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# Blind and Visually Impaired Users' Interactions with Digital Libraries: Help-Seeking Situations in Mobile and Desktop Environments

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**ABSTRACT**

With the goal of developing information retrieval (IR) systems, including digital libraries (DLs), that support universal access, the authors conducted two studies to identify the help-seeking situations that blind and visually impaired (BVI) users encountered in DLs. First, the authors quantitatively compared BVI users' help-seeking situations when interacting with the DL's mobile website (M.Web) and the mobile app (M.App). Using multiple data collection methods, the mobile study identified six situations BVI users faced more frequently when using M.Web than M.App. Second, the findings of the mobile study were qualitatively compared with the situations that occurred in the desktop environment, highlighting eight unique situations. It is more difficult for BVI users to interact with DLs in the mobile environment because of the reduced size of the mobile interface, complex DL structures, dynamic elements, diverse formats, and sight-centered design. Specific design recommendations were offered to enhance DLs in the mobile environment.

**KEYWORDS**

Digital libraries; blind and visually impaired users; help-seeking situations; mobile website; mobile application; desktop environment

## 1. Introduction

This study is motivated by the belief that 24 million blind and visually impaired (BVI) Americans (El, 2022) cannot effectively access and use digital libraries (DLs) and that they encounter diverse help-seeking situations due to sight-centered and complex designs of DLs in mobile contexts. Generally speaking, BVI people include those with different degrees of visual impairments (e.g., blindness, severe visual impairments, moderate visual impairments, and mild visual impairments) (Vaz et al., 2020). This study defines BVI users based on their unique way of interacting with devices. BVI users specifically refer to blind or severely visually impaired people who must rely on screen reader software to interact with different types of devices (e.g., desktops, laptops, and mobile phones) non-visually. DLs have become important online information resources for BVI users. A DL, as one type of information retrieval (IR) system, provides collections of digitized or born-digital items to satisfy the information needs of all kinds of users, including BVI users (Li & Liu, 2019; Xie & Matusiak, 2016). Due to the complexity of DL design and BVI users' unique interaction approach, BVI users confront different types of help-seeking situations; these are defined as problems that BVI users face in their interactions with DLs, requiring system help to accomplish specific tasks or goals. For example, BVI users may face accessibility-related situations, usability-related situations, and compatibility-related situations (Xie et al., 2015, 2018a, 2018b, 2021a, 2021b).

Help-seeking situations signify not only the problems that BVI users must overcome but also the types of DL designs that BVI users expect systems to offer. Compared with other types of IR systems, DLs have unique structural characteristics. Unlike search engines with straightforward search methods and simple interface design, DL designs are more complicated, consisting of layered navigation to reach individual items through searching the DL, browsing diverse categories, checking featured digital collections, etc. Moreover, DL materials are organized at both the collection-level and the item-level, and they are often mixed in the presented results. In terms of features, on the one hand, DLs have comprehensive browsing categories with multiple metadata-based filters that other types of IR systems do not have. On the other hand, DLs are not equipped with adequate search mechanisms to generate highly relevant results compared to some other IR systems. In terms of content, DLs contain items with diverse content formats (e.g., scanned documents of text without OCR, images, audio files, and video files) (Xie & Matusiak, 2016). These characteristics create challenges for BVI users because of their non-visual and linear interaction approach to using IR systems (Babu & Xie, 2017; Kuzma & Moscicka, 2018; Xie et al., 2021a, 2021b). Without research on BVI users' unique help-seeking situations, DLs cannot be designed to satisfy the needs of BVI users.

Recently, mobile devices have become increasingly popular among the BVI. The number of people with disabilities, of which the majority are BVI users, who utilize mobile devices via screen readers, has increased dramatically from 12% in 2009 to 90% in 2021 (WebAIM, 2021). In the mobile environment, BVI users can access information either using

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a mobile website (M.Web) or a mobile app (M.App). An M.Web is accessible via mobile browsers, while an M.App is developed for mobile environments and is used after being installed on a mobile device (Guerreiro et al., 2019; Marcotte, 2017; Zhang et al., 2017). Both BVI users and users in general found more problems in M.Web than in M.App when performing common tasks (Carvalho et al., 2018; Othman, 2021).

Researchers have examined different types of help-seeking situations that BVI users encounter in the mobile environment (Alajarmeh, 2022; Carvalho et al., 2018; Mateus et al., 2020; Nicolau et al., 2015) and in the desktop environment (Berget & MacFarlane, 2020; Borodin et al., 2010; Giraud et al., 2018; Power et al., 2012; Vigo & Harper, 2013). However, there is a lack of research on BVI users in adapting to technologies, which leads to poor user experience (Kim, 2021). In particular, existing research has not yet examined the help-seeking situations that BVI users face when interacting with DLs in the mobile environment.

The recognition of diverse help-seeking situations that BVI users experience in the DL environment and the lack of research on BVI users' help-seeking situations in mobile DL contexts has highlighted the need for an in-depth investigation. Therefore, this study aims to provide both quantitative and qualitative evidence about BVI users' help-seeking situations in both mobile and desktop DL environments. Specifically, the current study has significance in both theory and practice. Theoretically, this study helps identify and compare BVI users' help-seeking situations, contributing to an in-depth understanding of BVI users' problems in interacting with DLs. Practically, this study provides design recommendations for developing accessible and usable DLs for BVI users.

This study addresses the following research questions (RQs).

RQ1. Are there significant differences in the frequency of help-seeking situations encountered by BVI users when interacting with a DL using its M.Web vs. its M.App?
H0: There is no significant difference in the frequency of help-seeking situations between the M.Web and the M.App of a DL.
RQ2. What are the unique help-seeking situations BVI users encounter when using DLs in the mobile environment compared to the desktop environment?

This article is organized into five main sections, the first being the literature review section addressing previous research related to BVI help-seeking situations in mobile and desktop environments. The second section presents the research methodology for sampling, data collection, and analysis. In the third section, the article reports the findings of the research questions highlighting similarities and differences between the two mobile platforms and mobile and desktop environments. The fourth section discusses the theoretical implications and the design recommendations to support BVI users' interaction with mobile DLs. Finally, the article concludes by addressing the significance and limitations of the study as well as future research in enhancing DL accessibility tailored to BVI users' needs.

## 2. Literature review

### 2.1. BVI help-seeking situations in mobile environments

BVI users encounter various help-seeking situations when using mobile devices (e.g., mobile phones and mobile tablets). Some studies focus on situations BVI users face when interacting with mobile devices in general, and some examine situations when BVI users interact with M.Web and M.App.

Difficulty accessing information objects is a significant accessibility situation for BVI users. According to Carvalho et al. (2018), the lack of alternative text for images was one of the most frequent problems that blind users encountered when using M.Web and M.App. Similarly, Alajarmeh (2022) found that difficulty accessing visual media occurred for BVI users on both M.Web and M.App due to a lack of text or audio descriptions. Focusing on M.App, Park et al. (2014) found that BVI users could not read selected items or images when using certain M.Apps. In addition, BVI users may have difficulty reading PDF files (Al-Mouh & Al-Khalifa, 2015), and they expect smartphones to have features that describe colors and images (Abraham et al., 2022).

Difficulty providing or editing input also impairs BVI users' interactions with mobile devices. Research shows that BVI users suffer in efficiency, speed, and accuracy when typing using keyboards on mobile devices (Grussenmeyer & Folmer, 2017; Mi et al., 2014; Nicolau et al., 2015; Oliveira et al., 2011; Rodrigues et al., 2020). Specifically, Nicolau et al. (2015) found that blind users had difficulty reaching the intended keys, especially those far from the physical screen edges of smartphones. Mi et al. (2014) noted that difficulty understanding how and where to type was also a problem for BVI users. According to Rodrigues et al. (2020), blind users also found that "Changing written text is hard" (p. 1613).

Different types of design elements (e.g., buttons, labels, and headings) are incorporated into M.Webs and M.Apps. Difficulty identifying a button was among the most frequent problems for blind users in the mobile environment (Carvalho et al., 2018). Some studies specifically focus on M.Apps. For example, Al-Mouh and Al-Khalifa (2015) found that buttons of applications could not be recognized by screen readers. Moreover, Ross et al. (2018) pointed out accessibility issues of image-based buttons (i.e., clickable images, image buttons, and floating action buttons), including missing, duplicate, and uninformative labels. Additionally, BVI users had difficulty accessing or interacting with buttons because of unreadable button names and non-clickable buttons (Park et al., 2014). Labeling problems have been found on both M.Web and M.App (Alajarmeh, 2022; Carvalho et al., 2018). Mateus et al. (2020) noticed that difficulty accessing and using headings and labels was the most common problem unique to users with visual impairment when using M.Apps. In a study evaluating the accessibility of an M.App for banking and financial services, blind users reported the issue of improper or missing labels (Wentz et al., 2017).

Difficulty with navigation could occur on both M.Web and M.App (Alajarmeh, 2022; Carvalho et al., 2018). For example, Rodrigues et al. (2020) found that blind users often got lost when using M.App. To better navigate, BVI users prefer to have more "intuitive navigational cues" when using mobile devices (Mi et al., 2014, p. 359). Research shows that BVI users' difficulty navigating on M.App or M.Web may be related to the unusefulness of navigation elements, overlapping app or system controls, and illogical focus sequence (Buzzi et al., 2013; Carvalho et al., 2018; Mateus et al., 2020; Park et al., 2014). For example, Park et al. (2014) found that an illogical focus sequence hindered BVI users' navigation of M.Apps. Some missing elements (e.g., a "home" or back button) could also affect BVI users' experience with M.App and M.Web (Alajarmeh, 2022).

BVI users need to rely on different features to complete their tasks. However, it often occurs that they have difficulty with features. For example, Abraham et al. (2022) found that BVI users may be unaware of the functionality of smartphones when using M.Web or M.App. Carvalho et al. (2018) also found that blind users had difficulty inferring the existence of functionalities due to inappropriate presentation of elements (Carvalho et al., 2018). In addition, a lack of features was also a problem for BVI users, such as missing zooming features or search options (Abraham et al., 2022; Al-Mouh & Al-Khalifa, 2015).

Blind users also feel overwhelmed if there is too much information on one page when using mobile devices (Carvalho et al., 2018). In addition to avoiding displaying excessive information on each page, it is also important for M.App to have consistent interfaces and simple structures (Park et al., 2014). According to Carvalho et al. (2018), inadequate feedback was the most common problem for blind users when using M.App and M.Web. In addition, BVI users might encounter compatibility issues with assistive technologies when using M.App and M.Web (Alajarmeh, 2022; Carvalho et al., 2018).

### 2.2. BVI users' help-seeking situations in desktop environments

In desktop environments, researchers have found that BVI users have trouble accessing information. For example, Uckun et al. (2020) pointed out that blind people had difficulty accessing PDF forms. Also, BVI users have difficulty accessing images without alternative text (Vigo & Harper, 2013) because they rely on textual descriptions (e.g., alternative text) to access images (Kuppusamy, 2018). Power et al. (2012) identified different types of accessibility situations based on task-based user evaluations, such as difficulty scanning pages for specific items and difficulty accessing heading structure. Borodin et al. (2010) noted that screen reader users might have trouble accessing information because of complex web pages and dynamic and automatically refreshing content. It is also worth noting that visually impaired users are likely to have difficulty finding search buttons and search results when conducting their searches (Lunn et al., 2011).

BVI users encounter other difficult situations, such as confusion, disorientation, cognitive overload, and compatibility issues. For example, researchers have found that BVI users encounter confusion about feedback, headings, and features in their interactions with IR systems because of issues like confusing feedback from screen readers, unexpected content, and unfamiliar features (Lazar et al., 2007; Vigo & Harper, 2013). Specifically, Rømen and Svanæs (2012) revealed that one of the common situations for BVI users is heading confusion, such as "text and links that start with the same letter and almost read the same," "links with identical spelling that point to different targets," and "redundant links" (p. 382). Another common situation is getting disoriented on webpages where BVI users have difficulty determining their current location (Lunn et al., 2011; Saqr, 2016; Vigo & Harper, 2013). There are also situations specifically associated with information overload when users have limited time to effectively use information in certain situations (Savolainen, 2007). Giraud et al. (2018) stressed that blind users have difficulty with redundant and irrelevant information, which might prevent them from effectively finding relevant information. For BVI users, the use of screen readers seems to demand additional cognitive effort to hear repeated information and process information in small chunks when they are trying to understand the entire page (Chandrashekar et al., 2006).

In recent years, scholars have also paid attention to help-seeking situations that BVI users encounter in DL environments (Xie et al., 2015, 2018a, 2018b, 2021a, 2021b). Research shows that BVI users confront accessibility-related situations (e.g., difficulty locating or accessing information related to visual items or difficulty accessing the content of a scanned document), usability-related situations (e.g., confusion about digital library structure or browse categories, difficulty understanding results structure or layout), and compatibility-related situations.

### 2.3. Comparison studies involving different digital platforms

There have been studies comparing M.Web and M.App from sighted users' perspectives. For example, Othman (2021) found that users preferred M.App when pursuing common activities, such as using social media, e-mail, and games. Moreover, most users considered M.App faster, easier to use, more convenient, more user-friendly, and more reliable than M.Web, indicating that M.App generally outperformed M.Web in terms of usability. Tupikovskaja-Omovie et al., (2015) focused on fashion consumers' interactions with the M.Web and M.App of Topshop. They found that the most common difficulties for users on the M.App were small pictures in search results, unavailable color options, and difficult-to-find zoom-in options, while slow loading was the most frequent issue on the M.Web.

However, little research has compared the accessibility and usability of M.App and M.Web from BVI users' perspectives. Carvalho et al. (2018) examined the accessibility problems faced by blind and sighted users when using the M.Web and M.App of four websites. They found that blind users encountered more accessibility problems on both platforms than sighted users; furthermore, more problems were reported on M.Web than on M.App for both blind and sighted user groups. Similarly, Alajarmeh (2022) focused on accessibility problems encountered by BVI users when using M.Web and M.App. In total, he identified 34 problems related to input, interaction, content rendering, content organization, output, and feedback. Notably, most of the identified problems existed on both M.Web and M.App, except for a few problems unique to M.App (e.g., inoperative controls and missing search options).

In other mobile platform comparisons, some researchers have compared accessibility and usability issues in desktop and mobile environments. Wong (2012) compared the usage patterns of an M.App and its desktop counterpart for an official video site provided by a library, finding that both versions had similar view counts on a daily basis. Hasan (2018) compared the usability problems of a learning management system's desktop and mobile interfaces based on questionnaire results from student users. In total, 17 usability problems were identified, including 11 issues common to both platforms, four unique to the desktop platform and two unique to the mobile platform. Specifically, she pointed out two unique issues of the mobile interface: inappropriate or small font size and reduced readability due to the small screen size. Besides the screen size issue, Vatavu (2017) emphasized user interface design also affects mobile touch screen interactions.

## 3. Methodology

This article presents the data mainly collected from the study conducted in the mobile environment. To highlight the unique help-seeking situations, the findings were also compared to the results from the study performed in the desktop environment. The mobile study lasted for approximately twelve months, including four months of data collection. The desktop study took about 18 months, including ten months of data collection.

### 3.1. Sampling

For the mobile study, 30 BVI participants were recruited across the United States via the National Federation of the Blind (NFB). Potential participants were required to meet the following criteria: at least 18 years old, having an iPhone 6S (or newer) with iOS 11 (or later), using an iPhone non-visually by VoiceOver, searching for information on the Internet via iPhone for at least three years, verbalizing thoughts comfortably in English, and being willing to install the online meeting software (Microsoft Teams) and Library of Congress Digital Collections (LOCDC) app. The study chose to focus only on iPhone users because iOS devices are the most widely used (79.1%) by people with disabilities (WebAIM, 2021). Participants who completed a brief pre-screening questionnaire and met the requirements received an informed consent form before joining the study.

**Table 1.** Demographic data.

| Category | Sub-category | Mobile (n = 30) Percentage | Desktop (n = 64) Percentage |
|---|---|---|---|
| Age | 18–29 | 16.7 | 20.3 |
| | 30–39 | 30.0 | 15.6 |
| | 40–49 | 26.7 | 21.9 |
| | 50–59 | 13.3 | 17.2 |
| | >59 | 13.3 | 25.0 |
| Gender | Male | 50.0 | 46.0 |
| | Female | 50.0 | 54.0 |
| Information search skills | Beginner | 0.0 | 3.3 |
| | Intermediate | 10.0 | 44.3 |
| | Advanced | 63.3 | 50.8 |
| | Expert | 26.7 | 1.6 |
| Vision condition | Blindness (B) | 80.0 | 78.3 |
| | Severe visual impairment (SVI) | 20.0 | 21.7 |

For the desktop study, 64 BVI participants were recruited through NFB. Potential participants were required to meet the following criteria: at least 18 years old, using a screen reader as their primary access method, at least three years of Internet searching experience, and verbalizing thoughts comfortably in English. Participants who completed a brief pre-screening questionnaire and met the requirements received an informed consent form before joining the study. Thirty-two participants participated in the study onsite, while the other 32 participated offsite via diaries. Table 1 shows the demographic data of the participants of the two studies. In this study, VI users are severely visually impaired and must rely on screen readers to interact with DLs, just like blind users. Therefore, both blind and VI users are considered as one group of participants.

### 3.2. Data collection methods

Figure 1 presents the multiple data collection methods and procedures used in the two studies. For both studies, the researchers conducted interviews to obtain the participants' perceptions and opinions (Flick, 2019). Interviews at different stages helped the researchers collect BVI participants' responses to research questions and address BVI participants' potential difficulties when filling out questionnaires. Participants performed three diverse types of tasks: an orientation task, a specific information search task, and an exploratory search task (Figure 2). Think-aloud protocols and transaction logs were used to record BVI participants' thoughts and movements while working on the tasks (Xie et al., 2020, 2021b). Participants' interviews, think-aloud protocols, and transaction logs were recorded using Microsoft Teams in the mobile study and Morae in the computer study. All recorded audio and video files were transcribed verbatim for further analysis.

In the mobile study, LOCDC was selected because it is a national DL that provides both M.App (https://apps.apple.com/us/app/loc-collections/id1446790792) and M.Web (https://www.loc.gov/collections/) interfaces. LOCDC is the only national-level DL in the United States that has an app version. For M.Web, participants were asked to use the

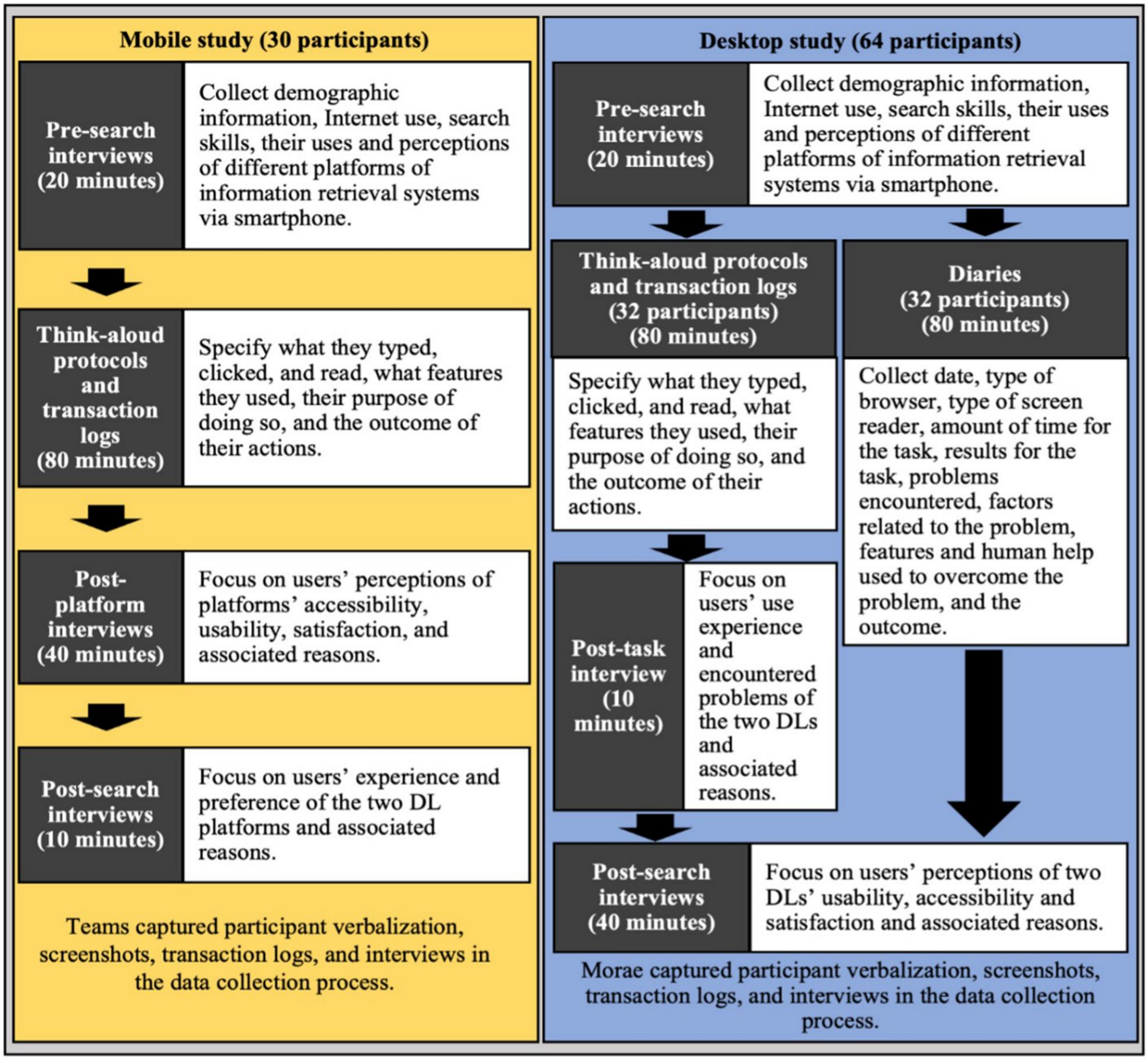



**Figure 1.** Data collection methods and procedures.

Safari browser because it is the most commonly used mobile browser for BVI users (WebAIM, 2021). Participants were instructed to conduct three search tasks on each platform. Following the Latin Square design, participants were assigned to either M.App or M.Web first since the mobile study applied a within-subjects design.

Five DLs were chosen based on their variety of structure, content, and media formats of interest to BVI users. These included Artstor Digital Library (Artstor), Digital Public Library of America (DPLA), HathiTrust Digital Library (HathiTrust), Library of Congress Digital Collections (LOCDC), and the LuEsther T. Mertz Library Digital Collections (Mertz). The chosen sites also represent diverse types of DLs. LOCDC is a stand-alone DL with multiple digital collections; DPLA and HathiTrust represent federated DLs; Artstor consists of art images; and the Mertz focuses on botanical and horticultural articles. Every participant performed three search tasks in LOCDC, while sixteen participants (eight from the onsite group and eight from the diary group) were randomly assigned to one of the other four DLs. They were instructed to complete three search tasks in each DL. Diaries were used in the desktop study, allowing participants to use their preferred screen readers and perform their tasks in their own settings. The diary document consisted of an instruction sheet, sample diaries, links to the assigned DLs, explanations of the tasks to be completed, and a task template form for participants to fill out.

### 3.3. Data analysis

Three steps of analysis were performed. First, open coding was applied to break down, examine, compare, conceptualize, and categorize unstructured textual transcripts (Strauss & Corbin, 1990) to identify help-seeking situations encountered by BVI users in the mobile and desktop studies. The

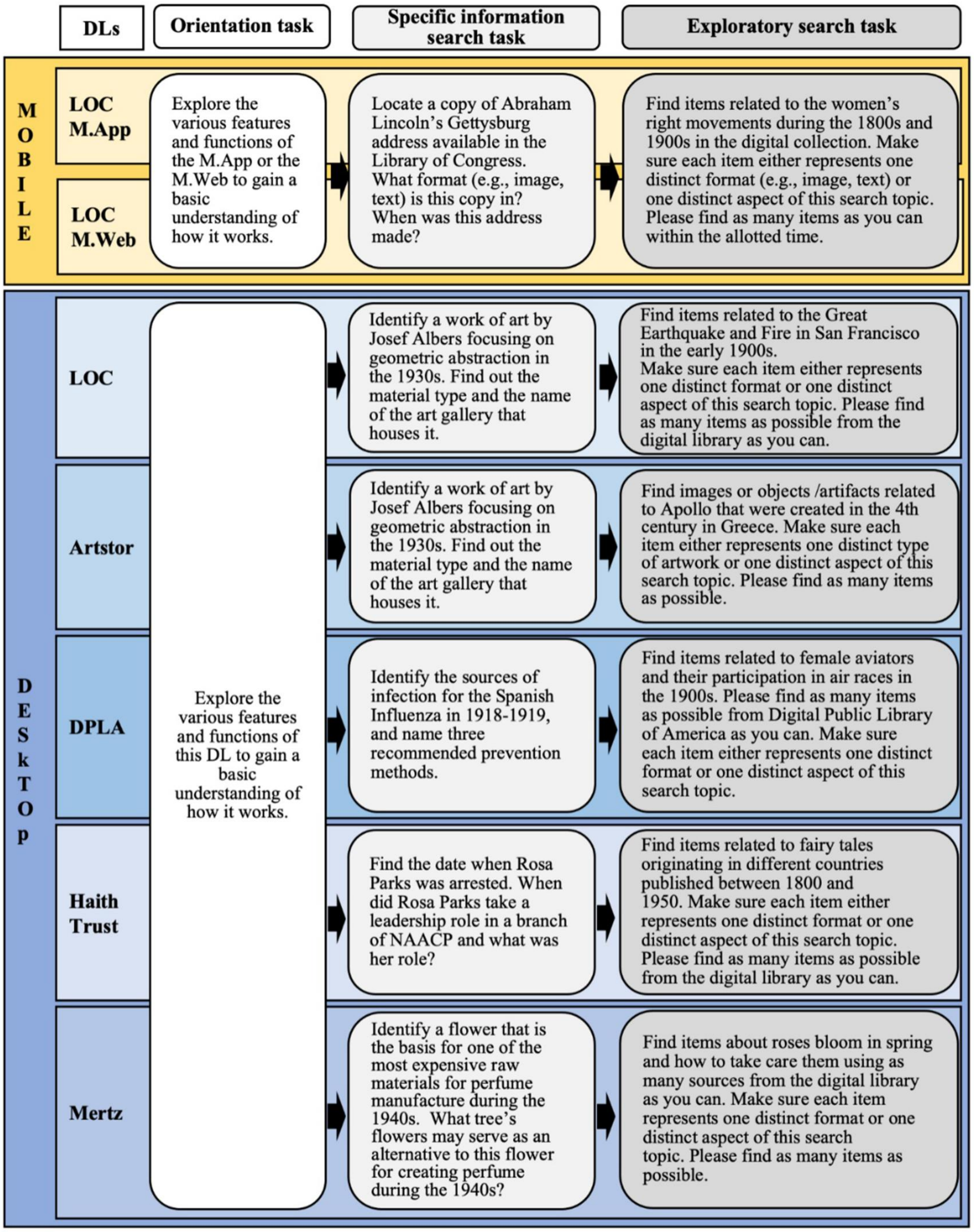



**Figure 2.** Types of tasks and their orders.

inter-coder reliability by two coders was 0.96 based on Holsti's (1969) formula. The research team discussed disagreements until an agreement was reached. Due to space limitations, Table 2 presents a portion of the coding scheme of the identified significant help-seeking situations between the two mobile platforms.

Second, quantitative analysis was applied to examine RQ1 and its associated hypotheses. A Shapiro-Wilk test was first applied for all hypotheses to check normality when comparing the number of help-seeking situations in the M.App and M.Web. Since data was not normally distributed in both groups ($p < .05$), a Mann-Whitney U test was conducted to test the differences between M.App and M.Web groups' frequencies of help-seeking situations for RQ 1. Additionally, descriptive analysis was performed for the frequencies of help-seeking situations that occurred in the M.App and M.Web.

Third, qualitative data from the think-aloud protocols and transaction logs in the mobile and desktop studies were examined for RQ2. By analyzing and comparing the situations in the two studies, situations with unique labels and situations with similar labels but with differences from the mobile study were identified. These situations were further illustrated with relevant quotes and screenshots in the Results section. Figure 3 presents the research questions, associated data collection methods, and data analysis methods.

**Table 2.** Coding scheme of significant help-seeking situations.

| Situation | Definition |
|---|---|
| Confusion about search results with collections (CSRC) | A situation that arises from being unclear about what search results consist of. |
| Difficulty accessing content of visual items (DACV) | A situation that arises from difficulty gaining access to alternative text, transcripts, or descriptions for visual items. |
| Difficulty accessing multimedia controls (DAMC) | A situation that arises from difficulty activating unlabeled controls to play audio/video files. |
| Difficulty detecting dynamic items (DDDI) | A situation that arises from difficulty identifying dynamic images. |
| Difficulty exiting out of an open item (DEOI) | A situation that arises from difficulty closing an open item. |
| Difficulty identifying current location (DICL) | A situation that arises from difficulty figuring out the current position. |
| Difficulty interpreting a label (DIL) | A situation that arises from difficulty understanding the meanings of labels associated with various features, elements, or objects. |
| Difficulty locating a feature (DLF) | A situation that arises from difficulty finding a feature, such as a search box or a search filter. |
| Difficulty locating metadata (DLM) | A situation that arises from difficulty finding the metadata of a DL item. |
| Difficulty locating search results (DLSR) | A situation that arises from difficulty finding search results. |
| Difficulty understanding or using a specific feature (DUSF) | A situation that arises from difficulty figuring out the functionality of a feature or difficulty executing a feature. |

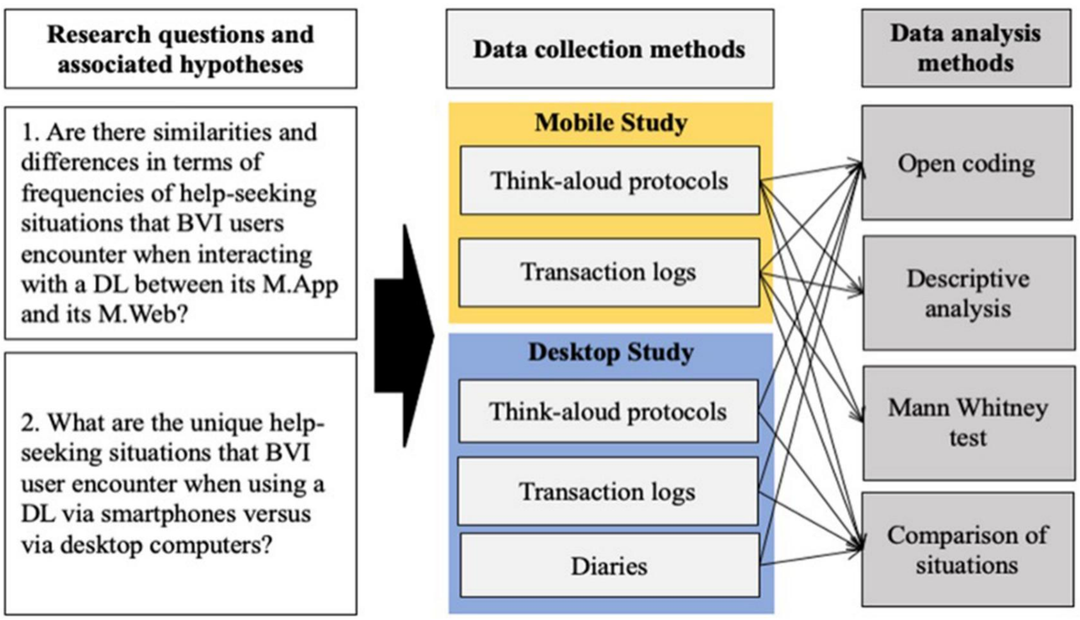



**Figure 3.** Research questions and associated data collection and data analysis methods.

## 4. Results

This section presents the answers to the two research questions and associated hypotheses.

### 4.1. RQ1: Similarities and differences of help-seeking situations between the two mobile platforms

For RQ 1 and associated hypotheses, 18 help-seeking situations (M.App: 16, M.Web: 18) were identified, and 11 showed significant differences between M.App and M.Web. To be more specific, there were six help-seeking situations whose frequencies were significantly greater for M.Web than M.App, and there were five help-seeking situations whose frequencies were significantly greater for M.App than M.Web.

Frequencies of significant help-seeking situations between the M.App and M.Web are presented in Figure 4 based on the frequency difference between M.App and M.Web in descending order. The figure indicates that difficulty accessing content of visual items (DACV) has the highest frequencies in both M.App (162) and M.Web (59) and also shows the biggest gap. In M.App, Difficulty locating metadata (DLM) and Difficulty accessing multimedia controls (DAMC) are presented in descending order. Accordingly, Difficulty locating a feature (DLF) and Difficulty understanding or using a specific feature (DUSF) are reported in M.Web. Notably, Confusion about search results with collections (CSRC) and Difficulty locating search results (DLSR) are only reported in M.Web.

Based on the Mann-Whitney test results, hypotheses $H_0$1:1-$H_0$1:11 were rejected. Table 3 presents the Mann-Whitney test results of the significant help-seeking situation between M.App and M.Web. Specifically, M.Web was significantly greater in CSRC ($H_0$1:1), DICL ($H_0$1:6), DIL ($H_0$1:7), DLF ($H_0$1:8), DLSR ($H_0$1:10), and DUSL ($H_0$1:11) than M.App, and M. App was greater in DACV ($H_0$1:2), DAMC ($H_0$1:3), DDDI ($H_0$1:4), DEOI ($H_0$1:5), and DML ($H_0$1:9) than M.Web.

### 4.2. RQ2: Unique mobile situations

For RQ2, five unique situations were identified in the mobile study after analyzing and comparing situations from the two studies, including Difficulty exiting out of an open

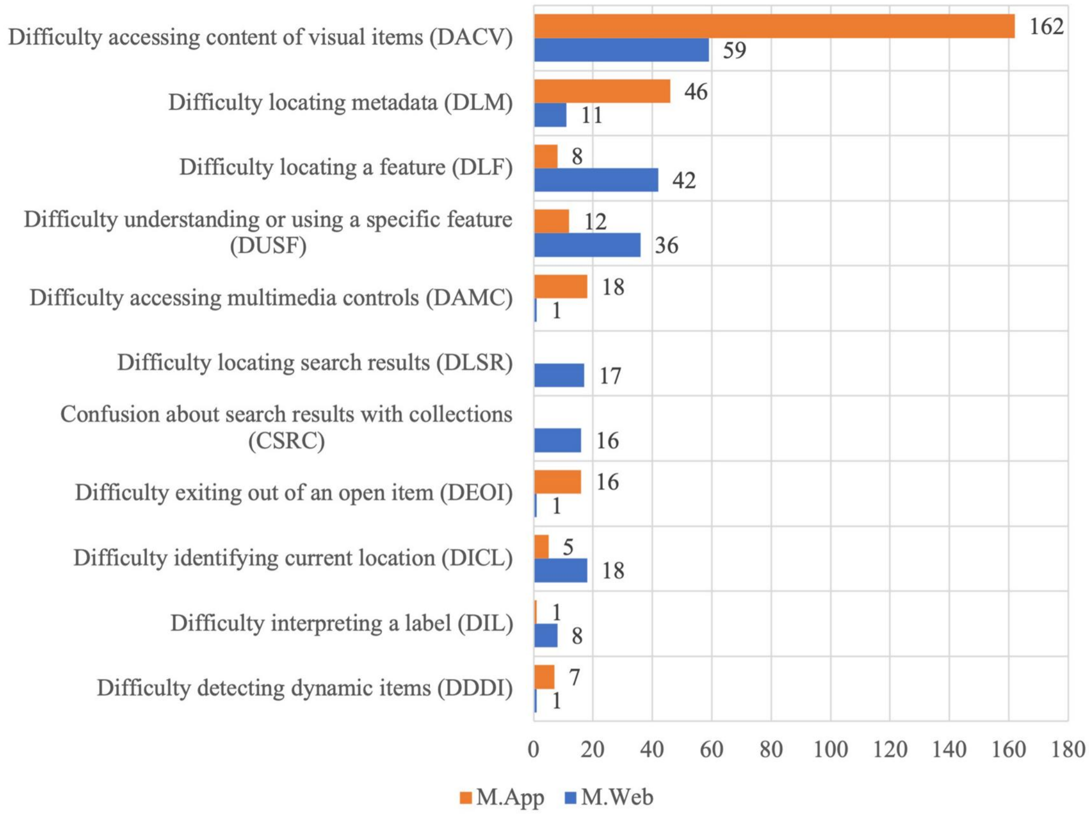



**Figure 4.** Frequencies of significant help-seeking situations in the M.App and M.Web.

**Table 3.** Mann-Whitney test result of significant help-seeking situations between M.App and M.Web.

| $H_0$/situation | Group | n | Mean rank | Sum of ranks | Mann-Whitney U | *p* value |
|---|---|---|---|---|---|---|
| $H_0$1:1 CSRC | M.App | 30 | 25.50 | 765.00 | 300 | <0.001 |
| | M.Web | 30 | 35.50 | 1065.00 | | |
| $H_0$1:2 DAMC | M.App | 30 | 36.57 | 1097.00 | 268 | <0.001 |
| | M.Web | 30 | 24.43 | 733.00 | | |
| $H_0$1:3 DACV | M.App | 30 | 40.57 | 1217.00 | 148 | <0.001 |
| | M.Web | 30 | 20.43 | 613.00 | | |
| $H_0$1:4 DDDI | M.App | 30 | 33.50 | 1005.00 | 360 | <0.02 |
| | M.Web | 30 | 27.50 | 825.00 | | |
| $H_0$1:5 DEOI | M.App | 30 | 35.58 | 1067.50 | 297.5 | <0.001 |
| | M.Web | 30 | 25.42 | 762.50 | | |
| $H_0$1:6 DICL | M.App | 30 | 26.05 | 781.50 | 316.5 | <0.01 |
| | M.Web | 30 | 34.95 | 1048.50 | | |
| $H_0$1:7 DIL | M.App | 30 | 27.48 | 824.50 | 359.5 | <0.02 |
| | M.Web | 30 | 33.52 | 1005.50 | | |
| $H_0$1:8 DLF | M.App | 30 | 22.83 | 685.00 | 220 | <0.001 |
| | M.Web | 30 | 38.17 | 1145.00 | | |
| $H_0$1:9 DLM | M.App | 30 | 37.40 | 1122.00 | 243 | <0.001 |
| | M.Web | 30 | 23.60 | 708.00 | | |
| $H_0$1:10 DLSR | M.App | 30 | 27.00 | 810.00 | 345 | <0.01 |
| | M.Web | 30 | 34.00 | 1020.00 | | |
| $H_0$1:11 DUSF | M.App | 30 | 25.95 | 778.50 | 313.5 | <0.02 |
| | M.Web | 30 | 35.05 | 1051.50 | | |

item (DEOI), Difficulty clearing a search box (DCSB), Difficulty navigating through search results (DNSR), Difficulty navigating within an item (DNAI), and Difficulty identifying a relevant collection/item (DIRC). Relevant quotes and screenshots from the mobile study were used to illustrate the uniqueness of these mobile situations.

#### 4.2.1. Difficulty clearing a search box

This situation arose when BVI users had difficulty removing previous search statements in the search box in a mobile DL. Being able to initiate a new search is particularly important in DLs because browsing can be time-consuming for BVI users due to the massive number of information resources of DLs, and they have to listen to all the results from top to bottom. BVI users expected to have a clear button to support them to quickly delete previous searches in a search box. For example, although there was an "X" in the search box that helps clear previous searches, it was not identified by VoiceOver. Therefore, S12 did not hear the notification of the “clear search” feature (Figure 5).

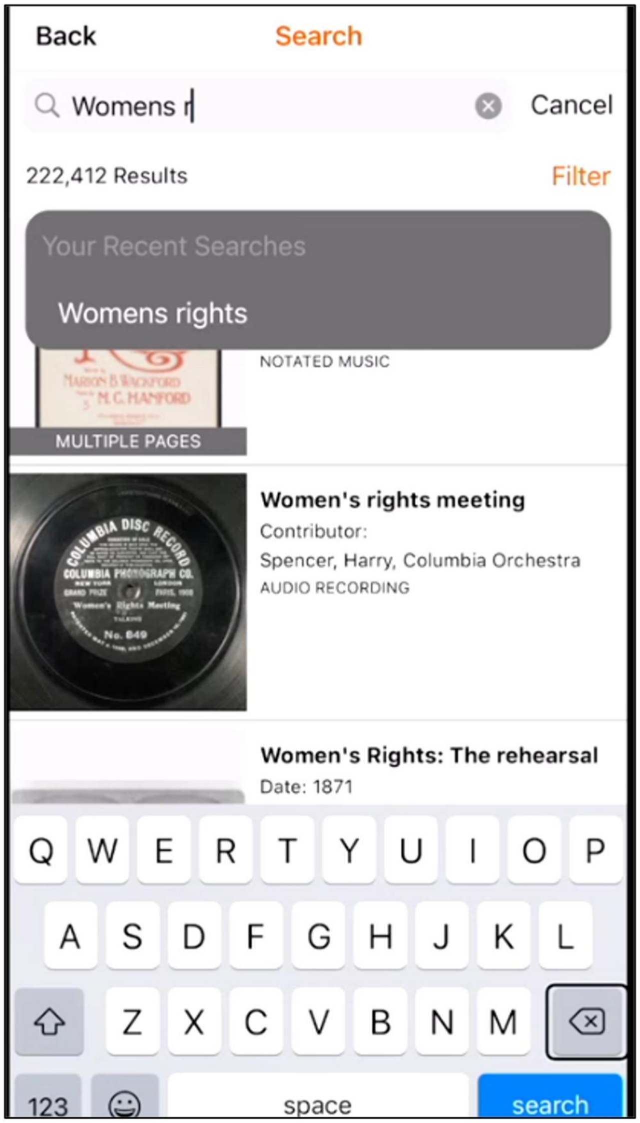



Figure 5. Screenshot of difficulty clearing a search box.

> [enters search box] Trying to clear the search. There doesn't seem to be a clear search button (S12-B-M.App).

### *4.2.2. Difficulty exiting out of an open item*

This situation occurred when users could not go back to a previously visited page from an open DL item (e.g., a scanned document or an image). When using DLs, users are likely to check multiple items before finding needed information because of comparatively low precision. Hence, the ability to move back and forth without barriers is essential. BVI users prefer an easy-to-locate back element on each interface to exit from individual items. For example, S19 wanted to get out of a photo of the Field of Gettysburg, but he could not locate the back element after zooming in on the photo. Interestingly, the back element appeared after S19 tried to double-tap the image (Figure 6).

> I'm going to the Gettysburg photo that's now showing, it says double tap for details.[zooms in on image]. An illustration of a map with text on it. Flick to the … yeah, there's nowhere to go. There's no back button. Let's double tap that photo again. [zooms out of image]. Okay, it seems to have shrunk and now I have a back button again. [Highlight Back arrow button] (S19-B-M.App)

### *4.2.3. Difficulty identifying a relevant collection/item*

This situation arose when BVI users could not identify a relevant collection/item from a trimmed result description because collection/item descriptions could not be fully displayed in a mobile DL due to the relatively small screen size. Unlike other IR systems, DLs often consist of collections containing items that focus on specific topics. Providing collection/item descriptions is essential for BVI users to get a basic idea of each collection or item. BVI users want access to full descriptions for collections or items to determine the relevance of a specific collection or item in the search list. For example, S3 could not listen to the complete description of one collection in the search result list because the description was trimmed (Figure 7).

> [Types' Women rights 1800 1900'. Initiates search] Okay. Alright, so I did the search now I'm going to go through and see what I can find. [skips to main content] We have the Goldstein collection … and it says it consists of drawings … [Screen reader stops reading the collection description because of the description being trimmed] (S3-B-M. Web)

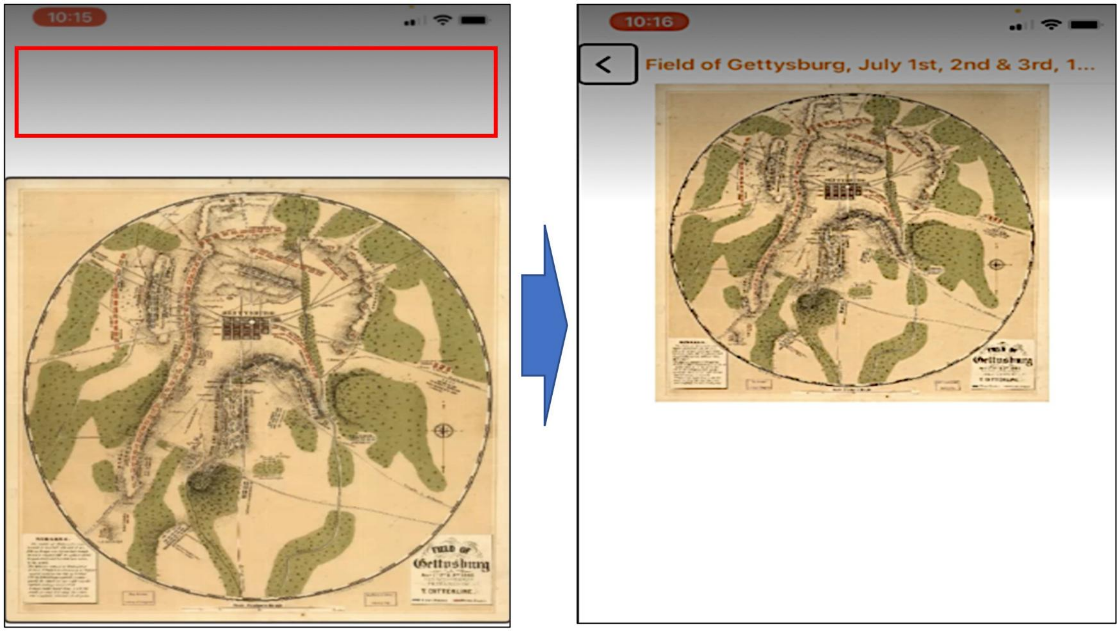
### *4.2.4. Difficulty navigating through search results*

This situation occurred when users could not quickly skip irrelevant results in the result list in a mobile DL. Because of the low precision of search results in DLs, navigating through a long list of search results can be challenging for all kinds of users, especially for BVI users who must go through the results sequentially to find relevant information in DLs. BVI users expect to have headings to help them quickly go through search results. It is worth noting that headings were present in the desktop environment, allowing users to skip to a specific heading. In contrast, M.Web used links rather than headings in the search result page, making it difficult for BVI users to skip to the desired item. For example, S9 could not quickly go through the search results but had to check each item line by line, and she thought having headings would help her navigate search results more efficiently (Figure 8).

> [Focus indicator moves down] So in the … collection … these are all very broad. His general correspondence. These are not, like a lot of times … search results pop up by, again, being labeled as headings so you can navigate them quickly. These are not headings … So I'm just going line by line … (S9-SVI-M.Web)

### *4.2.5. Difficulty navigating within an item*

This situation arose when BVI users could not quickly skip less relevant information in an open item (e.g., a scanned document) in the M.Web. DL users often need to locate specific information within an item rather than locate one relevant item. Navigating within an item in DLs can be especially challenging when BVI users access scanned




Zoom in the image (No back element)
S19-B-M.App

Double tapped on the image and then
zoom out/reappear back element
S19-B-M.App

**Figure 6.** Screenshots of difficulty exiting out of an open item.

documents containing images not readable by screen readers. In the desktop environment, BVI users could use search features embedded in browsers to find specific words. However, M.Web has no such word search feature for finding specific information in a PDF file unless specific PDF readers were installed. For example, S28 expected a word search feature to help her quickly locate specific information. Without such features, it took her considerable time to go through the entire PDF file since the screen reader read only the rectangle part of the screen starting from the second column (Figure 9).

> [highlights PDF link] … This is a very big document so I am just looking to see … because there is no word search, I cannot … [scrolls down page] This is going to take too long to look through. (S28-B-M.Web)

### 4.3. Similar situations with slight differences

Three pairs of situations have the same labels but vary slightly between contexts due to design differences in the mobile and desktop environments. These are Confusion about digital library structure or browse categories (CDLS), Difficulty locating a feature (DLF), and Difficulty locating help information (DLHI). With a focus on the mobile situations, relevant quotes and screenshots from the mobile study were chosen to illustrate the differences among these situations.

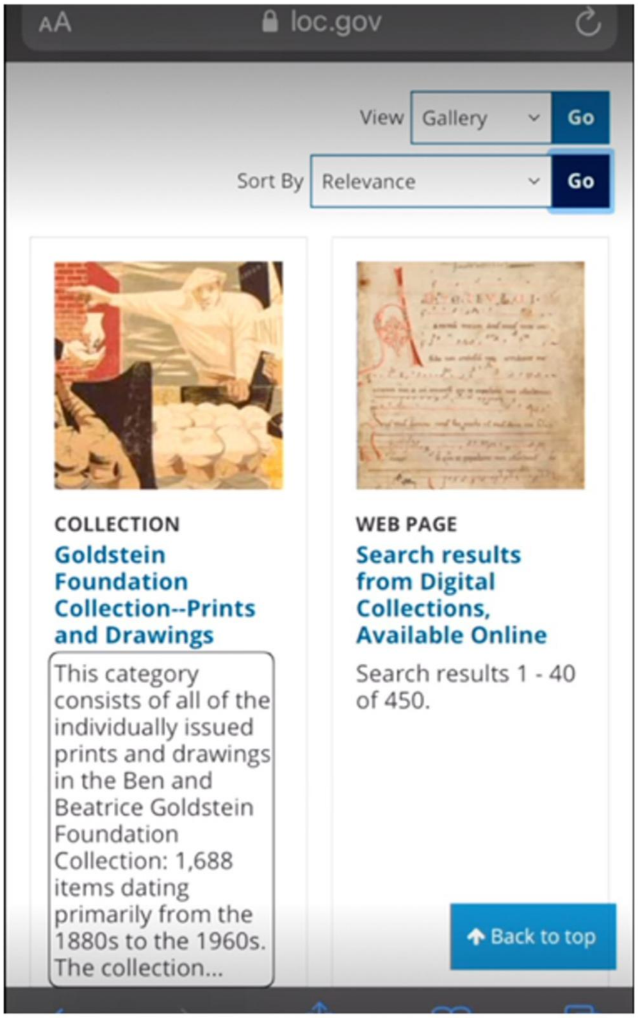
#### 4.3.1. Confusion about DL structure or browsing categories

This situation arose from difficulty orienting a DL's overall structure, layout, and browsing categories. DLs are commonly characterized by their layered and complex structures and layouts. Inappropriate design (e.g., complex information presentation) further contributes to users' confusion about DL structure and layout. S1 noted that the layout of the M.Web is unnecessarily complex. M.Web displays the same information as the desktop DL, but the structure of the M.Web differs from the desktop version of the DL (Figure 10). Specifically, there are two columns of information displayed in the desktop DL while there is only one column in M.Web. In addition, there is a dropdown menu in the M.Web for users to select what content to access, while the menu is directly provided as three tabs in the desktop DL. In the M.Web, BVI users only hear "About this collection" and "Collapse," so they might miss the other two options under the dropdown box.

> There's a lot of good information here, but it's more complex, unnecessarily complex than the application. I guess laid out in a more complex fashion than it needs to be (S1-B-M.Web).

#### 4.3.2. Difficulty locating a feature

This situation arose from difficulty finding a feature, such as a search box or a search filter. Some IR systems (e.g., search engines) have straightforward and easy-to-find features, while DL features can be difficult to locate due to complex DL interfaces that consist of multiple elements surrounding the features as well as inappropriate design (e.g., the invisibility of features). For example, S2 couldn't find the search button on the homepage of the M.Web, possibly because the search box did not appear. There were also several other elements at the top of the homepage, making it hard for BVI users to locate the search icon (Figure 11). A search box is directly displayed in the desktop DL, while M.Web users




Collection (S3-B-M.Web)

**Figure 7.** Screenshot of difficulty identifying a relevant collection.

must click the magnifying glass icon to find the search box and input their search terms.

> [jumps to top of page] Where is the search box again? Now it doesn't want to show up. Let's see if I can get the search box. Must not be there … Now the search button doesn't want to … show up. The toggle that I don't want to mess with again (S2-B-M.Web).

#### *4.3.3. Difficulty locating help information*

This situation arose from difficulty finding relevant information that assists users in understanding and using a DL under different circumstances. Help information is essential for users of complex systems (e.g., DLs) since they are more likely to encounter difficulties when using these systems. For example, S28 tried to find help information by going to the section "About the Library;" however, she found no help information provided there. The desktop DL offers a specific section for help resources, in contrast to the lack of available help information in the M.App (Figure 12).

> I'm going to click on the About the Library of Congress first because if you need help, I imagine that's where you would look. [highlights About tab] So I'm looking really quickly. I'm mainly looking for anything like help or settings. … they are not here. So I'm going to go back. (S28-B-M.App)

## 5. Discussion

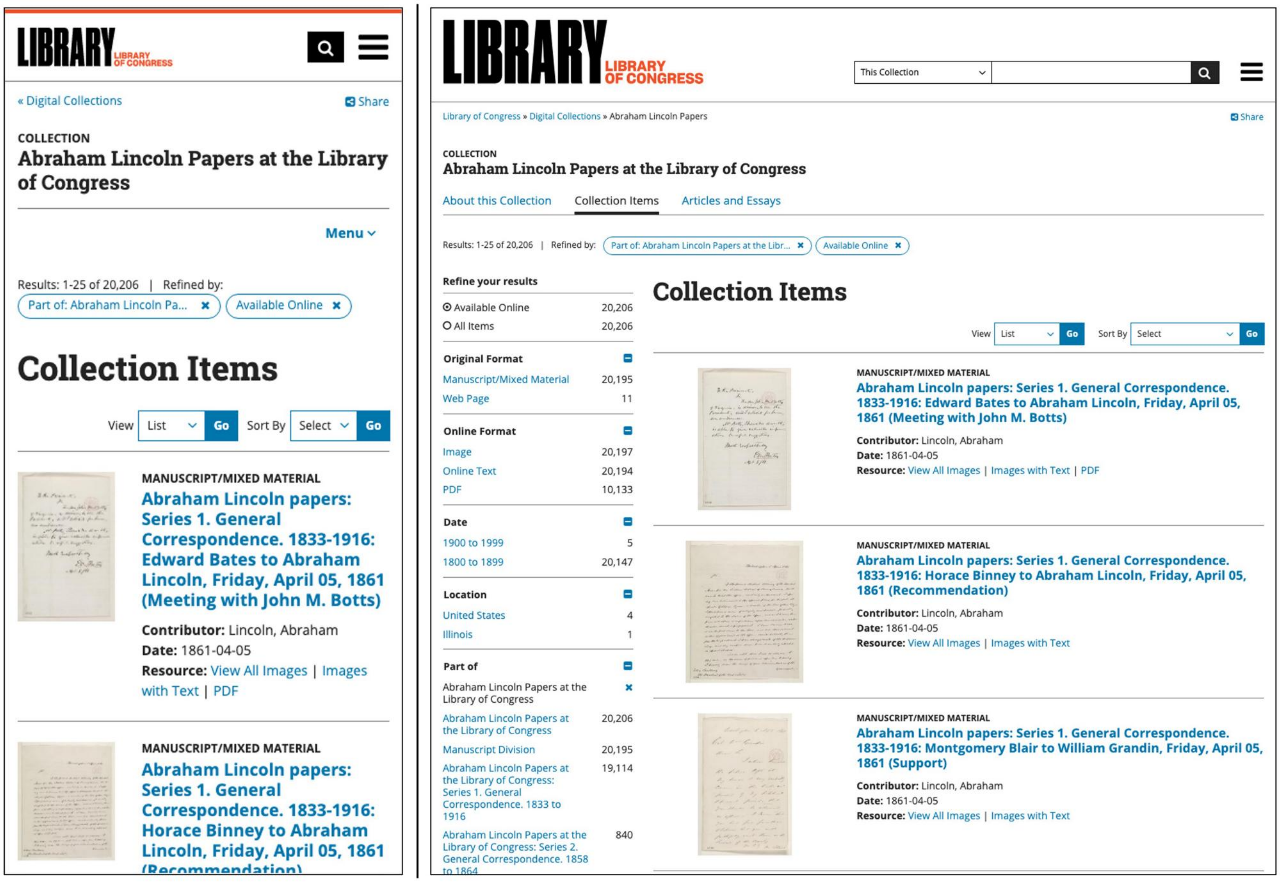
### *5.1. Theoretical implications*

It is critical to investigate the unique help-seeking situations that BVI users encounter in their interactions with DLs on M.Web and M. App, which is not well understood. Without such knowledge, the design of DLs cannot take into consideration BVI users' needs, and universal access cannot be achieved. It is the first study that identifies and compares BVI users' help-seeking situations in two mobile platforms and between the mobile and desktop environments. Even though only LOCDL was selected for this study, it represents the typical DL design. Help-seeking situations identified from this study can be extended to other DLs as well. The findings not only signified the problems that BVI users encountered in interacting with DLs but also the types of help that they needed to support their interactions. The study's findings significantly contribute to the research and design of DLs to support BVI users in the mobile environment based on the research questions.

#### *5.1.1. More situations and more severe situations encountered in DLs on M.Web than on M.App*

The findings of RQ1 highlight current problems of mobile DL design by identifying 18 help-seeking situations that occurred when BVI users interact with M.Web and M.App of a DL. These situations represent the problems BVI users had to deal with due to the DL design issues in the mobile environment. Without identifying these situations, researchers cannot uncover DL design problems in the two mobile platforms. It is worth noting that these situations arise in the entire information search process in relation to structure (e.g., Confusion about structure), features (e.g., Difficulty locating and understanding a feature), and items (e.g., Difficulty accessing content of visual items). Even though previous research has also identified some situations when using mobile devices, they are less comprehensive and systematic and mostly address navigation, features and labels, and information object problems (Alajarmeh, 2022; Carvalho et al., 2018), as well as issues related to providing or editing input (Grussenmeyer & Folmer, 2017; Mi et al., 2014; Nicolau et al., 2015; Oliveira et al., 2011; Rodrigues et al., 2020) without differentiating between either IR systems or specific platforms. This study, compared to previous studies, investigated unique situations that arise due to a specific context of DLs. The identified situations are related to the DLs' multi-level structure, diverse formats, and metadata (e.g., Confusion about DL structure or browsing categories, Difficulty identifying a relevant collection/item).

The results of the RQ1 hypotheses show significant differences in the frequency of help-seeking situations between the M.Web and the M.App of the DL, indicating that BVI users faced more situations in M.Web than in M.App. This




Search result page (S9-SVI-M.Web)    Search result page (S14-B-Desktop)

**Figure 8.** Screenshots of difficulty navigating through search results.

echoes the findings in non-DL settings (Carvalho et al., 2018; Othman, 2021). While Othman (2021) found that M.App is faster, easier to use, and slightly more user-friendly than M.Web, Carvalho et al. (2018) pointed out that more problems were reported on M.Web than M.App. Nevertheless, none of the studies compared different problems between M.Web and M.App. Our study went a step further and identified the six situations BVI users faced more frequently using M.Web than M.App: DLF, DUSF, DICL, DLSR, CSRC, and DIL. Simultaneously, BVI users experienced fewer problems in the following five situations when using M.Web: DACV, DLM, DAMC, DEOI, and DDDI. Interestingly, with previous BVI-related mobile research, no specific situations were discussed for M.Web only. Instead, the situations were identified for M.App, such as Difficulty accessing information objects (Park et al., 2014), Difficulty identifying a button (Al-Mouh & Al-Khalifa, 2015; Mateus et al., 2020; Park et al., 2014; Ross et al., 2018), Difficulty with labels (Mateus et al., 2020; Wentz et al., 2017), Difficulty with navigation (Buzzi et al., 2013; Mateus et al., 2020; Park et al., 2014; Rodrigues et al., 2020). Beyond these situations in the literature, some unique situations for M.App were identified in this study, such as DAMC, DDDI, DLF, DLM, DLSR, and DUSF. These situations are related to unique elements of DLs, including multimedia controls, dynamic items, metadata, search features, etc.

Moreover, the mobile platform affects how far a BVI user can go in the search process in the DL context, while researchers only found that mobile platforms influenced the search efficiency but did not discuss the search process in the non-DL contexts (ChanLin & Hung, 2016; Wu et al., 2016). As previous research has not compared situations identified between M.Web and M.App, the findings of RQ1, based on analysis of the two platforms, further indicated that M.Web of the DL interrupted BVI users' search processes and prevented BVI users from getting to individual items. The situations that BVI users encountered less frequently in the M.Web environment are mainly related to items such as DACV, DLM, DEOI, and DDDI. After checking the log data, the researchers found that most BVI users got stuck at the search stage or initial results evaluation stage. The situations they encountered prevented them from going further in their search process to access individual items. Thus, although M.Web appeared to perform better for these five situations than M.App, BVI users would likely still encounter these five situations arising primarily at the item level. The comparison of situations on M.Web and M.App clearly showed that the selected platform determined how far BVI users could go in their search process.

The complexity of DL structures, dynamic elements, and diverse formats makes it more difficult for BVI users to interact with DLs (Xie et al., 2021a, 2021b) in the mobile environment. Moreover, the sight-centered DL design does

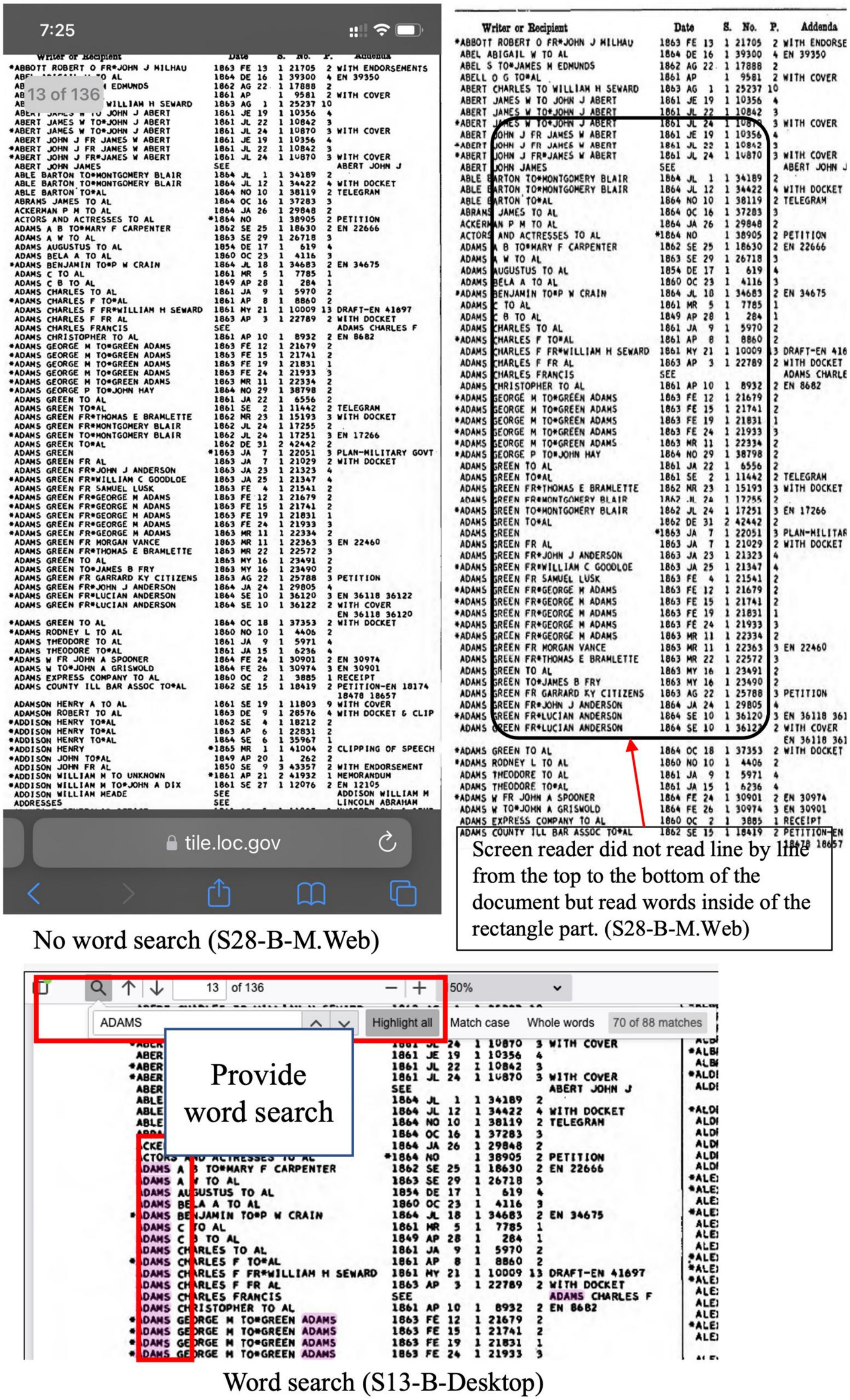
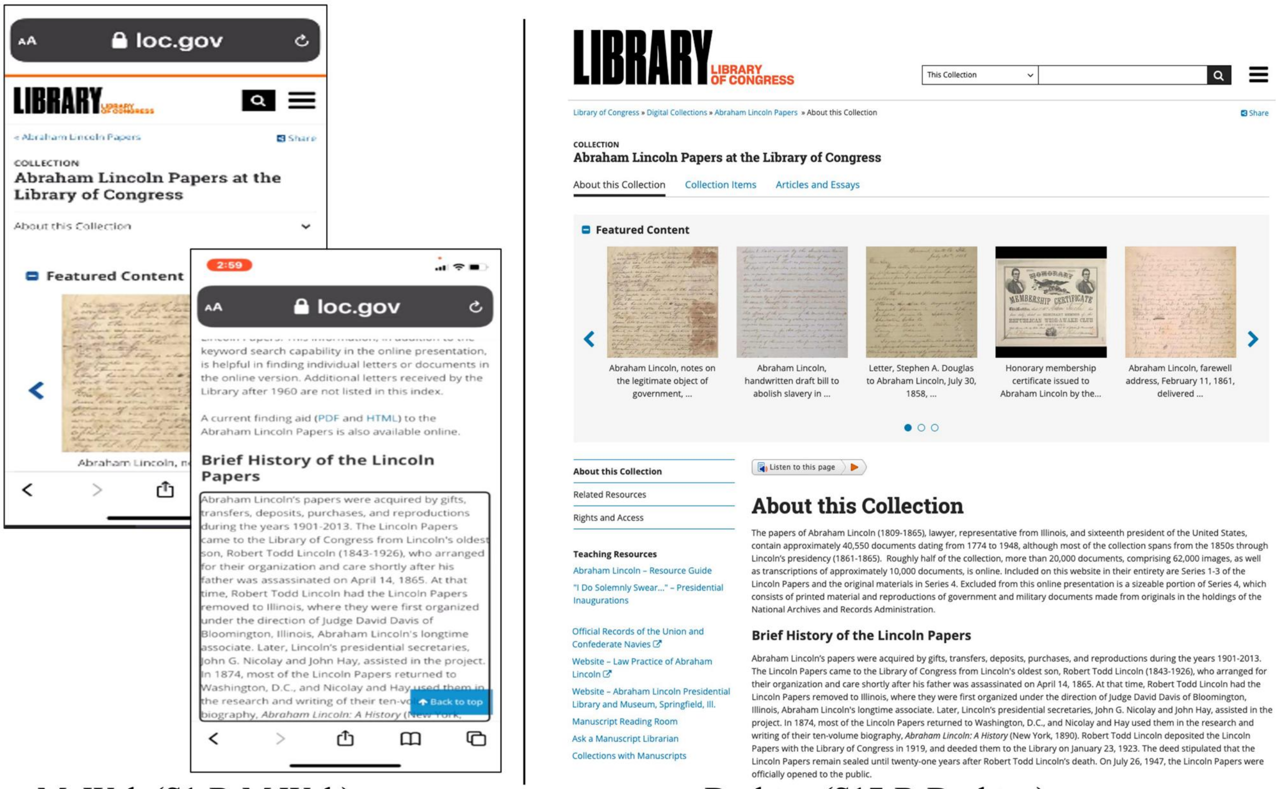


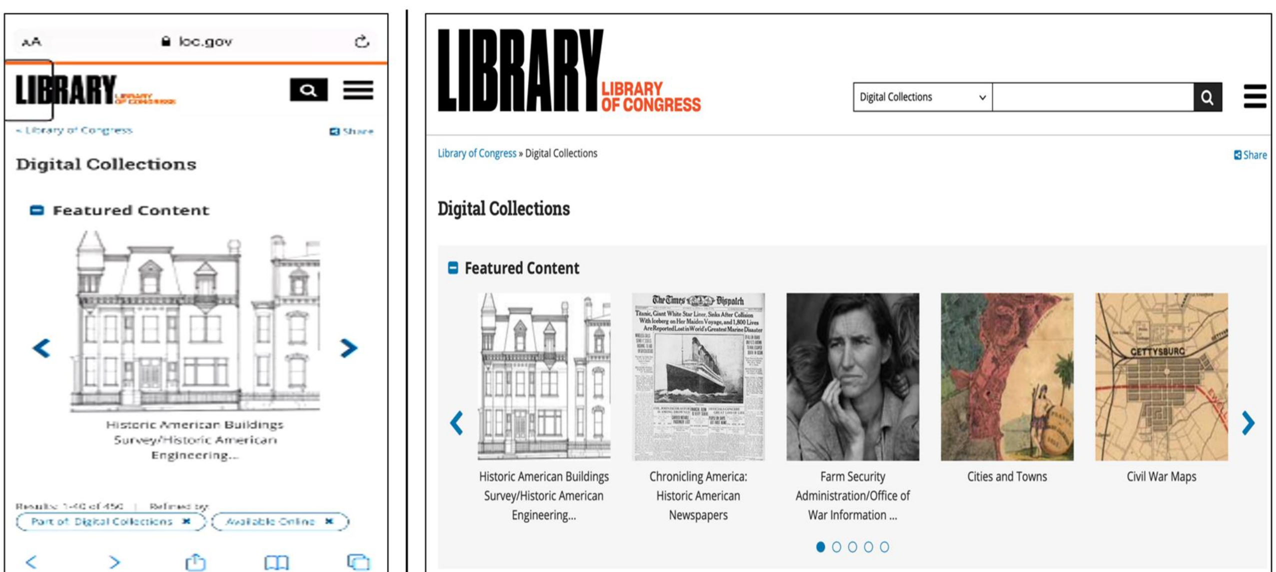

**Figure 9.** Screenshots of difficulty navigating within an item.

not consider BVI users' unique needs. As M.Web is derived from the desktop version but in a reduced size, it causes more situations for BVI users. To a degree, M.App has taken into consideration the problems of M.Web to design the interface in a more structured and simplified way. BVI users preferred M.App over M.Web because its straightforward structure helped them understand the structure of the DL, identify their current location, locate a feature, and



M. Web (S1-B-M.Web) Desktop (S17-B-Desktop)

Figure 10. Screenshots of confusion about DL structure.



M. Web (S2-B-M.Web) Desktop (S28-SVI-Desktop)

Figure 11. Screenshots of difficulty locating a feature.

locate search results. At the same time, M.App makes it easier for BVI users to comprehend a label and use a feature. Nevertheless, M.App has its own problems; in particular, DEOI arose when BVI users were unable to locate the back element.

#### *5.1.2. Situations encountered in mobile DL more related to structure, feature and item optimization*

RQ2 highlights eight BVI users' unique help-seeking situations in the mobile environment, which are derived from the comparison and analysis of the situations identified via

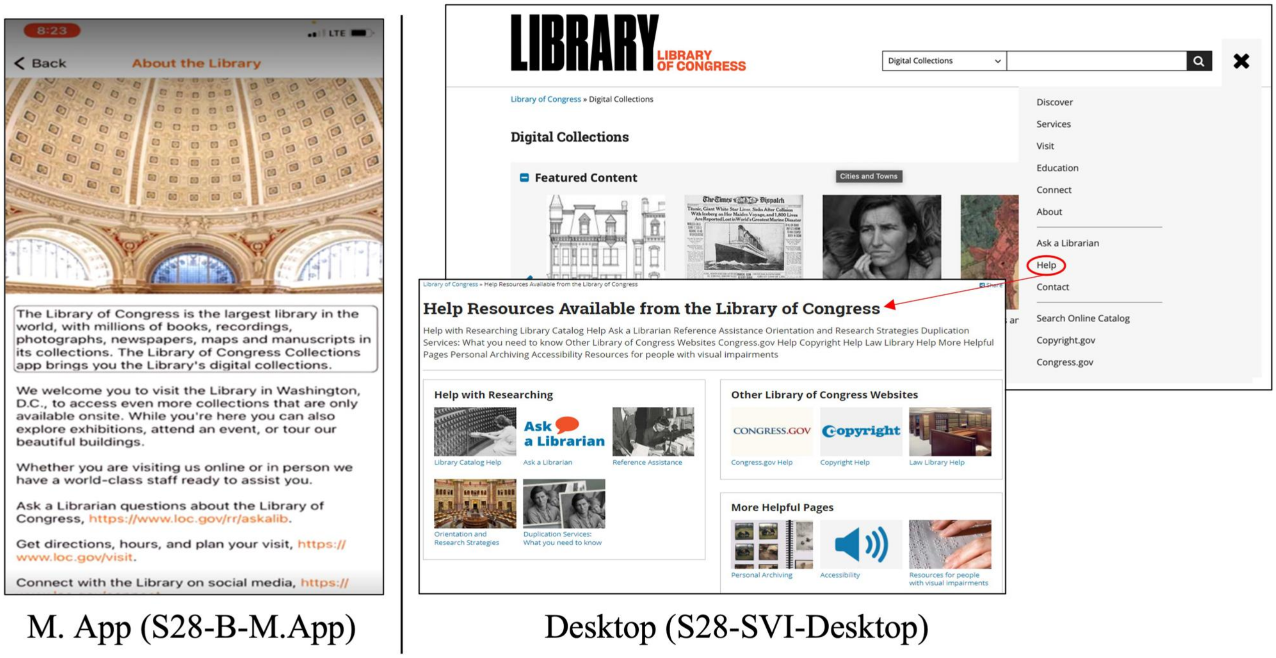



**Figure 12.** Screenshots of difficulty locating help information.

mobile devices versus desktops. Little research has compared help-seeking situations that occur between the two environments, including those studying broader non-DL contexts. Prior studies focused exclusively on sighted users. While Wong (2012) compared the daily usage pattern (e.g., view counts) of a library video site on M.App and desktop, Hasan (2018) differentiated usability problems that students faced when using a learning management system's mobile and desktop interfaces. Our study emphasizes not only the unique needs of BVI users but also incorporates two unique contexts: the exploration of DLs and the use of mobile platforms. Moreover, the study concentrates on the DL setting and highlights the unique situations encountered by BVI users when using both mobile platforms: DNSR, CDLS; for M.Web: DLF, DIRC, and DNAI; for M.App: DEOI, DCSB, and DLHI. Even though the three situations share the same labels in mobile and desktop environments, there are some differences in their coverage. The results of RQ2 indicate that the unique M.Web situations are more likely to prevent BVI users from completing their search process when utilizing the DL in terms of the DL features or item access. Unique M.App situations, on the other hand, are more likely to impact the efficiency of going through the search process when using the DL, as these do not prohibit BVI users from using the features or items but may decrease their ability to complete the search process in a timely manner.

The findings of RQ2 reveal that BVI users encountered greater numbers and types of situations in the mobile environment than in the desktop environment. The differences between the two environments are caused mainly by the smaller size of the mobile interface (Alajarmeh, 2022; Hasan, 2018), which is further exacerbated by the complexity of the DL structure (Li & Liu, 2019; Xie et al., 2021a, 2021b). The unique mobile situations can be classified into the following categories: overall structure, feature and location, search results, and items. Due to the reduced screen size, M.Web must collapse some of the key information on the main DL page, causing BVI users to miss some of the available desktop options that provide a better understanding of the overall DL. Another issue caused by the smaller screen size is the use of icons to represent DL features (ChanLin & Hung, 2016; Fung et al., 2016). For example, the portrayal of the search box as a magnifying glass icon might work well for sighted users, but BVI users found it challenging to find the invisible search box. Moreover, BVI users could not identify a relevant collection or an item from search results because the titles or descriptions were trimmed. Often, only the first portion of the description of collections was provided, and some titles of individual items are similar. In mobile environments, the absence of a search feature prevented BVI users from skipping irrelevant results and going directly to a relevant heading.

M.App is designed for mobile access, yet it also has its own problems caused by the simplified design. First, it does not provide Help information compared to the desktop version, which offers comprehensive synchronous and asynchronous help features. Second, it omits some common desktop features or elements, including exiting out of an item or going back to the previous page. Third, some design elements are incompatible with screen readers; for example, the "X" character cannot be recognized for clearing a search box.

### 5.2. Design implications

User interface (UI) design patterns are reusable components that designers employ to address recurring challenges in user interface design (Interaction Design Foundation, 2023). Even as mobile devices become increasingly significant in our day-to-day activities, established standards for mobile UI design patterns still need to be improved. The challenges in mobile UI design patterns primarily derive from two central problems: the limited availability of documented design patterns tailored explicitly to mobile environments and the propensity to utilize traditional desktop design patterns rather than developing and recording new patterns for mobile technology (da Silva et al., 2022; Punchoojit & Hongwarittorrn, 2017). Under this circumstance, Kim et al. (2021) delved into the intricacies of design patterns and the necessary compromises linked to responsive visualization to foster effective communication. The research spotlighted the hurdles in producing visualizations that can conform to various screen sizes and interactive environments while preserving their communication objectives. From previous scholarly work on responsive design visualization, they presented 76 design patterns (e.g., Change encoding, Reduce text, Serialized layout, Simplify labels) pertinent to responsive visualization on mobile devices. They stressed that designers must often balance flexibility, expressiveness, and usability with the constraints of different devices.

Given the space limitations of this article, the design implications presented here concentrate on the unique situations that BVI users encounter in the mobile environment derived from RQ2. It is difficult for BVI users to install all DL apps, and most of the leading DLs do not have an app version. Because of these issues, many BVI users rely on M.Web for DL access. Thus, it is critical to enhance the design of M.Web for universal access. As suggested above, the issues of M.Web are associated with an inability to access features, locations, and items. The authors proposed the following design patterns from structure to scanned document:

#### 5.2.1. Create a shallower and wider structure

DLs often exhibit intricate and multi-tiered arrangements and frameworks, and unsuitable design choices, such as convoluted information display, which can exacerbate the bewilderment experienced by BVI users regarding the DL configuration and organization. In the mobile environment of DL, a summary of the main options of the DL is critical for BVI users to comprehend the DL's overall structure. A shallower and wider navigational structure, as opposed to a narrower and deeper one borrowed from the desktop version, is the best option for BVI users to navigate the main DL page and understand its structure, leading to potential improvements in task performance for BVI users and also sighted users (do Carmo Nogueira et al., 2019; Hochheiser & Lazar, 2010).

#### 5.2.2. Add a meaningful label for an icon

Features of applications need to be clear and discoverable. Users cannot perform actions for some features due to a lack of discoverability rather than inaccessibility of content (Rodrigues et al., 2020). In contrast to the readily accessible features in various systems, features in DLs can be challenging to pinpoint owing to the elaborate interface of the DLs, which comprises a plethora of elements encasing particular features, compounded by suboptimal design, such as the invisible features. Among the situations, DLF occurred most frequently, particularly related to the search box. The image icon of a magnifying glass without the search box prevented BVI users from finding the search icon. Offering a meaningful label indicating the location of the search box would solve this issue (Apple, 2021).

#### 5.2.3. Skip to and navigate through search results

Due to the imprecision of search outcomes within DLs, sifting through an extensive array of search results can be daunting, and this is particularly arduous for BVI users as they endeavor to uncover pertinent information in DLs. Unlike in the desktop environment, BVI users could not skip irreverent results in M.Web because these results were presented as links rather than headings. The M.Web design of DLs can solve this issue by presenting search results using headings. In addition, new features, such as invisible "skip to" links only recognized by screen readers, help BVI users effectively navigate through search results (Xie et al., 2020).

#### 5.2.4. Reduce text

Unlike various IR systems, DLs typically encompass collections that are centered on particular subjects. It is imperative to furnish descriptions of collections or items, as this is crucial for BVI users to gain a basic understanding of each collection or item. BVI users had difficulty identifying a relevant collection/item because the descriptions were trimmed. Providing a concise summary or extracting the key information from the description allows BVI users to quickly determine whether a collection/item is relevant.

#### 5.2.5. Encode a scanned document

DL users frequently have the necessity to pinpoint particular information within a single item, as opposed to merely locating a relevant item. Consequently, it is vital that users have the ability to utilize the features at their disposal to aid them in maneuvering within items to locate the information they require. For BVI users, navigating within an item in DLs can be exceptionally demanding, particularly when examining scanned documents composed of images incompatible with screen readers. To allow BVI users to easily navigate within an item, especially a PDF document, the DL M.Web should present transcripts of the documents or extract and analyze PDF document elements using different research formulas (Fayyaz et al., 2021; Pradhan et al., 2022; Rastan et al., 2019), allowing BVI users to easily access information within PDF documents.

The enhancement of M.App is also essential even though M.App has overcome some of the unique problems of M.Web. The design needs to address issues that hinder BVI users in their exploration of DLs, focusing on the following improvements:

1. Offer key information about the DL, in particular, synchronous and asynchronous help information available in M.Web and desktop DL versions;

2. Ensure that all design elements are recognizable by screen readers. It is imperative to provide a clear indication that elements are actionable (W3C, 2015);
3. Perform accessibility and usability testing on M.App designs for different scenarios so that the lack of an element (e.g., back element) can be addressed before the M.App is made available to users.

Finally, some situations occurred in DLs on both M.Web and M.App. First, compared to the desktop version of the DL, the mobile version simply borrows desktop design patterns instead of creating and documenting new patterns for mobile devices or omits many useful options from the main page that help BVI users to understand the DL structure more fully (da Silva et al., 2022; Kim et al., 2021; Punchoojit & Hongwarittorrn, 2017). For example, responsive design is an approach to web design that makes web pages render well on a variety of devices and window or screen sizes and involves making strategic decisions that balance the need for flexibility, expressiveness, and usability (Kim et al., 2021). Therefore, it is important to consider the target audience, the purpose of the website, and the available resources for selecting a design pattern for the mobile version.

## 6. Conclusion

With the significant increase in the popularity of mobile devices, DLs can no longer rely on desktop interfaces to meet the needs of their users, especially BVI users with unique information-seeking needs and challenges. This is the first study that compares the situations BVI users face between two mobile platforms and between the mobile and the desktop environments. This article compares the situations BVI users encountered in the two mobile platforms and highlights the six situations that occurred more frequently in the M.Web than the M.App version of LOCDC. Notably, these situations prevented BVI users from completing their search process, and the majority of BVI users did not have a chance to reach individual items. Furthermore, eight unique situations in the mobile environment were identified after comparing them with the desktop environment; these situations were linked to the overall DL structure, features and locations, search results, and items. The reduced size of the mobile interface, complex DL structure, and sight-centered design created more difficulties for BVI users using DLs in the mobile environment.

Theoretically, the findings of this study contribute to an in-depth understanding of BVI users' problems in their information search process caused by DL design in mobile and desktop environments. Practically, the study's findings offer specific design implications to support BVI users' effective interaction with DLs in the mobile environment. By implementing recommended design modifications in both M.Web and M.App, DLs can provide improved usability and accessibility to BVI users. This study not only offers insights to investigate BVI users in their interactions with DLs, which can also be applied to BVI user studies in other types of IR systems, but also enhances the design of these systems to support BVI users' unique needs.

Limitations of this study are mainly related to the participant sample size, the sample of DLs, and the sample of mobile devices. While 30 BVI participants are appropriate for statistical analysis, it might not be sufficient to represent the broader BVI user group. Although LOCDC represents one national-level DL and is the only DL with an app version available at this level, future studies need to extend to different types of DLs and IR systems with diverse designs and coverage. Simultaneously, this study only focuses on iPhone usage; future studies should also consider additional mobile device types with various operating systems and sizes (e.g., tablets of different sizes). Moreover, this study concentrates on BVI users who must rely on screen readers to interact with DLs. Future studies need to examine how users' various degrees of visual impairments affect their interactions with DLs and their requirements for DL design. By examining BVI users' interaction with a variety of DLs and IR systems using diverse mobile devices, we can better enhance their designs to support BVI users in the mobile environment.

## Disclosure statement

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