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Enhancing usability of digital libraries: Designing help features to support blind and visually impaired users

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ABSTRACT

Blind and visually impaired (BVI) users experience vulnerabilities in digital library (DL) environments largely due to limitations in DL design that prevent them from effectively interacting with DL content and features. Existing research has not adequately examined how BVI users interact with DLs, nor the typical problems encountered during interactions. This is the first study conducted to test whether implementing help features corresponding to BVI users' needs can reduce five critical help-seeking situations they typically encounter, with the goal to further enhance usability of DLs. Multiple data collection methods including pre-questionnaires, think-aloud protocols, transaction logs, and pre and post search interviews, were employed in an experimental design. Forty subjects were divided into two groups with similar demographic data based on data generated from pre-questionnaires. The findings of this study show that the experimental group encountered fewer number of help-seeking situations than the control group when interacting with the experimental and baseline versions of a DL. Moreover, the experimental group outperformed the control group on perceived usefulness of the DL features, ease of use of the DL, and DL satisfaction. This study provides theoretical and practical contributions to the field of library and information science. Theoretically, this study frames vulnerabilities of BVI users within the social model of disability in which improper DL design impairs their ability to effectively access and use DLs. Practically, this study takes into account BVI users' critical help-seeking situations and further translates these into the design of help features to improve the usability of DLs.

1. Introduction

The global BVI population exceeds 1.3 billion (World Health Organization, 2018), of whom 25 million reside in the U.S. (American Foundation for the Blind, 2018). In this paper, a "BVI user" refers to someone without the sight necessary to see information presented on a display screen and who relies on screen-reader (SR) software to use information retrieval (IR) systems. The SR identifies and interprets text content on a system interface and presents this aurally through a synthetic voice (Di Blas, Paolini & Speroni, 2004). The BVI comprise a vulnerable user group that interacts with IR systems, including digital libraries (DLs), in different ways than sighted users.

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According to Aday (1994), to be vulnerable is to be in a position of being hurt, marginalized, or ignored—as well as helped—by others. BVI users are among these vulnerable groups mainly because there is inadequate support for their IR system interactions. It's important to note that, in recent years, disability theorists have developed a social model of disability to challenge traditional and reductive assumptions about disability that were based in the medical model of disability, where people with impairments are viewed as abnormal, lacking, and unable to fully participate in society (Andreas Kleynhans & Fourie, 2014). According to the medical model, which has traditionally been applied within fields such as science, medicine, and technology, those with disabilities are regarded as having an impairment or deficit that needs to be cured, altered, or normalized. Disability theorists challenge these notions, and instead focus on the social and cultural structures and conditions that limit, restrict, or fail to accommodate people with impairments (Walters, 2010). When considering universal design, accessibility, and usability in the context of DL design, it's important to consider how it is not the impairment of the individual that prevents access to information, but rather the barriers created by social context and environment (Brebner & Parkinson, 2006). BVI users remain vulnerable in the digital environment even though administrative supports such as the Americans with Disabilities Act (ADA), Section 508 of the U.S. Rehabilitation Act, Web Content Accessibility Guidelines (WCAG), and technological supports like SRs, have existed for the past two to three decades. Prior research (Babu & Singh, 2013; Clark, 2006; Di Blas et al., 2004; Leuthold, Bargas-Avila & Opwis, 2008) has consistently shown that while these supports are necessary for technical accessibility, they do not fully account for the differing abilities, needs, and challenges of BVI users in interacting with digital environments.

This research is concerned with designing BVI-friendly DLs. A DL is an online collection of digital content created by libraries and cultural heritage institutions excluding those purchased from publishers. It is envisioned as the gateway of universal access to information. Just as other library services, DLs are deployed to reach a wider user base. However, research shows this goal is yet to be fulfilled for marginalized and vulnerable communities like the BVI (Jaeger, Bertot & Franklin, 2010). One of the key factors could be the current designs of DLs fail to account for the needs of these users (Babu & Xie, 2017; Xie, Babu, Castillo & Han, 2018). Existing DLs, like other online systems, are sight-centered by design, and characterized by complex structures and multimedia formats—attributes that run counter to the non-visual mode of information access that SRs offer BVI users (Andronico, Buzzi, Castillo & Leporini, 2006; Jones, Farris, Elgin, Anders & Johnson, 2005; Lazar, Allen, Kleinman & Malarkey, 2007). Very scant research examines the DL experiences of BVI users. Relevant literature explains how it is significantly more challenging for non-sighted users to use a DL and understand the content presented than it is for sighted users (Kumar & Sanaman, 2013; 2015).

Existing literature does not adequately examine how BVI users interact with DLs, nor the typical problems encountered during their interactions. In order to design DLs to effectively support BVI users, we need to first identify help-seeking situations that these users face in their DL search process. Xie, Babu, Joo and Fuller (2015, 2018) conducted studies to address this problem and identified 17 unique help-seeking situations that blind users experience when interacting with DLs. A help-seeking situation is characterized by a problem that arises during a user's interaction with a DL that motivates them to seek some form of assistance in order to complete an information retrieval task. A DL design needs to support users to effectively search for information through implementation of a series of help features, which can influence the usability of the DL. In this study, help features refer not only to explicit help features but also to any DL features that assist users—regardless of their abilities—to overcome any problems in their interactions with DLs. In this way, DLs can actively support BVI users in effectively searching for information instead of passively waiting for them to seek help. Moreover, no research has been conducted to test the usability of DLs that are equipped with new help features based on the needs of BVI users, in particular, and therefore this topic provides fruitful ground for investigation. Theoretically, this study aims to link vulnerabilities of BVI users in the digital environment to help feature design, and the usability of DLs. Practically and methodologically, this study offers an approach that takes into account BVI users' critical help-seeking situations and further translates them into the design of help features to improve the usability of DLs.

2. Literature review

2.1. Help-seeking situations of BVI users' interaction with the web

The web is designed predominantly based on sighted users' experiences and their perceptions of usability, as stated in Introduction. As a result, BVI users experience difficulties using IR systems, and their cognitive and physical situations have been studied in order to identify non-visual interaction problems (Xie et al., 2015, 2018). Research investigating BVI users' interactions with the web has largely referred to these situations, or phenomena, as problematic or coping situations (Bigham, Cavender, Brudvik, Wobbrock & Lander, 2007; Borodin, Bigham, Dausch & Ramakrishnan, 2010; Lunn, Harper & Bechhofer, 2011; Vigo & Harper, 2013, 2014). These situations, which are not effectively addressed by existing IR systems, highlight BVI users' vulnerabilities when working on the web.

Researchers have found that many unique situations BVI users encounter in using the web are due to poor system design or poor usability that creates accessibility barriers in IR systems (Power, Freire, Petrie & Swallow, 2012; Rømen & Svanæs, 2012; Vigo & Harper, 2014). As a result, BVI users experience accessibility and usability problems related to accessing content or using system features (Vigo & Harper, 2013). Even though there are helpful assistive technologies available, BVI users continue to face obstacles in using the internet (Kumar & Sanaman, 2013, 2015). For example, SR navigation mainly supports sequential browsing, causing BVI users to lose contextual information because they are only able to access select portions of the text on the page at a time (Andronico et al., 2006). Most important, the linear nature of SR navigation and information architecture, based on graphical functions, causes BVI users to undergo difficulties when browsing and searching information systems (Borodin et al., 2010; Brophy & Craven, 2007; Craven, 2004; Lazar et al., 2007; Salampasis, Kouroupetroglou & Manitsaris, 2005; Vigo & Harper, 2014).

In addition to problems with SRs reading graphical interfaces, information overload is another distinctive situation that BVI users face. Static areas of websites, such as banners, indexes, frames, or copyright information might be read repeatedly by a SR so that BVI users hear duplicated or non-contextual information before accessing an item—or information—they are trying to reach (Andronico et al., 2006; Chandrashekar, 2010). Therefore, BVI users have been forced to expend additional cognitive effort to process information in small chunks in order to infer the structure of an entire page or website (Chandrashekar, Stockman, Fels & Benedyk, 2006). Due to information overload, BVI users exhibit avoidance patterns when they encounter webpages designed with dynamic and rich content (Bigham et al., 2007; Borodin et al., 2010).

Research has largely focused on situations BVI users experience on the web in general, whereas a few studies have investigated the experiences of BVI users in DL interactions. Xie et al. (2015, 2018) identified 17 types of help-seeking situations at both physical and cognitive levels encountered by BVI users in the DL environment, and they presented nine main categories: Difficulty accessing information, Difficulty evaluating information, Difficulty with help, Difficulty locating information or features, Difficulty refining collections or results, Difficulty identifying current status and path, Confusion about multiple programs or structures, Avoidance of format, approach, and input fields, and Difficulty constructing search statements. Simultaneously, four types of factors emerged from the prior findings: User, System, Task, and Interaction. These help-seeking situations, resulted from sight-centered DL designs that failed to consider the needs and capabilities of BVI users, hindered BVI users' ability to access and use DLs. Therefore, a clear understanding of these situations and associated factors are required for the design of DLs to support BVI users. Even though sighted users share some of the similar problems with BVI users in interacting with DLs, their needs in receiving system support are different. Most important, while sighted users can quickly visualize the DL interface as a whole, BVI users rely on screen readers to make sense of the interface. Current DL designs do not consider BVI users' unique needs. DLs should provide a quick overview of the interface before BVI users begin the search process and provide appropriate headings or links for different sections of the interface so users can obtain direct access to a specific section without listening to less relevant text first. Moreover, when BVI users encounter these situations, their DL interactions are obstructed and they become focused on solving the problems—losing overall sight of the goal—further preventing them from accessing and using DLs.

2.2. Usability studies in DLs and other IR environments

DLs organize and manage large collections of digital works or information. Since DLs are developed to provide multimedia information with rich information architecture and extensive content, DLs may introduce additional challenges to different types of users. Consequently, it is critical to evaluate their usability to support the needs of users (Jeng, 2005; Joo, 2010; Masrek & Khan, 2015). This section addresses relevant literature on usability studies in DLs. While there are several usability criteria used to evaluate DLs, ease of use, satisfaction, and usefulness of features are the most frequently applied criteria (Heradio, Fernández-Amorós, Cabrerizo & Herrera-Viedma, 2012; Hong, Thong, Wong & Tam, 2002; Jeng, 2005; Thong, Hong & Tam, 2002; Yang, Cai, Zhou & Zhou, 2004).

2.2.1. Ease of use

Ease of use is defined as a user's perception in determining how easy a system is to use (Adams, Nelson & Todd, 1992; Jeng, 2005). Ease of use is one of the primary attributes for evaluating the usability of a system (Chowdhury, Landoni & Gibb, 2006; Jeng, 2005, 2006; Liu & Luo, 2011; Masrek & Khan, 2015; Matusiak, 2012; Nielsen, 2012). In DLs, ease of use measures how a DL assists the interaction process (Mirel, 2004). In particular, Masrek and Khan (2015) conducted a usability assessment of undergraduate students' DL use via a survey and suggested that ease of use increases user satisfaction. Besides being an important attribute connected to user satisfaction, ease of use is recognized as a critical determinant of a user's perception of a DL and usefulness of its interface during the user's initial DL encounter (Matusiak, 2012). A core component of the technology acceptance model (TAM) indicates that ease of use strongly relates to one's use and adoption of a new DL (Liu & Luo, 2011).

2.2.2. Usefulness

Usefulness, or perceived usefulness, has been defined and used for accepting new information technologies and web technologies (Adams et al., 1992; Davis, 1989; Renny, Guritno & Siringoringo, 2013). In the digital age, usefulness is considered as another primary usability attribute (Booth, 1989; Gluck, 1997; Jeng, 2005; Johnson & Craven, 2010). Booth (1989) characterizes usefulness as one of four usability attributes (i.e., usefulness, effectiveness, learnability, and attitude). Usefulness has been defined in a variety of ways, such as a function of one's intention to use a system (Gluck, 1997), serving an intended purpose (Landauer, 1995), or an indicator of a user's willingness to use a product to achieve one's goals (Rubin & Chisnell, 2008). While usefulness is considered as one of the most important usability dimensions (Rubin & Chisnell, 2008), it is generally treated as a subjective measure based on users' assumptions and opinions related to users' goals or attention (Liu & Luo, 2011; Matusiak, 2012; Rubin & Chisnell, 2008). Usefulness is a key concept in the Technology Acceptance Model (TAM), in particular as it relates to DLs (Matusiak, 2012). Simultaneously, some studies on usefulness focus on the usefulness of specific features of IR systems (Johnson & Craven, 2010; Lee, Theng, Goh & Foo, 2006). Lee et al. (2006) found that usefulness of features helped users evaluate and judge documents in the ACM Digital Library. Johnson and Craven (2010) investigated the OPAC and examined features such as tagging and reading lists, and concluded that usefulness of features led to the improvement of the usability of the system. In sum, researchers have employed usefulness to assess targeted features of a system.

2.2.3. Satisfaction

DL satisfaction relates to the ways and to what extent users are satisfied with DLs (Joo & Lee, 2011). International Standards Organization's (ISO, 1998) "*ISO 9241–11*" standardized usability elements and designated satisfaction as a primary usability element. Satisfaction is considered to be a main criterion for usability and is a top measurement for evaluating users' DL perceptions (Alberton, 2015; Chowdhury et al., 2006; Jabeen, Qinjian, Yihan, Jabeen & Imran, 2017; Jeng, 2005, 2006; Joo, 2010; Khoo, Kusunoki & MacDonald, 2012; Liu & Luo, 2011; Masrek & Khan, 2015; Nasreen & Alawi, 2011; Xie & Matusiak, 2016). Researchers have investigated user satisfaction related to ease of use, information organization, labeling, visual appearance, and error correction (Jeng, 2005). Jabeen et al. (2017) employed a mixed-method approach for a usability study at a university library and found user satisfaction increased with the availability to access information and usability of the DL interface for resources. Liu and Lio (2011) applied survey questionnaires to collect data related to undergraduate and graduate students' satisfaction levels and pointed out that expectations, emphases, and frequency of use contributed to differences between the two groups in satisfaction levels. At the same time, Joo (2010) investigated efficiency, effectiveness and satisfaction of a Younsei University DL with graduate students in South Korea and identified correlations among these usability elements. Nasreen and Alawi (2011) investigated University of California Berkeley undergraduate students' satisfaction when using both the university DL and internet technology and concluded that design of the DL primarily affected user interactions and user satisfaction.

Several studies have investigated the usability of a DL by testing the incorporation of new interfaces or new features. DLs with new interfaces or features have been tested to assess how these features enhance DL usability (Suprapto, Ferdiana & Hartanto, 2016; Wu & Chen, 2016; Wu, Tang & Tsai, 2014). Wu and Chen (2016) studied children's search performance related to 2D or 3D navigation of a children's DL interface and found that 3D navigation interfaces provide better performance for children. Wu et al. (2014) investigated children's information search efficiency and memory of category features between a text-based and graphic-based DL and discovered that graphical interfaces improve children's search speed and overall success. After developing a new DL interface with a simple search for elementary school students, Suprapto et al. (2016) noted that the new interface reduced difficulties related to system use. Besides DL usability, some studies tested the usability between desktop and mobile platforms and between text and graphic-based systems (Ho, Bendrissou, Azman & Lau, 2017; Wentz & Lazar, 2011).

2.3. Usability studies of BVI users' interactions with the internet

No DL usability studies were conducted with BVI users, although there is a large quantity of research related to the website usability and the usability of other types of online systems for this user group. Accessibility and usability are critical in developing a universal design for websites and online systems for all users (Leuthold et al., 2008; Story, 1998; Vanderheiden, 2000). BVI users, in particular, are considered to be one of the main vulnerable user groups that experience problems using websites because most websites are based on sight-centered design principles focusing on graphical interaction (Andronico et al., 2006; Babu, 2013a, 2013b; Bradbord & Peters, 2008; Buzzi, Andronico & Leporini, 2004; Leuthold et al., 2008). Babu (2011) analyzed blind users' interactions with a web-based learning system and identified several major problems blind users faced, such as confusion while navigating across pages with framebased structures, and an inability to determine if a new page was available in the absence of feedback for link activation. Lazar et al. (2007) examined frustration of SR users on the web and discovered the primary causes for the issue were related to unclear graphic labels, confusing page layouts, and conflicts between screen readers and other applications. Similarly, graphical interfaces, such as those with dynamic features, are considered to be the biggest hindrance for BVI users, decreasing usability of websites (Bigham et al., 2007; Giraud, Colombi, Russo & Thérouanne, 2011; Jones et al., 2005). Andronico et al. (2006) pointed out that 80% of participants who relied on SRs and used search engines, such as Google, experienced difficulties accessing search results lists due to the linear sequential nature of web page navigation, while most non-visually impaired participants reported ease of accessing search results. In reviewing visually impaired users' interactions with mobile devices, Damaceno, Braga and Mena-Chalco (2018) identified 68 problems classified into the following seven categories: buttons, data input, gesture-based interaction, screen reader, screen size, user feedback, and voice command.

Some researchers created new interfaces or features to solve problems. Wentz and Lazar (2011) investigated the interactions of 15 blind users to compare the usability of mobile and desktop interfaces of the social networking platform, Facebook. Interestingly, they found Facebook's mobile interface was more usable to blind users than the desktop interface, even though there were some missing features that would benefit blind users. Ho et al. (2017) tested the usability of a graphical authentication system on a smartphone and proposed a new system to take the advantage of the graphical password with the security of a textual password for BVI users.

Since SRs are a crucial tool for BVI users to access online information, many researchers have investigated the SR's compatibility with online websites as well as limitations of using SR programs to navigate interfaces (Barreto, 2008; Chandrashekar, 2010; Lazar et al., 2007; Sahib, Tombros & Stockman, 2012, 2014). Researchers argue that a blind user's web interaction with the SR is far more complicated than a sighted user's web interaction in that blind users require additional short-term memory load and extended reading time (Chandrashekar, 2010; Sahib et al., 2012, 2014). Barreto (2008) and Lazar et al. (2007) pointed out that SRs read text on a webpage in a linear navigation pathway, which may cause blind users to experience frustration and miss important contextual information. In sum, BVI users' performance in the web environment is greatly hindered when compared to sighted users (Bigham et al., 2007; Takagi, Saito, Fukuda & Asakawa, 2007; Vigo & Harper, 2013).

Although previous studies have investigated BVI users' help-seeking or problematic situations in interacting with the web, usability studies in DLs and other IR environments—as well as usability studies on BVI users' web interactions—few studies have identified BVI users' help-seeking situations in the DL environment. Moreover, no research has been done to develop new help features to deal with these situations. While the authors of this study have previously identified help-seeking situations encountered

by BVI users when using DLs, there is a need for researchers to explore whether help features can be created to reduce different types of help-seeking situations and further improve DL usability. Therefore, this study compares the usability of two versions of a DL—including one baseline DL and an experimental DL with added help features—using data collected from two BVI user groups, and their interactions with these DLs. In particular, the focus is on the comparison of two BVI user groups in terms of the number of help-seeking situations users encountered, perceived usefulness of DL help features, perceived DL ease of use, and satisfaction levels.

3. Research questions and hypotheses

The limitation of the existing research calls for the need to test whether implementing help features corresponding to BVI users' needs can reduce the number of help-seeking situations BVI users may encounter, and further enhance DL usability. Research questions and associated null hypotheses are as follows:

RQ1: Do the control and experimental groups encounter the same number of critical help-seeking situations in interacting with the baseline and the experimental versions of a DL?
H1.1: There is no significant difference between the number of help-seeking situations associated with Difficulty accessing information between the control and experimental groups in interacting with the baseline and the experimental versions of a DL.
H1.2: There is no significant difference between the number of help-seeking situations associated with Difficulty evaluating information between the control and experimental groups in interacting with the baseline and the experimental versions of a DL.
H1.3: There is no significant difference between the number of help-seeking situations associated with Difficulty with help between the control and experimental groups in interacting with the baseline and the experimental versions of a DL.
H1.4: There is no significant difference between the number of help-seeking situations associated with Difficulty locating specific information, items or features between the control and experimental groups in interacting with the baseline and the experimental versions of a DL.
H1.5: There is no significant difference between the number of help-seeking situations associated with Difficulty constructing or refining searches between the control and experimental groups in interacting with the baseline and the experimental versions of a DL.
RQ2: Do the control and experimental groups experience the same level of perceived usefulness of help features in interacting with the baseline and the experimental versions of a DL?
H3.1: There is no significant difference between the level of usefulness of help features perceived by the control and experimental groups in interacting with the baseline and the experimental versions of a DL.
RQ3: Do the control and experimental groups experience the same level of perceived ease of use in interacting with the baseline and the experimental versions of a DL?
H2.1: There is no significant difference between the level of perceived ease of use by the control and experimental groups in interacting with the baseline and the experimental versions of a DL.
RQ4: Do the control and experimental groups share the same level of perceived satisfaction in interacting with the baseline and the experimental versions of a DL?
H4.1: There is no significant difference between the level of perceived satisfaction shared by the control and experimental groups in interacting with the baseline and the experimental versions of a DL.

4. Methodology

4.1. Implement help features in a selected DL collection

Based on the results of a previous user study investigating 30 BVI users' search processes in DL interactions, the authors (Xie et al., 2015, 2018) identified 17 physical and cognitive help-seeking situations. In this study, the researchers developed several help features to address the five critical help-seeking situations that are unique to BVI users in the previous user study.

First, the five critical help-seeking situations were selected according to the following criteria: (1) Unique situations that the sight-centered DL design has not addressed based on relevant literature; (2) Frequency of BVI users' help-seeking situations, which is measured as average frequency of help-seeking situations per task; (3) DL-oriented situations, or situations mainly caused by DL design, as opposed to situations resulting from an assistive technology component; and (4) Feasibility, where help modules associated with these situations can be built and implemented in the selected digital collection. The five situations selected based on the above criteria are: Difficulty accessing information, Difficulty evaluating information, Difficulty with help, Difficulty locating information or features, and Difficulty constructing or refining searches.

Second, the researchers implemented help features in "March on Milwaukee" (MoM)—a digital collection in the University of Wisconsin-Milwaukee (UWM) Digital Collections. Criteria for the selection of the digital collection include: (1) Contains content that may interest BVI users; (2) Contains multiple media formats or multimedia coverage of various topics; (3) Offers different types of help features; (4) Can be used as a testing collection with the number of collection items that are appropriate for the implementation of new help features. MoM is built in CONTENTdm, which is one of the most widely used digital collection management software in the United States and provides an open application programming interface (API). CONTENTdm APIs enable developers to easily customize the layout and integrate various features into the DL interface. Table 1 presents types of help features implemented into MoM.

Table 1
Types of help features and methods.

help feature type	Methods
Description	Provide added description or clear labels
Instruction	Provide instruction and context-sensitive help for features and webpages
Navigation	Improve ease of navigation and increase access points
Format	Modify text or spacing elements to eliminate confusion of screen reader interpretation
Search function	Enhance search functions or add new search features
Multimedia	Modify multimedia items (e.g., change start time of video to eliminate delay)

The MoM digital collection was revised based on two web frameworks for DLs, WordPress (https://wordpress.com/) and CONTENTdm (http://www.oclc.org/en-US/contentdm.html). New help features were designed by code revision, using the web administration tool, and open solution embedment. Figs. 1 and 2 present examples of implemented help features in the experimental version of MoM.

4.2. Sampling

The authors conducted a usability study with 40 BVI subjects in the United States, mainly in Wisconsin, featuring two separate groups of 20 BVI users each. Subjects at least 18-years of age were recruited from the Midwest. These subjects had as a minimum three years of experience in using a search engine with a (SR) and had basic information search skills to retrieve information from a DL. Purposive, convenience, and snowball strategies were applied for recruitment. To guarantee success in recruitment, the researchers worked closely with BVI-serving support organizations to recruit subjects. A pre-questionnaire was used to prescreen all subjects, ensuring both groups were comprised of similar demographic characteristics and information search skills. Forty subjects were divided into two groups with similar demographic data, system knowledge, and screen reader familiarity based on the data generated from the pre-questionnaires. The similarities of subjects' demographic characteristics between the control and experimental groups enabled researchers to compare the differences in usability of the DLs and their associated help features. Each subject was paid $75 as an incentive for participation in the study.

Gender distribution for the two groups are comparable. While the control group (n = 20) consisted of 65% males and 35% females, the experimental group (n = 20) was represented by 70% males and 30% females. Regarding age, the control group included a greater number of older subjects than the experimental group. 55% of the control group and 45% of the subjects were 50 years and older; 45% of the control group and 55% of the experimental group consisted of subjects between the ages of 18 to 49. Vision conditions for the two groups were slightly different: partially sighted (45%) and blind (55%) in the control group, and partially sighted (30%) and blind (70%) in the experimental group. As to frequency of use of the internet, both 95% of the control group subjects and 90% of the experimental group subjects reported "often" or "daily" use of the internet. 90% of the subjects in both groups reported intermediate or advanced search skill levels. Among these, the distribution revealed 50% intermediate and 40%

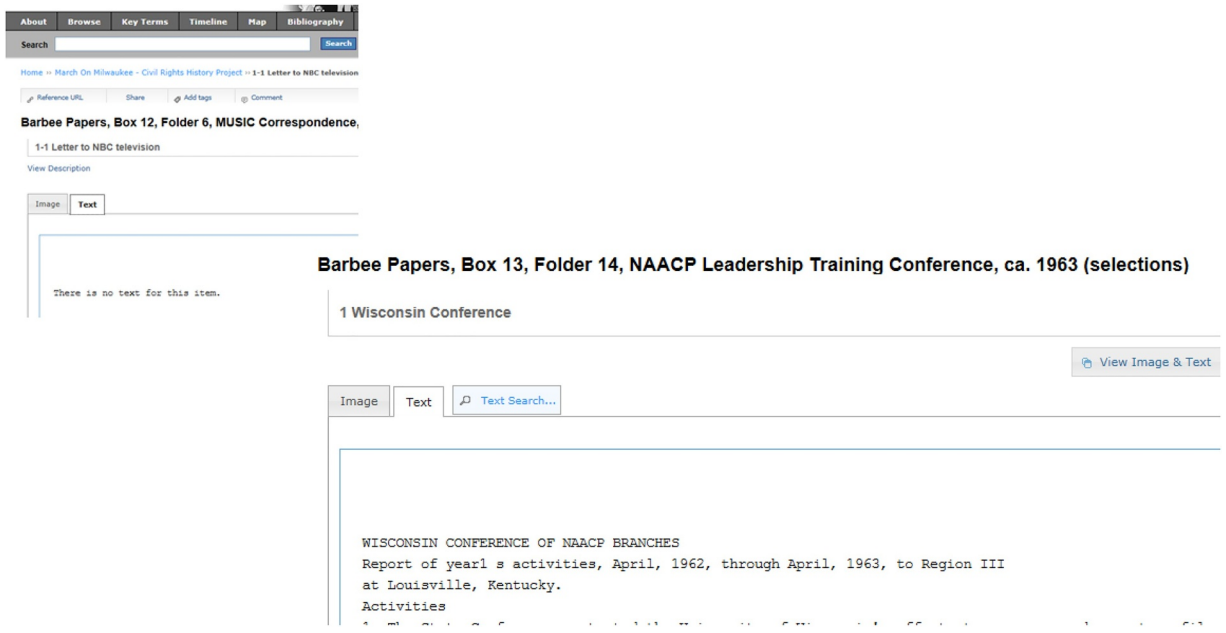

Fig. 1. Enabled transcript feature that provides text-based representation of the visual content.

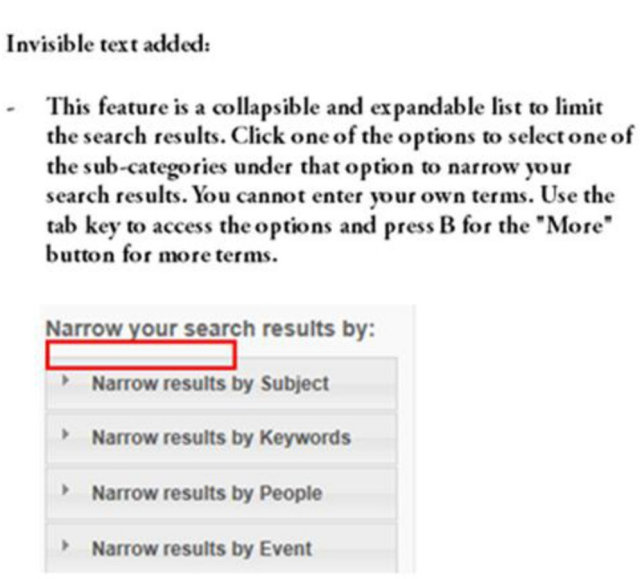

Fig. 2. Invisible description.

advanced users in the control group, compared to 70% intermediate and 20% advanced users in the experimental group. All subjects relied on SRs to access the DLs. All subjects, except one in the control group and one in the experimental group, were familiar with JAWS software. These two subjects mainly used other screen reader software, and they were offered the opportunity to practice using JAWS. They participated in the study after they felt comfortable using JAWS. The average familiarity with JAWS in the control and experimental groups was 5.16 and 5.05, respectively, on a 7-point Likert scale (1 = not at all familiar, 7 = extremely familiar), indicating they were familiar with JAWS. Subject knowledge between the two groups was also comparable for the three assigned tasks on a 7-point Likert scale (1 = not at all knowledgeable, 7 = extremely knowledgeable). Table 2 presents JAWS experience and prior subject knowledge of tasks as reported by subjects in the pre-questionnaire and pre-search interview.

4.3. Data collection methods and data analysis

The control group (n = 20) used the real digital collection equipped with existing help features, and the experimental group (n = 20) worked on the testing digital collection equipped with new help features. Subjects conducted three search tasks that BVI users typically perform, which represent known item search, specific information search, and exploratory search. These tasks help to reveal different types of help-seeking situations BVI users experience in their DL interactions. Here are the three tasks:

- *Known item search*: Find the clip with the speech of Martin Luther King Jr. at the University of Wisconsin-Milwaukee dated November 23, 1965 in two approaches: employ the browse approach and a keyword search to find the clip. Play the clip briefly to verify that the audio is the correct one.
- *Specific information search*: Identify at least two different events regarding housing discrimination in Milwaukee. What happened at these events? Name two key figures who fought against housing discrimination.
- *Exploratory search*: Find information about Vel Phillips' involvement with legislative issues. Please find as many items as possible from the DL as you can. Make sure each item either represents one distinct format or one distinct aspect of this search topic.

Multiple data collection methods including pre-questionnaires, think-aloud protocols, transaction logs, and pre and post search interviews, were employed in the experimental design. Pre-questionnaires were utilized to solicit subjects' demographic information,

Table 2
Subjects' JAWS experience and subject knowledge of tasks.

Subject	All	Control	Experimental	GAP (E-C)
Internet years (Year)	15.85	15.37	16.30	0.93
JAWS experience				
Familiarity (1 to 7)	5.10	5.16	5.05	−0.11
Subject Knowledge (1 to 7)				
Martin Luther (Task 1)	1.69	1.75	1.63	−0.12
Housing (Task 2)	2.53	2.40	2.65	0.25
Vel Phillips (Task 3)	1.75	1.60	1.90	0.30

Table 3
Research questions, associated data collection, and analysis.

Research questions	Data collection instruments	Data analysis methods
RQ1: Do the control and experimental groups encounter the same number of critical help-seeking situations when interacting with the baseline and the experimental versions of a DL?	Think-aloud protocol; transaction logs	Content analysis; Descriptive analysis; *t*-tests, non-parametric tests
RQ2: Do the control and experimental groups experience the same level of perceived usefulness of help features when interacting with the baseline and the experimental versions of a DL?	post-search interviews	Descriptive analysis; t-tests, non-parametric tests
RQ3: Do the control and experimental groups experience the same level of perceived ease of use when interacting with the baseline and the experimental versions of a DL?	post-search interviews	Descriptive analysis; t-tests, non-parametric tests
RQ4: Do the control and experimental groups share the same level of satisfaction when interacting with the baseline and the experimental versions of a DL?	post-search interviews	Descriptive analysis; t-tests, non-parametric tests

search and system knowledge, and assistive technology use. Pre-search interviews were conducted to obtain their levels of subject knowledge for each assigned task. Laptops with JAWS Screen Reader and Morae software were used for this study as JAWS is the most popular SR in the BVI community, and Morae software captures participant verbalization, screen shots, and transaction logs. Think-aloud protocols and transaction logs recorded subjects' behaviors and their thoughts behind these behaviors, including the help-seeking situations they encountered, the DL features used (or did not use), and user feedback on these features during the search process. Previous researchers have employed both Morae and screen readers in their studies and demonstrated that the Morae software does not interfere with JAWS (Francisco-Revilla & Crow, 2010; Rohani Ghahari, Ferati, Yang & Bolchini, 2012). Finally, post-search interviews solicited additional information regarding subjects' perceptions of ease of use of the DL, the usefulness of the help features, and satisfaction levels with the DL.

The researchers applied both quantitative and qualitative approaches to examine the proposed research questions and corresponding hypotheses. Table 3 presents the research questions, associated data collection instruments, and approaches for analysis. First, types of help-seeking situations were analyzed based on the coding scheme developed by the authors' previous work on help-seeking situations (Xie et al., 2018). The researchers performed content analysis to code and calculate frequency of each of the five types of help-seeking situations. Table 4 illustrates the five types of help-seeking situations and their definitions. Two independent coders analyzed these situations, selecting a random sample from the 40 subjects. Based on Holsti's (1969) formula, the inter-coder reliability of identified types of help-seeking situations between the two coders was 91.9%. The coders calculated the frequency of each type of help-seeking situation, and further applied these to the statistical analysis for hypotheses testing associated with research questions 1–4.

Following coding, the researchers analyzed collected data mainly quantitatively, using statistical analysis. Quantitatively, *t*-tests were applied to test the hypotheses associated with research questions 1–4. If the data did not show a normal distribution, the researchers applied the nonparametric test, Mann–Whitney *U*, to test the hypotheses.

5. Results

This section reports the results of four research questions and associated hypotheses in relation to the comparison of the number of help-seeking situations that the control and experimental groups encountered, their perceived DL ease of use, usefulness of help features, and DL satisfaction levels. The findings of this study show that the control and experimental groups did not encounter the same number of help-seeking situations across all situations (Table 5) when interacting with the baseline and the experimental versions of a DL. The experimental group encountered significantly fewer number of help-seeking situations than the control group for Difficulty accessing information and Difficulty with help. There were no significant differences between the two groups in terms of the number of help-seeking situations faced related to Difficulty evaluating information, Difficulty locating information or features, and Difficulty constructing or refining searches. Simultaneously, the experimental group outperformed the control group for perceived usefulness of the DL features, ease of use of the DL, and DL satisfaction.

Table 4
Coding scheme for the five types of help-seeking situations.

Types of help-seeking situations	Definition
Difficulty accessing information	Problems related to detecting, or recognizing, item(s).
Difficulty evaluating Information	Difficulty making sense of search results, collections, or subject organization criteria; difficulty understanding the relevance of search results, or identifying relevant collections or subjects.
Difficulty with help	Difficulty understanding labels; problems understanding how to use a specific function; inability to understand help information.
Difficulty locating information	Difficulty finding specific information, type or format of an item, or features.
Difficulty constructing or reformulating searches	Difficulty formulating and reformulating search queries.

Table 5
Number of help-seeking situations in C and E groups.

Types of help-seeking situations	Control	Experimental	Difference
Difficulty accessing information	113	65	48
Difficulty evaluating information	74	72	2
Difficulty with help	112	63	49
Difficulty locating specific information, items or features	110	98	12
Difficulty constructing or refining search statements	56	55	1
Total	465	353	112

When comparing the number of help-seeking situations in the control and experimental groups for H1.1, a Shapiro-Wilk test was first applied to check for normality for the two groups related to Difficulty accessing information. The data was normally distributed across both groups (control, $p = .213$, $p > .05$; experimental, $p = .106$, $p > .5$).

An independent-samples *t*-test was conducted to test for differences between the control and experimental groups. According to Table 6, there is a significant difference in the number of help-seeking situations associated with Difficulty accessing information between the control group ($M = 5.65$, $SD = 3.911$) and experimental group ($M = 3.25$, $SD = 2.359$), ($t = 2.35$, $p = .025$, $p < .05$). The experimental group encountered fewer help-seeking situations associated with Difficulty accessing information than the control group. Hypothesis H1.1 was rejected.

For H1.2, a Shapiro-Wilk test was applied to check for normality for the two groups related to Difficulty evaluating information. The data was normally distributed across both groups (control, $p = .304$, $p > .05$; experimental, $p = .279$, $p > .5$).

An independent-samples *t*-test was conducted to test for differences between the control and experimental groups. According to Table 7, there is no significant difference in the number of help-seeking situations associated with Difficulty evaluating information for the control group ($M = 3.7$, $SD = 1.895$) and experimental group ($M = 3.6$, $SD = 2.521$), ($t = 0.142$, $p = .888$, $p > .05$). We fail to reject Hypothesis H1.2.

For H1.3, a Shapiro-Wilk test was applied to check for normality for the two groups related to Difficulty with help. The data for the control group was normal ($p = .185$, $p > .05$), but the data for the experimental group was not normally distributed ($p = .037$, $p < .5$).

A Mann-Whitney test was conducted to test for differences between the control and experimental groups, and results (Table 8) indicated that the number of help-seeking situations associated with Difficulty with help was significantly greater for the control group (Mdn = 5.5) than the experimental group (Mdn = 2.5), $U = 125$, $p = .041$. Hypothesis H1.3 was rejected.

For H1.4, A Shapiro-Wilk test was applied to check for normality for the two groups related to Difficulty locating specific information, items or features. The data for the control group was not normally distributed ($p = .010$, $p < .05$), but the experimental group was normal ($p = .126$, $p > .5$).

A Mann-Whitney test was conducted to test for differences between the control and experimental groups, and the results (Table 9) indicated that the number of help-seeking situations that participants encountered associated with Difficulty locating specific information, items or features was not significantly greater for the control group (Mdn = 5) compared to the experimental group (Mdn = 5.5), $U = 194.0$, $p = .870$. We fail to reject Hypothesis H1.4.

For H1.5, a Shapiro-Wilk test was applied to check for normality for the two groups related to Difficulty constructing or refining searches. The data was normally distributed across both groups (control, $p = .104$, $p > .05$; experimental, $p = .274$, $p > .5$).

An independent-samples *t*-test was conducted to test for differences between the control and experimental groups. According to Table 10, there is no significant difference in the number of help-seeking situations associated with Difficulty constructing information for the control group ($M = 2.8$, $SD = 1.322$) and experimental group ($M = 2.75$, $SD = 1.410$), ($t = 0.116$, $p = .908$, $p > .05$). We fail to reject Hypothesis H1.5.

For 2.1, a Shapiro-Wilk test was applied to check for normality of the usefulness of help features. The data for the control group was normal ($p = .973$, $p > .05$), but the experimental group was not normally distributed ($p = .035$, $p < .5$).

A Mann-Whitney test was conducted to test for differences between the control and experimental groups, and the result (Table 11) indicated that the median number of perceived usefulness levels of help features was significantly greater for the experimental group (Mdn = 4.69) when compared to the control group (Mdn = 3.64), $U = 94$, $p = .004$. Hypothesis H2.1 was rejected.

For H3.1. A Shapiro-Wilk test was applied to check for normality of the ease of use of DLs. The control data for the group was normal ($p = .174$, $p > .05$), but the experimental group data was not normally distributed ($p = .033$, $p < .5$).

A Mann-Whitney test (Table 12) was performed to test for differences between the control and experimental groups, and result indicated that the perceived ease of use levels were significantly greater for the experimental group (Mdn = 5) when compared to the

Table 6
T-test results for number of help-seeking situations associated with Difficulty accessing information between C and E groups.

Situation	Group	*N*	Mean	SD	*t* (df); *p* value
Difficulty Accessing Information	Control	20	5.65	3.911	2.35 (38); 0.025
	Experimental	20	3.25	2.359	

Table 7
T-test results for number of help-seeking situations associated with difficulty evaluating information between C and E groups.

Situation	Group	*N*	Mean	SD	*t* (df); *p* value
Difficulty evaluation information	Control	20	3.7	1.895	.142 (38); 0.888
	Experimental	20	3.6	2.521	

Table 8
Mann-Whitney test results for number of help-seeking situations associated with difficulty with help between C and E groups.

Situation	Group	*N*	Mean rank	Sum of ranks	Mann-Whitney *U*	*p* value
Difficulty with Help	Control	20	24.25	485.00	125.000	.041
	Experimental	20	16.75	335.00		
	Total	40				

Table 9
Mann-Whitney test results for number of help-seeking situations associated with difficulty locating specific information, items or features between C and E groups.

Situation	Group	*N*	Mean rank	Sum of ranks	Mann-Whitney *U*	*p* value
Difficulty with Locating	Control	20	20.20	404.00	194.000	.870
	Experimental	20	20.80	416.00		
	Total	40				

Table 10
T-test results for number of help-seeking situations associated with Difficulty constructing information between C and E groups.

Situation	Group	*N*	Mean	SD	*t* (df); *p* value
Difficulty constructing information	Control	20	2.8	1.322	.116 (38); 0.908
	Experimental	20	2.75	1.410	

Table 11
Mann-Whitney test results for perception of usefulness levels of help features by the C and E groups.

Perception	Group	*N*	Mean rank	Sum of ranks	Mann-Whitney *U*	*p* value
Usefulness	Control	20	15.20	304.00	94.000	.004
	Experimental	20	25.80	516.00		
	Total	40				

Table 12
Mann-Whitney test results for perception of ease of use levels by C and E groups.

Perception	Group	*N*	Mean rank	Sum of ranks	Mann-Whitney *U*	*p* value
Ease of Use	Control	20	16.80	336.00	126.000	.039
	Experimental	20	24.20	484.00		
	Total	40				

control group (Mdn = 4), $U = 126$, $p = .039$. Hypothesis H3.1 was rejected.

A Shapiro-Wilk test was applied to check for satisfaction levels. The data was normally distributed for both groups (control, $p = .262$, $p > .05$; experimental, $p = .063$, $p > .5$).

An independent-samples *t*-test was applied to compare the perceived satisfaction levels between the control and experimental

Table 13
T-test results of the perception of satisfaction levels by the control and experimental groups.

Situation	Group	*N*	Mean	SD	*t* (df); *p*-value
Satisfaction	Control	20	4.15	1.387	−2.031(38); 0.049
	Experimental	20	5.00	1.257	

groups. According to Table 13, the satisfaction levels for the experimental group ($M = 5.00$, $SD = 1.257$) was significantly higher than the control group ($M = 4.15$, $SD = 1.387$), ($t = -2.031$, $p < .049$). Hypothesis H4.1 was rejected.

6. Discussion

Prior research suggests that social and cultural structures and conditions in digital environments can constrain or fail to accommodate needs of BVI users (Walters, 2010). Consequently, BVI users do not receive adequate interaction support in such environments (Borodin et al., 2010; Brophy & Craven, 2007; Craven, 2004; Kumar & Sanaman, 2013; 2015; Lazar et al., 2007; Power et al., 2012; Rømen & Svanæs, 2012; Vigo & Harper, 2014). Our study shows the vulnerability of BVI users in DL environments is largely because existing DL designs do not adequately support these users' different abilities in their interactions with DL content and features. This study echoes previous study findings that DL features are not designed with the needs of the BVI in mind (Xie et al., 2015, 2018), and the results demonstrate that current DL design has not taken into the consideration of BVI's help-seeking situations based on the comparison of the number of help-seeking situations met by users in the control and experimental groups. In this study, a greater number of help-seeking situations occurred in the baseline version of a DL when compared to an experimental version with added help features. Users' satisfaction levels in using the DL—particularly the original DL—is another indication that social barriers are at play in DL design. It is, therefore, imperative that both researchers and designers accurately understand the social barriers that give rise to help-seeking situations created by specific elements of the DL environment to fully account for the accessibility and usability problems in the interface design.

Existing research reveals that DL accessibility and usability requires interface design that addresses social and environmental factors that lead to barriers in BVI users' effective information retrieval (Brebner & Parkinson, 2006). This paper innovatively addresses the critical issue of DLs by incorporating help features in DLs designed specifically for BVI users. A majority of research has focused on the constraints that BVI users face in other types of web environments (Damaceno et al., 2018; Ho et al., 2017; Wentz & Lazar; 2011) or usability studies addressing the needs of sighted users (Jeng, 2005; Joo, 2010; Liu & Luo, 2011; Masrek & Khan, 2015; Matusiak, 2012), but has not explicitly addressed help-seeking situations that BVI users encounter when interacting with DLs. Results of this study demonstrate that this social barrier could be remedied if DL interfaces are designed to address the unique help-seeking situations experienced by BVI users in IR tasks through the implementation of help features. This is indicated by the fact that when BVI participants interacted with the DL equipped with properly designed help features, they experienced fewer help-seeking situations as compared to those who used that DL equipped with improperly designed help features. The higher level of satisfaction reported by the experimental group regarding DL use compared to the control group is the second indication. The higher level of perceived usefulness associated with new DL features compared to existing DL features is the third indication. Hence, we argue that DL researchers and designers need to adopt the social model perspective in providing interaction support to SR users and create a barrier-free DL environment.

Our results also show the feasibility of designing DL features that serve the unique needs of BVI users for specific IR tasks. It proves that a careful examination of the DL interaction experiences of BVI users affords a deep understanding of their help-seeking situations in their information search process. Analysis of these situations reveals what system help is needed to retrieve information by listening to SR renditions. This confirms the findings of previous research which reveals that many situations BVI users face in using the web are due to poor usability, creating obstacles during their IR system interactions (Power et al., 2012; Rømen & Svanæs, 2012; Vigo & Harper, 2013, 2014). In turn, this research allows the authors to define the function and placement of help features offering description, instruction, navigation, format, search function and multimedia required to address the need.

Our analysis uncovered several examples:

- *Menu bar (Feature: Navigation; Situation: Difficulty with help):* To launch their DL interaction, BVI users need immediate help about how to proceed. Considering this need, we designed a menu bar with the Help Menu as its first item and placed this menu bar at the top of the page (the location where the screen-reader focus typically lands after arriving on a new web page).
- *Labels (Feature: Description; Situation: Multiple situations):* It is noted that to recognize the available functions of the DL, BVI users rely on the meaningfulness of labels for individual menu items. Accordingly, when assigning labels to the items in the top menu bar, we made sure each label unambiguously described the purpose of the relevant menu item.
- *Transcript (Feature: Description/Format; Situation: Difficulty accessing information):* To access information embedded in documents, including images, BVI users need the capability to transcribe the embedded content into descriptive text. Accordingly, the transcription functionality of the content management system was enabled, thereby offering a Transcript feature in the DL.
- *Search results (Feature: Navigation; Situations: Difficulty locating information and difficulty evaluating information):* To tell what the outcome of a search query was, BVI users need direct access to the text describing its status (e.g., whether search results were generated or altered). Correspondingly, two features were created. First, a title was added to the search results section describing the status of the executed search. Second, a heading marker was added to this title to enable section header navigation.
- *Item (Feature: Navigation/Description; Situation: Difficulty locating information):* To determine if a searched item is immediately available or reachable, BVI users need step-by-step directions to locate that item in the DL. Consequently, three features were incorporated into the DL. First, a breadcrumb was added, indicating the path to the searched item. Second, meaningful labels were assigned to each breadcrumb element. Finally, a hyperlink was embedded in each breadcrumb element to lead to the destination page.

Most important, the results demonstrate that users encounter fewer difficulties when interacting with a DL equipped with help

features than one whose features do not take into account their specific needs. The findings strongly support this finding in two types of help-seeking situations: (1) accessing DL information, and (2) using system help. BVI participants who interacted with the experimental DL interface reported significantly fewer help-seeking situations when attempting to complete tasks relevant to information access and help use compared to those who used the baseline DL. At the same time, the authors observed a positive difference in the frequencies of the three types of help-seeking situations between the experimental and controlled conditions (e.g., evaluating information, locating specific information, items, or features, and constructing or refining search statements). Ultimately, these differences were not significant, pointing to possible inadequacies in the design of features to address the help needs identified and confirming that the authors need to return to the drawing board and redesign the features after analyzing qualitative feedback provided by BVI subjects. Nevertheless, the results of our analysis establish that DL usability is positively impacted by the degree of alignment between help features and help needs of this vulnerable population.

Interestingly, this study also identified a crucial problem in designing DLs for universal use. Just as previous research has pointed out that linear nature of SR navigation and information architecture elicit problems for BVI users in navigating web interfaces (Borodin et al., 2010; Brophy & Craven, 2007; Lazar et al., 2007; Vigo & Harper, 2014), this problem also exists in DL design and needs to be addressed. Nevertheless, some of the newly added features that benefit BVI users might cause confusion for sighted users. For example, BVI users have to rely on a SR to navigate the interface. Before they can access the search results, they may have to listen to additional irrelevant information. In order to help BVI users quickly locate the first search result, a feature labeled as “Skip to first search result” was incorporated into the interface design. However, sighted users do not need this feature since they can quickly identify the location of the search results, and this new feature may cause added confusion. For this reason, the research team decided to make this feature visible to SRs, but invisible for sighted users. The same design principles also apply to “Skip to event details” and “Return to thumbnail” for the DL timeline browser. The invisible feature design demonstrates an effective approach for DL design to satisfy the needs of both sighted and BVI users.

To truly promote universal access to information, DL designers should endeavor to remove barriers that prevent users from accessing information, rather than expect those with impairments to adapt their behaviors to overcome such barriers (Brebner & Parkinson, 2006). At the same time, we continue to work on understanding the barriers these users face as we strive towards a more inclusive design and equitable society.

7. Conclusion and future research

To the best of the authors' knowledge, this is the first research linking help-seeking situations of BVI in digital environments to the usefulness of help features offered. Moreover, it shows how to tailor the help features of a DL in line with the needs of BVI information seekers, and further test the usability of an experimental interface equipped with the new features compared to a baseline DL interface. The social barriers are created by the DL environment—a combination of structural complexity, use of multimedia, and non-standard nature of design compounds the difficulties of using DLs non-visually—thereby making BVI users extremely vulnerable in DL environments. With the volume of information being collected and disseminated through DLs increasingly on the rise, it is imperative that DLs are designed to be inclusive of BVI users by providing features tailored to their needs. This study makes both theoretical and practical contributions to the field of library and information science. Its theoretical contribution is a broad understanding of the experience of BVI users in retrieving information from a DL. Its practical contribution is related to how to design help features that are actually useful in reducing help-seeking situations BVI users typically face. Its approach can also be applied to investigate how to design DLs to satisfy the needs of other types of vulnerable communities as well. This exploratory research serves as the first stage of an iterative process that will offer new insights on how to develop appropriate and useful help features for BVI users dealing with different types of situations.

This research also has several limitations: first, this study is based on 40 BVI users’ interactions with two versions of a DL, and its results cannot be generalized to all DLs. More research is needed to involve more DLs and more BVI users. The research team will continue to enhance the design of DL help features involving more studies incorporating multiple DLs and diverse BVI users. Moreover, the research team is creating DL design guidelines that offer specific design principles and features for DL developers to support BVI users. Second, this study mainly focuses on BVI users’ help-seeking situations. For DLs to become the gateway to the universal access to information, it is essential to implement help features that meet the needs of both BVI and sighted users. Additional research that helps us better understand the impact of accessible and usable infrastructure design for both sighted and BVI users of DLs is a vital next step.

Third, this study only focuses on BVI users’ interactions with computers even though several subjects stated that they were frequent users of mobile devices. Mobile devices are emerging as a trend for BVI users to quickly and efficiently access information; therefore, the next step for future research that supports knowledge discovery in the 21st century will include user studies exploring BVI and sighted users’ help-seeking behaviors while interacting with DLs on mobile devices, offering further design implications.

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