: while some pasted snippets as well as web addresses in their notes, others only wanted to keep track of the search terms that led them to specific results. Other common approaches for managing encountered information were bookmarking (47%) or saving as favorites (47%). All these different strategies had the common goal of serving as memory aids to allow the visually impaired searchers to get back to specific pages which had previously been useful.

During the semi-structured interview, we probed searchers on this practice and found out that given that complex search tasks are likely to be completed in multiple search sessions which are often spread over a period of time, visually impaired searchers need a way of remembering the information they encountered previously and also the stage they were at in their search process. As previously discussed, the search process progresses at a slower pace for the visually impaired searchers and usually takes a much longer time to complete. Therefore, visually impaired participants developed coping strategies to support them in their tasks (Bigham et al., 2007). Note taking was less common (46%) among sighted searchers as most of them reported that they would try to remember the link to the result or they would search for it again. However, 60% of sighted participants reported using bookmarks and 13% said that they would save the link as a favorite or print out the content of the page of interest.

Discussion

In this section, we discuss findings from our observational study focussing particularly on the search behavior of visually impaired searchers. We structure the discussion according to the four stages of the information-seeking process under study namely, *Query Formulation*, *Search Results Exploration*, *Query Reformulation*, and *Search Results Management*.

Query Formulation

Query formulation is a critical stage in the search process as users try to express the mental model of their information need using a query. Our observations showed that visually impaired searchers try to express their complete information need in a long precise query and as a result, their queries were more expressive. Therefore, visually impaired searchers displayed a *teleporting* behavior (Teevan et al., 2004), which is in contrast to the *orienteering* behavior (O'Day & Jeffries, 1993) displayed by sighted searchers who formulated broad queries initially to get to the relevant part of the information space. This difference in behavior can be readily understood when one takes into account the fact that, as shown by the findings, many aspects of the search process are slower for visually impaired searchers than for sighted searchers. Providing an initial search request, which is specific enough that it reduces the number of interactions required from submitting that query to reaching the required results, is one of the most effective strategies a visually impaired searcher can employ to try to reduce the overall search time.

Sighted searchers can afford to display an orienteering behavior as they can decide within seconds of submitting a query whether it has been successful or not. This is a more difficult and time-consuming process for visually impaired searchers. Despite shortcut navigation strategies such as *link-to-link* or *heading-to-heading* navigation, screen readers still have to linearly process all or a big part of the results list before the visually impaired searchers can decide whether their search is going in the right direction and whether their choice of keywords was correct. These findings show that the beginning of the search process can be challenging for users of speech-based screen readers and that these users should be supported during query formulation especially for longer queries. There are speculations that an orienteering strategy

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with shorter queries could be less cognitively taxing (Teevan et al., 2004). Therefore, visually impaired searchers could benefit from an awareness of such alternative search strategies to increase the effectiveness of their search activities.

In addition, visually impaired searchers cannot benefit from visual cues on search interfaces that could help their query formulation strategy. For example, dynamic query suggestions, which appear in a drop down box in real time as a query is being typed, require screen-reader users to navigate away from their focus, listen to the suggestions, and navigate back again. In these cases, such features are considered to have a poor cost-benefit ratio in terms of the time required for access and the likely benefits of such strategies. Therefore, query-level support features were not popular among visually impaired searchers. The lack of awareness and use of support features was unexpected as the previous research suggest that searchers are more likely to use support features for difficult or unfamiliar tasks (Fowkes & Beaulieu, 2000; Sahib, Tombros, & Ruthven, 2010). Yet, in our study, all visually impaired participants performed complex search tasks but they still did not use any of the support features because despite being accessible, those support features were not usable in the following ways:

Query Suggestions are only noticeable to users of screen readers when they are typing at a relatively slow pace and to access them, users have to navigate away from the search box. This interferes with the way visually impaired users interact with search systems, making the cost of using query suggestions higher than the benefits they could provide. Therefore, from a screen-reader user's perspective, query suggestions have low utility (Russell et al., 1993) and are most often ignored. Query suggestions was the most-used feature among sighted searchers during our observation. This is because sighted users can interact with query suggestions without any additional effort and hence perceive the feature to have high utility.

Spelling Suggestions are accessible by the screen readers only if the user is not navigating the search page through headings, because if they are, they will not find the spelling suggestions as they are not at the same heading level as the retrieved results. As searchers are focussed on exploring retrieved results once they have submitted a query, they never reach the part of the interface where spelling suggestions are presented. When using the feature for one of her queries, one participant was still confused as to why suggestions were being presented to her as the screen reader often pronounces misspelt words as they would be pronounced when correctly spelt. This caused confusion and frustration during our observations.

Related Searches was the least-known feature both by visually impaired and sighted searchers, given its position at the bottom of the search interface. If they are not satisfied with the retrieved results, most searchers will not wait until they reach the bottom of the first results page to reformulate their queries. Therefore, searchers rarely encounter the list of related searches. In addition, this feature is not available for all queries and thus is not consistently present on the search interface. This inconsistency is a challenge for users of screen readers who "learn" how to use interfaces, that is, visually impaired searchers often memorize the layout and structure of the webpages that they frequently visit. For example, for search interfaces, visually impaired searchers are likely to learn whether the results will be presented in a table or using headings in order to decide on their navigation strategy.

The lack of awareness and use of search support features highlights the importance for search interface features to be both accessible and usable because if interface components are viewed as having low utility (potential benefits do not exceed required efforts), they will remain unpopular with users of speech-based screen readers. Therefore, it is essential to ensure that support features are designed to be accessible with assistive technologies such as screen readers, but they should also be usable and easy to integrate with the mode of interaction.

Search Results Exploration

The results exploration stage is critical for visually impaired searchers as they take 2–3 times longer than sighted searchers to explore search results (Ivory et al., 2004). Sighted searchers in our study needed a few seconds to quickly get the gist of the retrieved information to decide whether a query has been successful or not. They used the structure, the layout, and the style of webpages to decide, within seconds, whether pages were relevant or not as also observed in Tombros, Ruthven, and Jose (2005). This was however not readily possible for visually impaired searchers who describe graphical user interfaces, firstly by their content and later augment their description with information about the spatial layout (Mynatt, 1997). Hence, visually impaired searchers based their assessment of relevance mainly on the content of the page rather than its structure or layout.

The use of speech-based screen readers necessitates that visually impaired searchers take a longer time to acquire the content of the page as they need to build their mental model of the page from the pieces of information being read to them by the screen reader. This was reflected in our findings which showed that sighted searchers progressed more rapidly during the search process and in the same amount of time, they submitted a significantly higher number of queries and viewed more search results. Given the time and efforts required by screen-reader users to explore search results, there is the need make this process more efficient. Alternative presentation methods should be evaluated to enhance visually impaired searchers' browsing strategies in order to increase the efficiency of the search process.

This stage of the information-seeking process is likely to be the one where the lack of *information scent* impacts the search behavior of visually impaired searchers the most as additional information conveyed by visual cues are not accessible. Hence, due to this lack of contextual information, visually impaired searchers displayed a limited exploratory

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behavior during our observations and visited a significantly lower number of external links compared to sighted searchers. This behavior can be explained by the fact that when visiting webpages from the search results list, visually impaired searchers fail to grasp the benefit that external pages could have on their search process. Therefore, unless there is a clear benefit in visiting an external link, screen-reader users are discouraged from doing so as the costs associated with visiting and understanding a new page is high. This calls for further work on information scents for visually impaired searchers; what act as information scents for visually impaired searchers and how they should be designed to be successfully conveyed via a screen reader?

Query Reformulation

Despite completing complex search tasks, the number of query reformulations among visually impaired searchers was low. This supports our observations of a goal-oriented strategy at the initial stages of the information-seeking process as visually impaired searchers often think that unsatisfactory retrieved results are not the search system's fault but their own. Instead of fine tuning current queries, visually impaired searchers preferred to submit different ones. One of the reasons for such behavior is that for users of screen readers, it is more difficult to pick up cues of what might be useful to direct a query in the desired direction. Lack of contextual information and information scent as well as inaccessible search support features also impact the query reformulation process for visually impaired searchers.

This implies that despite the presence of multiple support features on current search engines interfaces, visually impaired searchers do not see the benefits of iteratively reformulating queries and are not fully supported to do so. Therefore, there is the need to increase the awareness of visually impaired searchers on the potential effectiveness of a query reformulation strategy. The process of query reformulation is relatively easier for sighted searchers and in our study, they reformulated their queries significantly more. Currently, search engines retrieve results in a fraction of a second and it is effortless for sighted searchers to get the gist of retrieved results and reformulate in case of unsatisfactory results. In addition, features such as Google Instant[7] that shows search results as queries are being typed, further enhance support for sighted searchers for query reformulation.

Search Results Management

Our observations showed that at this stage of the information-seeking process, the most common strategy displayed by the visually impaired participants to keep track of encountered information was note taking. Visually impaired searchers currently rely mostly on external applications such as word processors to take notes during their search process. While this is an effective strategy to relieve the load on working memory and to reduce the time-consuming need to revisit pages, it also requires visually impaired searchers to constantly switch between applications which can be inconvenient and contribute to cognitive load.

The screen reader already requires significant cognitive effort from their users and when managing search results, visually impaired searchers are faced with a high level of cognitive load while comparing and analyzing information from multiple sources. Therefore, they develop coping strategies such as bookmarking and note taking to make relevant webpages more "persistent" and to make them easier to re-find in the future. Note taking was not popular among sighted searchers as they found it relatively easy and effortless to re-find results of interest either by searching for them again or by keeping them open in multiple tabs and windows. This implies that, unlike sighted searchers, visually impaired searchers need to be supported by search systems to manage the information they find during the search process as re-finding is relatively more taxing.

Implications and Guidelines

The findings reported in this article and in the previous work (Andronico, Buzzi, Leporini, & Castillo, 2006; Bigham et al., 2007; Buzzi et al., 2004; Craven & Brophy, 2003; Leporini et al., 2004) clearly indicate that the needs of visually impaired searchers are not adequately addressed in current search engines and that a number of currently provided support mechanisms are not beneficial to the users of speech-based screen readers. It is clear therefore that the importance of taking an inclusive and user-centered approach to user-interface design cannot be underestimated in the development of search engines that are both accessible and usable. Hence, in this section, we firstly discuss the implications of our findings and provide specific guidelines to consider when developing accessible and usable search interfaces for visually impaired searchers.

Implications for Search Interface Design

Our findings on the awareness and use of query-level support features among visually impaired searchers highlighted an important point about accessibility of interfaces. They suggest that, while it is essential to make interface components *technologically accessible* via assistive technologies, it is equally important to ensure that they are usable and do not interfere with the way visually impaired users interact with interfaces. Previous efforts, for example, Andronico et al. (2006) have often addressed the issue of accessible search interfaces by adapting what already exists, that is, making components of existing interfaces accessible through assistive technologies. While this is a step forward, we believe it is unlikely to be as effective an approach as one which takes into account the specific needs of the user group from the start. As interfaces are usually designed using a user-centred approach, many design decisions are usually dependent on the cognitive abilities of the target group of users and

[7]http://www.google.com/instant/

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factors such as users' approaches to processing information, users' use of interface components, users' gaze pattern on the screen etc. are taken into consideration during usability testing.

Thus, we should take the needs of the target population into consideration to ensure that we are not assuming capabilities that screen-reader users do not have (Craven, 2004). For example, the drop down list with query suggestions can be made accessible with screen readers, but how to make suggestions accessible on a cognitive level is of utmost importance as this is what determines whether searchers will ultimately use this function or not. Query suggestions are useful for sighted searchers because the way they are presented captures the attention of the searchers as they type their queries. This is not currently the case for visually impaired searchers and as a consequence, this group of users ignores a feature that could potentially support them in their search process. Thus, merely making accessible features which have been designed based on visual cues is unlikely to help visually impaired searchers in their tasks, and will increase the cognitive load imposed on such users. This is why we believe that when making design decisions for interfaces, the cognitive load that interface components will impose on the target users should also be considered.

Our findings on the differences in search behavior also suggest that we should take into consideration the mode of interaction when designing interfaces, that is, whether users will be interacting with the system visually or using an auditory interface. This is important because differences were observed between the two groups of searchers in how they explore and manage search results when accessing the search interface in different modes. This is in agreement with the previous work (Tombros & Crestani, 2000) which reported how users' perception of relevance for spoken documents were affected by the way the documents were presented to them. Tombros and Crestani (2000) also argued for more sophisticated ways of presenting documents as a result of the low accuracy and low speed of relevance judgements for spoken documents.

Guidelines for Designing Accessible Search Interfaces

Our comparative analysis of visually impaired and sighted searchers for complex search tasks revealed some differences in their search behavior especially at the query formulation and results exploration stages. Therefore, in this section, we suggest the following guidelines that we believe are important to consider when designing accessible search interfaces for visually impaired searchers:

- *Design interface components that provide the right type of information scent*. When designing components for accessible search interfaces, we should ensure that they are compatible with assistive technologies and do not affect the way visually impaired users interact with search interfaces. Interface features, such as query-level support features, should provide the right type of information scent to allow visually impaired searchers to navigate effectively through the information space. The web is a large unstructured source of information and to encourage an information foraging behavior as described by Pirolli and Card (1999), the right type of information scent should be provided to screen-reader users, taking into consideration their mode of interacting with the search interfaces. However, we also believe that assistive technologies should be enhanced to cope with the secondary information that is provided by interfaces, that is, information that is not directly relevant to the user's task but might be useful for the completion of the task.
- *Consider at which stages of the information-seeking process the target group of users are most likely to need support*. In this way, it will be possible to provide the right type of support at the right stage in the search process, which for the visually impaired participants in our study, are the query formulation and search results exploration and management stages. Depending on the mode of interaction that the target group of searchers use to interact with search systems, information-seeking behavior studies should be carried out to determine when searchers need most support and these studies should be used to inform the design of interfaces.
- *Include auditory previews and overviews for search interfaces*. As an information-rich interface, the search interface would benefit from the use auditory previews and overviews. Previews (acting as a surrogate for a *single* object of interest) and overviews (representing a *collection* of objects of interest) have been defined and designed to support the dynamic and iterative process of information seeking in digital libraries (Greene, Marchionini, Plaisant, & Shneiderman, 2000). Such representations of objects on the search interface, for example, individual results or a complete results set, would help visually impaired searchers to speed up their search process by allowing them to manage their time more efficiently. Visually impaired searchers could spend more time viewing content that they are interested in and avoid viewing retrieved results that are not relevant to their information need.
- *Display search results to allow more efficient results exploration*. Screen readers impose a sequential processing of retrieved results which is time consuming. Grouping techniques such as clustering should be used to put similar results together so that only an overview of the results is provided to the users of screen readers. In this way, searchers can get the gist of the results retrieved and if they find them useful, they can view the more specific results within each group. Therefore, more work and research is needed to explore how new techniques could be applied for the results presentation so that searchers are provided with a more efficient exploration strategy.
- *Support searchers in managing their search results so that they can make sense of encountered information*. Visually impaired searchers have to rely tremendously on their memory when searching as they do not benefit from persistent information on interfaces. Therefore, system designers should ensure that they provide visually impaired searchers with an integrated solution to keep track of the information they encounter. Also, as there is evidence that the search process of speech-based screen-reader users is time consuming and likely to be completed over multiple search sessions, visually impaired searchers should be supported to record their progress with their search task, especially for complex search tasks where they may be uncertain about the search domain or the task itself.

History mechanisms should be designed to automatically monitor the progress of the search task, for example, through search trails. Search trails show the routes that searchers have traveled within the information space, including details about the origin of the search (queries), the destinations (relevant pages) as well as the information gathered along the way (White & Huang, 2010). While such an interface feature may be able to help visually impaired searchers in managing the search process, it also has the potential to motivate an orienteering behavior towards searching which, as previously reported in this article, was not observed among visually impaired searchers. This is likely to make their search process more efficient.

Conclusions and Future Work

In this article, we investigated the search behavior of 15 visually impaired and 15 sighted searchers through an observational study. Participants chose their own tasks, used their own equipment and were observed in settings close to those in which they perform their day-to-day search activities. We studied search behavior for complex tasks as they are challenging, cognitively intensive, and affect the performance of all types of searchers. We enhanced the understanding of the search behavior of visually impaired searchers especially at the query formulation, search results exploration, query reformulation, and search results management stages of the information-seeking process. Through our comparative analysis, we reported significant differences in the query formulation process, the awareness and use of query-level support features, such as query suggestions and spelling suggestions, as well as in browsing and navigation strategies. We also observed differences in the exploratory behavior, query reformulation strategies, and approaches to manage found information.

While we presented findings for both groups of participants, we focussed a considerable amount of effort on visually impaired searchers as this work attempts to address the lack of previous research on the information-seeking behavior of this population. We view this study as a first step toward understanding their online searching behavior so that more accessible and usable search interfaces can be designed and implemented. Studying visually impaired searchers also provided insight into search behavior when using auditory interfaces. In this respect, we explored how a lack of visual cues can impact the search behavior of searchers. Lastly, we used our findings to discuss implications for designing accessible and usable interface components and we also proposed guidelines to consider when designing accessible search interfaces. We believe that the findings from our user study highlight the need for the adaptation of search interfaces for different types of searchers such as children, older adults, and users with learning difficulties.

In the future, we plan to investigate ways in which the existing query-level support features can be made more usable for visually impaired searchers. We are aware that the effectiveness of the guidelines we proposed, for example, auditory overviews and previews and search trails, can only be evaluated through usability studies to ensure that they are designed in a highly usable way for speech-based screen readers. Therefore, we aim to design and implement a search interface for visually impaired searchers through a user-centred approach to evaluate the guidelines we proposed and to address the issues identified during our comparative analysis.

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