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Blind and visually impaired (BVI) individuals face significant accessibility and usability problems while interacting with web and mobile applications. Current approaches to resolve those problems are overly techno-centric and ignore the role of BVI users in determining the success or failure of an interaction. Using the "Theory of Affordances" as a theoretical lens, this research includes the users in the equation. This research argues that the interaction strategies of BVI users play a vital role in determining the success or failure of their web and mobile interactions.

Extant Information Systems literature lacks a comprehensive understanding of the BVI users' interaction strategies. Therefore, the purpose of this research was to produce a comprehensive understanding of the BVI web and mobile users' interaction strategies, respective accessibility, and usability problems, and use that knowledge to resolve the identified problems.

This research is situated in the context of BVI users' personal health information management using web and mobile applications. The research adopts a novel semi-ethnographic, conversation-style qualitative data collection methodology. The research design is an observation study with BVI web and mobile users. The research produces the comprehensive understanding of the web and mobile interaction strategies of BVI participants, and the respective accessibility and usability problems.

The identified Web interaction strategies are:

- Use of screen-reader specific navigation functions
- Use of links list
- Use the up and down arrow keys
- Use the “table layer”
- Using arrow keys
- Use of the tab key
- Use of the screen-find function
- Hit the enter key
- Hit the spacebar
- Tab and shift + tab in succession
- Up and down arrow keys in succession
- Use screen-reader function such as insert + tab in JAWS
- Re-doing the component-level operation
- Restarting the browser and re-doing the entire task-flow
- Trial and error

The identified mobile interaction strategies are:

- Sequential scanning
- Gambling scanning
- Direct-touch scanning
- Read character-by-character
- Read word-by-word

- Read line-by-line
- Skim through headings
- Flick left and flick right in succession
- Flick left and flick right in succession
- Use of handwriting
- Use of braille screen input
- Use of direct-touch typing
- Use the dictation feature
- Use of an external keyboard
- Use of standard typing
- Use of touch typing
- Re-doing the component-level operation
- Moving one step back and re-tracing the path
- Restarting the application and re-doing the entire task-flow
- Trial and error

The web interaction strategies are very similar to the mobile interaction strategies. The participants often develop multiple strategies to achieve their objectives and then choose to execute one or more of the strategies considering various contextual factors. The strategies can be broadly classified as exploration or exploitation. The strategies in the exploration category intend to gather the information about the interface. The strategies in the exploitation category intend to use the properties of the interface without exploring the interface.

This research makes the following contributions:

- Defines the construct "interaction strategy" as a coordinated sequence of user interactions with online resources that is intended to achieve an interaction goal. It allows us to study the entire interaction as a single unit.
- Develops a semi-ethnographic, conversation-style qualitative data-collection methodology to study human technology interactions. It implements the methodology to study the BVI users' web and mobile interactions using a screen-reader.
- Develops the theoretical analysis methodology to identify the areas of improvement in human technology interactions.
- Generates the design and interaction principles to resolve the identified accessibility and usability problems.

UNDERSTANDING THE INTERACTION STRATEGIES OF BLIND HEALTH IT USERS: A QUALITATIVE STUDY

by

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APPROVAL PAGE

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CHAPTER I

INTRODUCTION

Motivation

The number of blind and visually impaired (BVI) Americans with diabetes is likely to increase sharply. According to the American Diabetes Association, in 2015, 30.3 million Americans, or 9.4% of the U.S. population, had diabetes, and 1.5 million Americans are diagnosed with diabetes every year (American Diabetes Association, 2018). It is likely that as the number of Americans with diabetes soars, so does the number of BVI Americans with diabetes. It is because BVI adults are substantially more likely to report poor, fair, or worsening health than are adults who are sighted (Capella-McDonnall, 2005; Tielsch, Sommer, Katz, Quigley, & Ezrine, 1991; Wang, Mitchell, & Smith, 2000) and more likely to have serious health issues such as diabetes (Thylefors, Négrel, Pararajasegaram, & Dadzie, 1995). While on one hand the number of BVI Americans acquiring diabetes increases, so does the number of diabetic Americans going blind. This is not surprising, as diabetes is a leading cause of blindness (American Optometric Association, 2018; National Eye Institute, 2015). The National Eye Institute estimates that the number of Americans suffering with diabetic retinopathy will almost double from 7,685,237 in 2010 to 14,559,464 in 2050 (National Eye Institute, 2017). Thus, the two health problems, diabetes and blindness, go hand in hand, and the number of Americans with both diabetes and blindness is rising continuously. This motivates us to situate our research in the context of personal health information management pertaining to diabetes for BVI individuals.

The National Standards for Diabetes Self-Management, Education and Support (Haas et al., 2012) suggests that the primary interventions to manage blood sugar involve awareness, education, and support. Research demonstrates the efficacy of diabetes self-management education and support interventions. For example, diabetes self-management education and support interventions improve hemoglobin A1c (HbA1c) levels by as much as 1% (Powers et al., 2015). These interventions are often delivered through health information technology (Health IT) which is comprised of eHealth and mHealth systems. For example, eHealth systems such as “My Diabetes Home” available at www.mydiabeteshome.com, and mHealth systems such as “GoMeals” available through the Apple App Store allow patients to manage their blood sugar logs on the internet. The World Health Organization (WHO) defines eHealth as the use of information and communication technologies for delivering health services and mHealth as a subset of electronic health (eHealth) that provides health services and information via mobile technologies such as mobile phones and PDAs (WHO, 2011). In this dissertation, eHealth refers to the web-applications accessible using a computer web-browser, which provide personal health information management services to patients; mHealth refers to the mobile applications, which provide personal health information management services to patients.

The use of Health IT by patients and their doctors both benefit patients. For example, the use of Health IT by patients enables them to search for the relevant health information online (Eckler, Worsowicz, & Rayburn, 2010), and to get involved with the patient community (Thielst, 2011) to discuss topics pertaining to patient education, health promotion, and crisis communication (Eckler et al., 2010). The use of Health IT by doctors benefits patients by improving the clinical outcomes such as the rate of use of vaccinations. For example, computerized physician reminders increased the use of influenza and pneumococcal vaccinations for hospitalized patients (Dexter et al., 2001) and computerized reminders improved influenza and pneumococcal vaccination rates among rheumatology patients-at-home taking immunosuppressant medications (Ledwich, Harrington, Ayoub, Sartorius, & Newman, 2009). Similarly, mHealth interventions can improve clinically relevant diabetes-related health outcomes by increasing knowledge and self-efficacy of patients to carry out self-management behaviors (Krishna & Boren, 2008). Thus, use of Health IT by patients and their doctors has significant benefits for patients.

On the other hand, the use of Health IT by doctors benefits the doctors too. For example, implementation of electronic health records (HER) benefits the clinical outcomes such as improvements in the quality of care, a reduction in medical errors, and allows quicker access to clinical support such as guidelines, lab reports, etc. Consequently, the doctors using EHR had fewer malpractice claims against them (Virapongse et al., 2008). Additionally, the use of Health IT is an important driver of patient engagement in healthcare (Barello et al., 2016). Thus, in general, the use of Health IT by doctors offers them the potential for enhanced reach, including traditionally underserved populations at a relatively low cost, scalability, time-efficiency, and the capacity to provide tailoring and customization for individual patients (Ahern, Kreslake, & Phalen, 2006).

Unlike sighted users BVI engage in non-visual interactions with Health IT using screen-readers. A screen-reader reads out the textual content of the user's screen in a sequential manner and allows access to the various functions that may be on the web or mobile application interface (Leuthold, Bargas-Avila, & Opwis, 2008). This applies to computer-based applications including web browsers, as well as mobile devices across platforms. Screen-readers provide numerous keystroke and gesture combinations to allow their users to interact with the computer or mobile (Harper, Goble, & Stevens, 2005). Some examples of computer screen-readers include Job Access With Speech (JAWS) and NonVisual Desktop Access (NVDA) for the Windows operating system and VoiceOver for the MAC operating system, etc. Some examples of mobile screen readers include TalkBack on the Android mobile operating system, VoiceOver on the iOS mobile operating system, and Nuance Talks on the Symbian mobile operating system, etc. VoiceOver and TalkBack are by default included in the respective operating systems. However, other screen-readers need to be procured of the shelf and manually installed.

It is important to note that the nature of BVI screen-reader users' Health IT interactions is significantly different than the nature of sighted users' Health IT interactions. Computer and mobile phone users, both sighted and BVI, should first locate the interface element they want to operate on and then operate on that element. Sighted computer-users can scan the visual interface in a non-sequential manner to locate the desired interface element, directly move the mouse pointer to the interface element, and perform the desired operation such as double click. However, BVI users need to scan the interface in a sequential manner using numerous commands, simultaneously listening to the screen-reader output to locate the desired interface element, move the keyboard cursor to the interface element, and then perform the desired operation such as hitting the return key. In case of touchscreen mobile phone, sighted users can scan the visual interface in a non-sequential manner to locate the desired interface element, and directly perform the desired operation such as touch, swipe right, etc. However, BVI users should scan the interface in a sequential manner using several gestures, simultaneously listening to the screen-reader output to locate the desired interface element, and then perform the desired operation such as double-tap. BVI users' interactions with both the computer and mobile, therefore, involve many more key commands and gestures than the sighted users' computer and mobile interactions do.

Differences in how BVI and sighted users interact with computers and mobile devices affects how these users think about their technology interactions. BVI users conceptualize their interactions with technology in a manner that is different from sighted users. Research establishes that online resources are sight-centric—they are developed with sighted users in mind (Bradbard, Peters, & Caneva, 2008). It is not surprising, therefore, that BVI users face significant accessibility and usability problems in interacting with these resources (Hailpern, Guarino Reid, Boardman, & Annam, 2009). Here, accessibility refers to how well, or not, the system allows users access to the system's functionality (Goodhue, 1986). Usability refers to how well the system fits with the intended user's notion of performing a system-based task (Goodwin, 1987). Poor accessibility and usability are undesirable in any system for any user. However, the lack of accessibility and usability creates additional, often insurmountable challenges for BVI users (Leuthold et al., 2008). Correani, Leporini, and Paternò (2004) found that BVI users are half as likely to complete tasks as their sighted counterparts when using online resources with a screen-reader. Zeng and Parmanto (2003) found that the then prevalent eHealth systems did not comply even with the bare-minimum accessibility requirements. Sahasrabudhe and Singh (2016) found that mHealth lacks adequate accessibility and usability for BVI users. Presence of such accessibility and usability problems suggest that over 20 million BVI Americans may not be able to use health IT (eHealth and mHealth resources) in an effective manner and benefit from their intended purpose. It motivates us to investigate ways to improve the accessibility and usability of Health IT for BVI users.

Current Approaches and Open Questions

Current approaches to ensure the accessibility and usability of the web and mobile technologies include developing guidelines such as Web Content Accessibility Guidelines 2.0 (Caldwell, Cooper, Guarino Reid, & Vanderheiden, 2008), developing assistive technologies (AT) such as screen-readers, and developing accessibility legislatures such as Section 508. The guidelines tell us how to develop the accessible and usable interfaces. Assistive technologies leverage the accessibility and usability features embedded in the interfaces to assist BVI users in interacting with those interfaces. Whereas the legislatures compel the technology developers to follow the accessibility guidelines to produce accessible and usable interfaces. On one hand, AT cannot be effective if the interface does not comply with the guidelines; and on the other hand, even if the interface is 100% compliant with the guidelines it cannot guarantee effective accessibility and usability for BVI users (Power, Freire, Petrie, & Swallow, 2012). BVI users might still face usability problems. The question then becomes: Which is the missing piece of the puzzle?

We argue that the missing piece of the puzzle is the user. If a BVI user's interaction with an interface is successful then it means that the interface implements the accessibility and usability features appropriately, as well as that the user knows how to utilize the accessibility and usability features embedded in the interface. Whereas, if a BVI user's interaction with an interface is not successful then it may mean that either the interface does not implement the accessibility and usability features appropriately, or the interface implements the accessibility and usability features appropriately but the user doesn't know how to utilize the accessibility and usability features embedded in the interface. Therefore, if we want to improve the success of BVI users' interactions then we must inform both the design as well as the user's strategies of interaction with the interface. However, current approaches are overly techno-centric and advocate that accessibility and usability should be achieved by fixing the technology alone. They completely ignore the role of the user in the success or failure of an interaction. Therefore, we propose to include the user in the equation.

To include the user in the equation, we turn to the theory of affordances (Gibson, 1986). We view a BVI user's interaction with a Health IT interface as an exercise to realize an affordance. An affordance is defined as an action potential which emerges from the contextually situated interaction between a user and an interface to achieve a specific goal.

For example, in the case of a log-in screen, the user recognizes that there is a webpage with certain controls on it, such as the user name field, password field, and submit button. This interface affords its users to log-in to the system. Similarly, an eHealth system such as WebMD.com affords its users to find health-related information such as the normal blood sugar levels for an adult without diabetes. A BVI user's interaction is successful if, and only if, that user realizes the intended affordances in a reasonable amount of time. Research has demonstrated that mere technical accessibility does not guarantee successful interaction. Therefore, when a BVI user fails to realize an affordance it can be because of a faulty design or faulty strategy of interaction. Therefore, along with the technical solutions, a sound understanding of BVI users' interaction strategies to achieve specific goals is necessary to inform both the design and the user behavior as applicable. In this dissertation, we define the concept of "interaction strategy" as a coordinated sequence of user interactions with online resources that is intended to achieve a goal.

We study the application and utility of this concept in the context of Health IT (eHealth and mHealth systems) to achieve the objectives which are commonly associated with Personal Health Information Management (PHIM). We understand BVI users' accessibility and usability problems as they employ various interaction strategies. We investigate and analyze the constituents of these strategies to explain successes and failures in achieving objectives. Understanding what works and what doesn't, as well as why, allows us to develop design principles for Health IT which are amenable to the interaction strategies of BVI users and interaction principles which will improve BVI users' interaction strategies. This dissertation attempts to answer the overarching research question: "How can we improve the design of Health IT (eHealth and mHealth systems) resources for the BVI using interaction strategies employed by BVI users?"

More specifically, we answer the following sub-questions:

RQ1: What are BVI users' interaction strategies and the accessibility and usability problems in executing those interaction strategies in the context of achieving the PHIM goals using eHealth and mHealth resources?

RQ2: How can the design and interaction principles be designed to alleviate the accessibility and usability problems identified in RQ1?

Our Approach

To answer RQ1, we conduct an observation study with five BVI JAWS screen-reader users and five BVI iPhone users. We request every participant to perform five personal health information management tasks using the respective eHealth or mHealth. We collect the participants' concurrent and retrospective verbal protocols. We audio-record participant verbalizations, and screen-reader announcements if any while the participants complete the tasks. Then, we transcribe the audio recordings and conduct the interpretive analysis using the theoretical foundation we develop in the next chapter.

We code and analyze the transcripts corresponding to user goals pertaining to the Personal Health Information Management tasks, respective interaction strategies, user rationale for choice of the respective strategies, expected outcomes, actions executed, perception of system responses and their interpretations, problems experienced by the users in executing their interaction strategies, and user strategies to work around those problems. The expected outcome of our analysis is (a) a framework comprising the interaction strategies of BVI participants while completing the Personal Health Information Management tasks using eHealth and the problems in executing those interaction strategies, and (b) a framework comprising the interaction strategies of BVI participants while completing the Personal Health Information Management tasks using mHealth and the problems in executing those interaction strategies.

To answer RQ2, we conduct a comparative analysis of the BVI participants' interaction strategies to achieve respective goals, then identify the reasons of the accessibility and usability problems in terms of the technology design and the participant's interaction strategy, then analyze the respective user interfaces using the web and mobile accessibility guidelines to identify (a) the plausible causes of the identified problems, and (b) the potential remedies to address those problems, and then use the outcomes of the comparative analysis of BVI participants' interaction strategies, and eHealth and mHealth UI analysis to develop design principles and interaction principles to address the problems. The expected outcome of this investigation is the theoretically validated technology design principles and interaction principles which resolve the problems identified in RQ1.

Dissertation Organization

In this chapter, we explained that the goals of this research are (a) to create a comprehensive understanding of blind and visually impaired (BVI) users' web and mobile interaction strategies and the accessibility and usability problems in executing those interaction strategies in the context of their interactions with eHealth and mHealth systems, and (b) to develop the design and interaction principles to alleviate the identified accessibility and usability problems. Chapter II discusses the results of our literature review. It develops the theoretical foundation for this research and describes our novel approach to create the theoretically validated design and interaction principles. Chapter III describes the research design to achieve the research goal described in this chapter. Chapter IV discusses the analysis and results of our research. Chapter V concludes this dissertation with a discussion of research contributions, implications, limitations and future directions.

CHAPTER II

LITERATURE REVIEW

The blind and visually impaired (BVI) is a user population that interacts with the web and mobile in entirely different ways than sighted users do. Existing literature recognizes that the web and mobile interactions are prone to various accessibility and usability problems; however, current approaches to create an accessible and usable interaction experience are overly techno-centric and are insufficient. Moreover, the current approaches do not take an advantage of various interaction strategies of BVI users. We still do not have a comprehensive understanding of the strategies of this user population to interact with the web and mobile applications. It prevents us from designing the web and mobile applications which support the BVI users' interaction strategies. In this chapter, we discuss the results of our literature review, and develop a theoretical foundation to create a comprehensive understanding of the interaction strategies of BVI web and mobile users, and various problems they face in executing their interaction strategies. We also propose a new approach for creating theoretically validated technology design principles and user interaction principles to alleviate those problems.

About Blind and Visually Impaired (BVI)

Worldwide, 285 million people are estimated to be BVI, 39 million are blind and 246 million are visually impaired (WHO, 2017). Out of those, 23.7 million are American Adults (National Center for Health Statistics, 2016). This number is likely to increase as the American population ages (U.S. Census Bureau, 2014). Individuals go blind due to various causes, such as cataract (Klaver, Wolfs, Vingerling, Hofman, & de Jong, 1998), Optic neuropathy (Klaver et al., 1998), uncontrolled diabetes (National Eye Institute, 2017), old age (National Institutes of Health, 2016), and accidents, etc. BVI is a heterogeneous population. They differ in terms of level of blindness, namely complete or partial blindness (U.S. Department of Veterans Affairs, 2018), the nature of blindness, namely color-blindness, peripheral vision, etc., the time of onset of blindness, namely blind from birth, going blind in early childhood, and going blind in later ages. They also vary in terms of their technology proficiency. Thus, the BVI population is diverse in various ways. In the context of this research, a BVI user is the one who is legally blind. In the United States, legal blindness refers to a medically diagnosed central visual acuity of 20/200 or less in the better eye with the best possible correction, and/or a visual field of 20 degrees or less (American Foundation for the Blind, 2017).

In the following sections, we describe how do BVI users interact with the web and mobile applications, what accessibility and usability problems they encounter in those interactions, what are the prevalent approaches to mitigate those problems, what are the pitfalls in those approaches, and the theorization to propose a new approach.

Interaction of BVI Users with the Web and Mobile

Unlike sighted users, BVI engage in non-visual interactions with the web and mobile applications using screen-readers. A screen-reader reads out the textual content of the user’s screen in a sequential manner and allows them access to the various functions that may be on the web or mobile application interface (Leuthold et al., 2008). This applies to computer-based applications including web browsers, as well as mobile devices across platforms. Screen-readers provide numerous keystroke and gesture combinations to allow users to interact with the computer or mobile application interfaces (Harper et al., 2005). Often, screen-readers are compatible with the Braille Displays on the market. A Braille Display is a device capable of rendering a digital content in form of Braille (American Foundation for the Blind, 2017). Instead of producing a speech output which can be delivered through speakers attached to the computer, screen-readers can produce an output which can be rendered using the Braille Display attached to the computer. However, WebAIM, a leading organization in the field of accessibility, reported that very few, 27% of the survey respondent BVI users use braille output with their screen readers (WebAim, 2017). Some screen-readers are included in the respective operating systems by default. Some screen-readers should be procured of the shelf. Commercial Screen-readers such as Job Access With Speech (JAWS) are expensive and can cost more than $1,500 per license. Tables 2.1 and 2.2 show various screen-readers used by BVI computer and mobile users.

Table 2.1

Computer Screen-readers Used by BVI

Screen-reader Name	**Operating System**	**Free (Y/N)**
Job Access With Speech (JAWS)	Microsoft Windows	N
NonVisual Desktop Access (NVDA)	Microsoft Windows	Y
Window-Eyes	Microsoft Windows	N

Table 2.1

Cont.

Screen-reader Name	Operating System	Free (Y/N)
System Access or System Access To Go	Microsoft Windows	N
ZoomText	Microsoft Windows	N
VoiceOver (VO)	Mac OS	Y
ORCA	Linux	Y

Table 2.2

Mobile Screen-readers Used by BVI

Screen-reader Name	Mobile Operating System	Free (Y/N)
VoiceOver	iOS	Y
TalkBack	Android	Y
Talks	Symbian	N
Mobile Speak	Symbian	N

Although screen-readers exist to enable BVI users to reap the benefits of the Web and mobile revolution, the non-visual interactions are constrained by the factors such as high cognitive load (Theofanos & Redish, 2003), inefficiency (Lazar, Allen, Kleinman, & Malarkey, 2007), and loss of graphical information (Harper et al., 2005; Leuthold et al., 2008). Literature demonstrates that BVI users encounter significant difficulties while interacting with the web and mobile applications (Andronico, Buzzi, Castillo, & Leporini, 2006; Babu, Singh, & Ganesh, 2010; Lazar et al., 2007; McGookin, Brewster, & Jiang, 2008; Sahasrabudhe & Lockley, 2014; Sahasrabudhe & Singh, 2016; Salampasis, Kouroupetroglou, & Manitsaris, 2005).

The following section describes the accessibility and usability problems BVI users encounter in their interactions with web and mobile applications.

Accessibility and Usability

The terms accessibility and usability are often used, misused, and confused. Therefore, it is important to understand the concepts of accessibility and usability and the relationship between them. Accessibility and usability are two related but distinct concepts. Accessibility allows users access to system functionality (Goodhue, 1986). For BVI users, accessibility is treated as a technical construct. It allows screen-readers the necessary access to interface elements of a system (Leuthold et al., 2008). Usability refers to how well a system conforms to users' conceptualization of performing a task (Goodwin, 1987). It is a cognitive construct that depends on the task the user performs. A system that is not accessible is not usable; however, an accessible system does not guarantee usability (Di Blas, Paolini, & Speroni, 2004). For example, accessibility problems prevent access to features and functionality of a website or mobile applications. Usability problems prevent the use of these features and functionality. Our research considers both accessibility and usability issues of BVI users in their web and mobile interactions.

Web and Mobile Accessibility and Usability Problems of BVI

Literature demonstrates that the web lacks adequate accessibility and usability (Babu et al., 2010; Correani et al., 2004; Di Blas et al., 2004; Gerber & Kirchner, 2001; Leuthold et al., 2008; Theofanos & Redish, 2003). Consequently, interacting with web applications is a challenging task for BVI (Babu & Singh, 2009; Babu et al., 2010;

Brophy & Craven, 2007; Erin, 2006; Kulkarni, 2011; Lazar et al., 2007; Sahasrabudhe & Lockley, 2014; Theofanos & Redish, 2003). Several studies demonstrate prevalence of various accessibility and usability problems in BVI user interactions with the web. For example, the accessibility and usability problems of BVI web-users include:

- Inadequate accessibility of presented information such as, lack of an appropriate text-equivalent for graphical information (Husnain, 2011; Lazar et al., 2007; Sahasrabudhe & Lockley, 2014; Lazar et al., 2013; Zeng & Parmanto, 2003), and use of inaccessible PDF documents (Lazar et al., 2007).
- Inadequate accessibility of dynamic content such as, webpages which use asynchronous javascript (AJAX) (Bigham, Cavender, Brudvik, Wobbrock, & Lander, 2007), and use of inaccessible javascripts (Lazar et al., 2013; Wentz, Jaeger, & Lazar, 2011).
- Problems in understanding the purpose and inter-relationships of text and controls on the interface, such as form fields without associated labels (Babu et al., 2010; Lazar et al., 2007; Wentz et al., 2011), inappropriate on-screen text for links (Lazar et al., 2013; Wentz et al., 2011), and inappropriate table headers (Lazar et al., 2013).
- Problems in comprehending the presented information such as, confusing reading order of page content (Lazar et al., 2007; Sahasrabudhe & Lockley, 2014), and difficulties in searching information within a web page (Salampasis, Kouroupetroglou, & Manitsaris, 2005).

- Missing or inconsistent feedback on user actions (Babu et al., 2010; Sahasrabudhe & Lockley, 2014; Wentz et al., 2011).
- Inadequate support for navigation using the keyboard (Wentz et al., 2011).

Although, the volume of research investigating touchscreen mobile accessibility for BVI users is not very high, extant research suggests that creating accessible touchscreen mobile interfaces for BVI users remains a challenge (Arroba, Vallejo, Araujo, Fraga, & Moya, 2011; Bonner, Brudvik, Abowd, & Edwards, 2010; McGookin et al., 2008). Research demonstrates prevalence of various accessibility and usability problems in BVI user interactions with the touchscreen mobile interfaces. For example:

- Problems in working with text such as, difficulty in acquiring screen targets (Oliveira, Guerreiro, Nicolau, Jorge, & Gonçalves, 2011), and difficulties in text entry (Leporini, Buzzi, & Buzzi, 2012).
- Problems in navigation such as, difficulty in reaching the desired information quickly. Specifically, while reading through long lists of information (Guerreiro, Lagoá, Nicolau, Gonçalves, & Jorge, 2008).
- Problems in understanding the purpose and inter-relationships of text and controls on the interface such as, difficulty in associating form controls and tabular data with the respective labels (Milne, Bennett, & Ladner, 2014; Sahasrabudhe & Singh, 2016), and lack of clarity of interactive elements due to the missing functional information (Leporini et al., 2012; Sahasrabudhe & Singh, 2016).

- Problems in use of gestures such as, accidental activation of gestures (McGookin et al., 2008; Oliveira et al., 2011), difficulty in using screen-location specific gestures due to the users' lack of awareness of their location on the touchscreen with respect to its borders (McGookin et al., 2008), and difficulty in drawing complicated shaped gestures and performing short-impact gestures (Kane, Wobbrock, & Ladner, 2011).

Thus, BVI user interactions with the web and mobile applications are prone to several problems. It prevents them from taking an advantage of those applications. The following section describes the prevalent approaches to incorporate the accessibility in the web and mobile applications.

Current Approaches

The three main approaches are:

- Developing the accessibility guidelines
- Developing various assistive technologies
- Strengthening the accessibility legislatures

The following section describes these approaches.

Accessibility Guidelines

Web Content Accessibility Guidelines

In the context of accessibility of the information on the web, the Web Content Accessibility Guidelines (WCAG) is the de facto standard. It comprises a set of accessible web design principles established by the World Wide Web Consortium (W3C) Web Accessibility Initiative (WAI) in 1999. Since then, recommendations of WCAG 1.0, updated to WCAG 2.0 in December 2008 (Caldwell et al., 2008), represent the primary source of guidance for developers and designers on accessible web design (Kelly, Sloan, Phipps, Petrie, & Hamilton, 2005). WCAG 2.0 comprises 12 guidelines, which are organized under four accessibility principles, viz. perceivable, operable, understandable, and robust. Each guideline is broken into testable Success Criterion (SC). To meet the needs of different groups and different situations, three levels of conformance are defined: A (lowest), AA, and AAA (highest). Each SC has an associated level of compliance, viz. A, AA, or AAA. To meet the level A compliance, the web interface should satisfy all the SCs at level A; to meet the level AA compliance, the web interface should satisfy all the SCs at level A and all the SCs at level AA; and to meet the level AAA compliance the web interface should satisfy all the SCs at level A, AA, and AAA. WCAG SCs are considered normative and include implementable techniques which are sufficient to meet the respective SC.

However, research demonstrates the inadequacy of the testable SC to identify the problems, and the insufficiency of the proposed techniques to address the problems. For example, using task-based BVI user evaluations on 16 websites, Power et al. (2012) discovered that only 50.4% of the problems encountered by users were covered by SC in WCAG 2.0. They also demonstrated that implementation of the WCAG 2.0 recommended techniques did not solve the problems.

Standards for Designing Accessible Mobile Applications

Mobile platforms provide Application Programming Interfaces (APIs) to access the information on the screen. The most widely used mobile platforms, viz. Google

Android, Apple iOS, Microsoft Windows, and Blackberry provide respective accessibility APIs. These APIs are accompanied by the design guidelines specified by the respective platform manufacturers (Android, 2018; Apple, 2018; Microsoft, 2018). These guidelines assist the respective mobile app developers to develop applications which are accessible to users with variety of disabilities. Usually, such guidelines are an outcome of the accessibility knowhow and experience of the mobile platform manufacturers. Those are not an outcome of any systematic empirical user-centric research. Therefore, like WCAG, these guidelines tend to be overly techno-centric.

Assistive Technologies (AT)

Another body of research focuses on improving specific aspects of BVI users' web and mobile interactions by improving the web and mobile interface design and developing various AT. For example, in the context of the web interactions, Salampasis, Kouroupetroglou, and Tektonidis (2005) attempted to use semantic annotation of web pages to improve the information seeking efficiency of BVI users. Yu, Kuber, Murphy, Strain, and McAllister (2006) attempted to use audio and haptic feedback to improve BVI users' web navigation. Takagi, Saito, Fukuda, and Asakawa (2007) attempted to use voice browsing to improve BVI users' web navigation. To help BVI use Google search interface, Andronico et al. (2006) redesigned the Google search interface by structuring the UI in logical sections, grouping interface elements by function using headings and hidden labels, and adding aural feedback on the page elements using the aural CSS. Similarly, in the context of mobile interactions, several studies, such as Yfantidis and

Evreinov (2006) and Bonner and colleagues (2010), develop AT to improve BVI users' text entry using touchscreens.

However, mere improvement to the design and development of newer and better AT is not sufficient to solve the accessibility and usability problems of BVI users. For example, in their study, Takagi et al. (2007) found that, despite the improvements to the design, BVI participants adhered to their familiar scanning navigation strategies. Their mental models were not built to understand the logical contents. It indicates that mere improvements in the technology design to improve BVI users' web interactions is not effective unless they are trained to take an advantage of such techniques by improving their interaction strategies.

Accessibility Legislatures

Several governments have incorporated WCAG recommendations into laws on web accessibility (e.g., Section 508) of the U.S. federal government (Leuthold et al., 2008). There are many instances when these laws were invoked to force organizations to rectify severe accessibility gaps in their websites and to pay millions of dollars in compensation. The Target accessibility lawsuit in 2006 is one such landmark in the history of accessibility. With this class lawsuit, Target Corporation, a famous retailer, had to pay hefty compensation of $6 million in addition to retrofitting accessibility of its website. Along with monetary damage, such lawsuits create negative publicity which is detrimental to the company brand.

It is evident that accessibility legislatures do possess the potential to impact the business negatively. However, evidence also demonstrates that such laws are not effective in ensuring accessibility of the web and mobile for BVI. Loiacono, McCoy, and Chin (2005) evaluated 417 federal websites and federal contractor websites using the Bobby and found only 23% of websites were compliant with Section 508. Goette, Collier, and White (2006) evaluated the government websites of the 50 states and the District of Columbia and found that nearly one third did not meet even the most fundamental requirements for web accessibility. Jaeger (2006) evaluated 10 federal websites, and found that none of those websites were compliant with the Section 508 web accessibility requirements. Olalere and Lazar (2011) evaluated the accessibility of 100 federal websites and their results show only 8 home pages were free of accessibility violations. Loiacono and colleagues (2005) evaluated the accessibility of the top online product/service sites in eight industries and found that, from the 44 websites, around eight were accessible based on the WCAG Priority 1 guidelines. Thus, the evidence clearly demonstrates that the accessibility legislatures cannot guarantee that the developers incorporate the necessary accessibility in the interfaces they develop.

Theoretical Foundation

Current approaches to ensure the accessibility and usability of the web and mobile technologies comprise developing guidelines such as Web Content Accessibility Guidelines 2.0 (Caldwell et al., 2008), developing Assistive Technologies (AT) such as screen-readers, and strengthening accessibility legislatures such as Section 508 of the United States Workforce Rehabilitation Act. The guidelines tell us how to use the accessibility and usability features of the technologies such as Hypertext Markup Language (HTML) to develop accessible and usable interfaces. Assistive technologies leverage the accessibility and usability features embedded in the interfaces to assist BVI users in interacting with those interfaces. Whereas the accessibility legislatures compel the technology developers to follow the prevalent accessibility guidelines to produce the accessible and usable interfaces. On one hand, AT cannot be effective if the interface does not comply with the guidelines; and on the other hand, even if the interface is 100% compliant with the guidelines it cannot guarantee effective accessibility and usability (Power et al., 2012). Consequently, BVI users encounter significant accessibility and usability problems. Then the question is, “Which is the missing piece of the puzzle?”

The missing piece of the puzzle is the BVI users themselves. If a BVI user’s interaction with an interface is successful then it means that the interface implements the accessibility and usability features appropriately, as well as the user knows how to utilize these features embedded in the interface. Whereas, if a BVI user’s interaction with the interface is not successful then it means that either the interface doesn’t implement the accessibility and usability features appropriately or the interface implements the features appropriately but the user doesn’t know how to utilize them. Therefore, if we want to improve the success of BVI users’ interactions with the interface then we must improve both the design as well as the users’ strategies of interaction.

However, current approaches are overly techno-centric and emphasis that accessibility and usability should be achieved by improving the technology alone. They completely ignore the role of the user in the success or failure of an interaction with that technology. Therefore, we propose to include the user in the equation.

To include the user in the equation, we turn to the theory of affordances (Gibson, 1986). The concept of affordances was originally proposed by Gibson in his book, *The Ecological Approach to Visual Perception*. He believed that studying the visual perception of an animal independent of the environment being perceived is insufficient and results into false understandings. In other words, he believed that the perception is not a property of what is being perceived but is a dyadic effect of what is being perceived and what are the action capabilities of the actor who perceives it. Gibson's definition of an affordance intended an action possibility available to an individual whether or not the individual can perceive the possibility. In Gibson's view, we perceive the world as a combination of medium, surfaces, and substances which together offer some meaningful action possibility to us.

Norman (1988) brings the affordance concept in the technology design. He departs from the Gibsonian definition of affordances. According to Norman, the term affordance refers to the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used. In Norman's view both perceived properties and actual properties of a thing qualify as affordances. He believes that an affordance is a sole property of a thing and is not relative to the action capabilities of an actor. Unlike Gibson, Norman claims that an existence of an affordance is dependent upon the previous experiences of an actor. Norman distinguishes between perceived and actual affordances. He also states that usability is all about the perceived affordances. Therefore, in Norman's perspective, an affordance is the design aspect of an object which suggests how the object should be used (Psychology of Everyday Things).

In the context of this research, an affordance is defined as an action potential which emerges from the contextually situated interaction between a user and an interface to achieve a specific goal. On one hand, developers create various affordances through the interface design and communicate the existence of those affordances to its users by providing an appropriate information as a part of the interface design. BVI users on the other hand, perceive those affordances using a screen-reader and act upon the interface to realize the perceived affordances. Therefore, a BVI user's interaction with an interface is a process to realize the affordance intended by that interface design. For example, in case of a log-in screen, the user recognizes that there is a webpage containing certain controls such as, the user name field, the password field, and the log-in button. This interface affords its users to log-in to the system. The user executes the necessary actions to realize the affordance intended by the interface design. A BVI user's interaction with an eHealth system is successful, if, and only if the user can realize the intended affordances in a reasonable amount of time.

When a BVI user cannot realize an affordance, it may mean either the user cannot perceive the existence of that affordance or the user can perceive the affordance but cannot perform the necessary action to realize it.

- If a BVI user cannot perceive the existence of that affordance then it means either

  - the design is faulty and the information to reveal the existence of that affordance to a user is missing or
  - the design is faulty and although the information to reveal the existence of that affordance is present, it is presented in a way which is not accessible to the BVI user or
  - the design is not faulty but the BVI user does not know how to access that information.
- If the information to reveal the existence of that affordance to a user is missing then the design needs to change to include the information in a way that it is accessible for a BVI user. In other words, we need a design principle to specify how to provide the information to reveal the existence of that affordance in an accessible manner.
- If the information to reveal the existence of that affordance is present but is presented in a way which is not accessible to a BVI user, then the design needs to change to include the information in a way that it is accessible for a BVI user. In other words, we need a design principle to specify how to provide the information to reveal the existence of that affordance in an accessible manner.
- If the user does not know how to access the information which reveals the existence of that affordance then the user needs training. In other words, we need an interaction principle to teach the interaction strategies to access the available information which reveals the existence of that affordance.

- If the user can perceive the affordance but cannot perform the necessary operation to realize it then it means either
  - the design is faulty and does not allow the user to operate on the UI element or
  - the user does not know how to perform the operation on the UI element.
- If the design is faulty and does not allow the user to operate on the UI element then the design should change. In other words, we need a design principle to specify how to design the UI element such that it is operable for a BVI user.
- If the user does not know how to perform the operation on the UI element then the user needs training. In other words, we need an interaction principle to teach the interaction strategies to perform the operation on the UI element.

Our approach, therefore, is to develop the design principles and the interaction principles to remedy the problems encountered by BVI users in their web and mobile interactions. Table 2.3 depicts our theoretical foundation.

Table 2.3

Theoretical Foundation

	Appropriate interaction strategy	**Inappropriate interaction strategy**
Appropriate UI design	• The goal we seek to achieve.	• Improve the BVI users' interaction strategies.
Inappropriate UI design	• Improve the UI design.	• Improve the UI design. • Improve the BVI users' interaction strategies.

Theoretical Approach to Develop the Design and Interaction Principles to Remedy BVI Users' Accessibility and Usability Problems

Based on the theoretical foundation described in the previous section, we now propose our theoretical approach to guide the data analysis and the development of the design and interaction principles. There are three possibilities when two BVI users interact with a technology interface to achieve a goal "G." (1) Both users succeed to achieve "G" or (2) Both users fail to achieve "G" or (3) One user succeeds and another user fails to achieve "G."

- Possibility I: Both users succeed to achieve "G"

If both users succeed to achieve "G" then it means that

1. both users used appropriate strategies to achieve "G."

   We will then identify the interaction strategies which will become part of the interaction strategy knowledge-base. It will enable us to develop interaction principles.

2. the user interface design supported BVI users' interaction strategies to achieve "G."

We will then analyze the interface design to understand (1) why the affordances could be conveyed to the blind users? and (2) why the interaction strategies were successful? Answering the why questions will lead to (1) the relationship between the properties of the interface elements and their resultant ability to convey the affordances to the BVI users and (2) the relationship between the properties of the interface elements and their ability to support the respective interaction strategies. This knowledge will enable us to build design principles to design an interface which supports BVI users' interaction strategies.

- Possibility II: One user succeeds, and another user fails to achieve "G"

If one user succeeds and another fails to achieve "G" then it means that the interface may be difficult to use to achieve "G" but there is at least an interaction strategy to achieve that goal. We will analyze the interface design to find out why one BVI user failed. If it was because of the inability of the design to support the user's interaction strategy, then we will develop a design principle to remedy the problem in the design. If the design was appropriate, then we will identify the successful strategy and will develop an interaction principle to train the users.

- Possibility III: Both users fail to achieve "G"

If both users fail to achieve "G" then it means that both users used inappropriate strategies to achieve "G" OR the user interface design did not support both BVI users' interaction strategies to achieve "G."

We will analyze the interface design to find out why both users failed. If both users used inappropriate interaction strategies to achieve "G" then the users need to be trained on using the appropriate interaction strategies. We will develop interaction principles to train the BVI users on using the appropriate interaction strategies to achieve "G."

If the user interface design did not support both BVI users' interaction strategies to achieve "G" then this is an example of bad design. The interface is not accessible/ usable to BVI users. in that case, we will analyze the interface design to understand (1) why the affordances could not be conveyed to the BVI users? and (2) why the interaction strategies were not successful? Answering the why questions will lead to (1) the relationship between the properties of the interface elements and their resultant inability to convey the affordances to the BVI users and (2) the relationship between the properties of the interface elements and their inability to support the respective interaction strategies. This knowledge will enable us to develop the design principles to remedy the problems encountered by the BVI users in executing their interaction strategies.

Theory of Problem-Solving

We view BVI users' interactions with the web and mobile interfaces as a problem-solving process as proposed by Babu et al. (2010). To better understand BVI users' interaction with Web and mobile application interfaces as a problem-solving process, it is important to understand three key concepts—state, operator, and problem space. A state denotes a data structure that defines possible stages of progress in moving from a problem to a solution (Newell, 1966). In human computer interaction, data structure includes users' actions and system responses (Borgman, 1986). An operator is a procedure that may be used for moving from one state to another by performing some action (Newell & Simon, 1972). In this research, we use the above definitions to understand the different stages BVI users go through, and corresponding processes they employ to progress towards goal attainment. A problem space is the fundamental organizational unit of all goal-oriented activity carried out by human beings (Newell, 1979). This problem space (or problem schema) comprises a collection of states and operators available for achieving a goal, including the knowledge of initial state and goal state (Wood, 1983). It represents the given situation, and various possibilities for transforming this situation (Newell & Simon, 1972). We use this definition to understand the notions of BVI users about (a) different stages they must go through, and (b) corresponding procedures they must follow to complete a PHIM task.

Interaction Strategies of BVI Web and Mobile Users

Many studies have discussed the problems of BVI users while using web or mobile applications. These problems make users underperform and generate frustration (Lazar et al., 2007). In such situations, users employ behavioral adaptations such as the use of coping strategies to overcome the problems encountered. However, a smaller number of studies focus upon the BVI users' behavior in the web setting. Consequently, the information regarding how BVI users interact with the Web, as opposed to what problems they encounter, is surprisingly thin (Power et al., 2013). In the following section, we review the research pertaining to the interaction strategies of BVI web and mobile users.

Harper and his colleagues conducted a series of studies concerning the browsing behavior and coping strategies of BVI users. Their earlier set of studies (Goble, Harper, & Stevens, 2000; Harper, Goble, & Stevens, 2000; Harper, Stevens, & Goble, 1999; Yesilada, Stevens, & Goble, 2003) employed the real-world travel metaphor to define the web mobility of the BVI. They identified browsing pattern, cues in the web that aid travel, and obstacles that hinder travel for the BVI. Power et al. (2013) identified seven interaction strategies of BVI web2.0 users. Those were (a) navigation, (b) discovery, (c) exploration, (d) anchoring, (e) help seeking, (f) reset, and (g) task acceleration. Takagi et al. (2007) identified exhaustive scanning (a scanning tactic by listening to content in a sequential fashion) and gambling scanning (by jumping forward and skipping a determined amount of lines until bumping into content that draws user's attention) as two key browsing strategies of BVI web users.

In other studies (Lunn, Harper, & Bechhofer, 2011; Vigo & Harper, 2013, 2014), researchers focused on the challenges the BVI participants faced while browsing websites and identified coping tactics such as impulsive clicking, exploration tactics, redoing, and giving up. These studies used coping theories and considered the BVI adaptive strategies as coping mechanisms. A few other researchers also explored the coping strategies BVI users employ when faced with a challenging situation while browsing a website. Bigham et al. (2007) identified (a) use of simulated mouse to read text when faced with accessibility problems, for example, using the JAWS cursor in JAWS screen-reader to read the text under mouse focus, and (b) avoidance, for example, avoiding visiting the pages that contained either dynamic content or which issued AJAX requests as the coping strategies of BVI users. Similarly, Borodin, Bigham, Dausch, and Ramakrishnan (2010) identified increasing the speech rate of the screen reader, exploring the visual interface with a keyboard-driven mouse, and falling back to external help as the coping strategies used by BVI users.

Saqr (2016) explored the browsing patterns and adaptive behaviors of BVI computer users across different web environments which are commonly used in daily activities. They identified (a) force load mobile version, (b) use Safari "reader mode," (c) use multiple assistive technologies, (d) use of extensions and plugins, (e) change assistive technology settings, (f) invert colors, (g) using hot keys (shortcuts), (h) search functions, (i) use familiar environment, (j) probing/backtracking, (k) asking for assistance, (l) avoidance, and (m) giving up as the BVI users' adaptive behaviors. They classified the identified adaptive behaviors as technology adaptation or behavioral adaptation.

The different browsing strategies of BVI users identified by previous studies are shown in Table 2.4.

Table 2.4

Browsing Strategies Identified in the Literature

Identified strategy	**Studies**
Anchoring	Power et al. (2013)
Avoidance	Bigham et al. (2007); Saqr (2016)
Change assistive technology settings	Saqr (2016)
Chunk Discovery	Lunn et al. (2011)
Clustered Element	Lunn et al. (2011)
Discovery	Power et al. (2013)
Exhaustive scanning	Takagi et al. (2007); Saqr (2016)
Exploration	Power et al. (2013)
Exploring the visual interface with a keyboard-driven mouse	Bigham et al. (2007); Borodin et al. (2010)
Force load mobile version	Saqr (2016)
Gambling scanning	Takagi et al. (2007)
Giving up	Vigo and Harper (2013); Vigo and Harper (2014); Lunn et al. (2011); Saqr (2016)
Help-seeking	Borodin et al. (2010); Lunn et al. (2011); Power et al. (2013); Sar (2016)

Table 2.4

Cont.

Identified strategy	Studies
Impulsive clicking	Vigo and Harper (2013); Vigo and Harper (2014); Lunn et al. (2011)
Increasing the speech rate of the screen-reader	Borodin et al. (2010)
Masthead Avoidance	Lunn et al. (2011)
Navigation	Power et al. (2013)
Probing	Lunn et al. (2011)
Redoing	Vigo and Harper (2013); Vigo and Harper (2014); Lunn et al. (2011); Power et al. (2013); Saqr (2016)
Task acceleration by using shortcut keys provided by the respective screen-reader	Power et al. (2013); Saqr (2016)
Use Familiar Environment	Saqr (2016)
Use of extensions and Plugins	Saqr (2016)
Use of multiple assistive technologies	Saqr (2016)
Use of search Functions	Saqr (2016)
Use Safari Reader mode	Saqr (2016)

Research Questions

It is important to note that in the extant accessibility and usability literature, the term interaction strategy is loosely defined. For example, strategies such as, “navigation” (Power et al., 2013) are not actually the strategies but a goal a user aims to achieve using the respective strategy. It is important to clearly define the term interaction strategy and distinguish it from the interaction goals. It will enable us to organize the interaction strategies in more meaningful manner which will in turn help us compare the competing interaction strategies to identify the effective strategies for the given context. Moreover, all the identified strategies do not execute at the same level of interaction. The strategy types can be classified under three levels of interaction as shown in the Table 2.5.

Table 2.5

Execution Levels of Interaction Strategies

Interaction strategy	Problem	Task	Component
Navigation	Y		
Discovery		Y	
Anchoring		Y	
Exploration			Y
Task acceleration		Y	Y
Reset	Y	Y	Y

This classification of the strategies according to the level at which they execute is useful to organize the interaction strategies in a meaningful manner. Also, the extant literature did not identify the strategies to work with specific type of control such as a textbox, a password box, clickable text which is not a link or a button etc. It is important to identify the interaction strategies specific to the common controls used in web and mobile user interfaces and the convergences and divergences in those interaction strategies to meaningfully inform the technology design as well as the training for BVI users. We also do not yet know the interaction strategies of BVI users in their interactions with mobile applications. Thus, we do not yet have a comprehensive understanding of the interaction strategies of BVI web and mobile users. This understanding is essential to improve the technology design and the BVI user strategies to improve the outcomes of BVI users' interactions with web and mobile interfaces.

This dissertation will attempt to answer the overarching research question: "How can we improve the design of Health IT (eHealth and mHealth systems) resources for the BVI, using interaction strategies used by BVI users?" More specifically, we will answer the following sub-questions:

RQ1: What are BVI users' interaction strategies and the accessibility and usability problems in executing those strategies in the context of achieving the PHIM goals using eHealth and mHealth resources?

RQ2: How to develop the design and interaction principles to alleviate the accessibility and usability problems identified in RQ1?

Chapter Summary

In this chapter, we discussed the results of our literature review and identified the gap in the literature. We also developed a theoretical foundation to create a comprehensive understanding of the interaction strategies of BVI web and mobile users, and various problems they face in executing those strategies. We also proposed a new approach to create theoretically validated design and interaction principles to alleviate those problems. In the next chapter, we will describe the methods and the research design to answer the research questions.

CHAPTER III

METHODOLOGY

Research Design and Methodology

The overall goal of this research is to produce a comprehensive understanding of the BVI web and mobile users' interaction strategies and the respective accessibility and usability problems while executing those strategies, and to use that knowledge to propose ways to resolve the identified accessibility and usability problems. In this chapter, we describe our methodological approach to achieve that goal.

Table 3.1

Research Design

Study Objectives	Methods	Participants	Analysis	Outcomes
• To produce the frameworks of the eHealth and mHealth interaction strategies of BVI participants and the respective accessibility and usability problems. • To create the theoretical principles to address the accessibility and usability problems identified in the two frameworks.	observation study	• Five legally blind JAWS screen-reader users • Five legally blind iPhone VoiceOver screen-reader users	• Interpretive inductive analysis • Set theoretic analysis • User interface analysis	• The frameworks of the eHealth and mHealth interaction strategies of BVI participants and the accessibility and usability problems in executing those interaction strategies. • Design principles and interaction principles to address the accessibility and usability problems identified in the two frameworks.

Choice of Personal Health Information Management (PHIM) Tasks, eHealth, and mHealth

In this section, we describe the importance of the chosen Blood Sugar Management task context, the five tasks, and the respective eHealth and mHealth to perform those tasks. We select this task context because Diabetes is a leading cause of Blindness and the number of BVI individuals with diabetes is rising (American Optometric Association, 2018). The seven essential self-care behaviors in individuals with diabetes which predict good outcomes are (a) monitoring of blood sugar, (b) risk-reduction behaviors, (c) compliance with medications, (d) healthy eating, (e) being physically active, (f) good problem-solving skills, and (g) healthy coping skills (American Association of Diabetes Educators 2008).

The first three behaviors, (a) monitoring of blood sugar, (b) risk-reduction behaviors, and (c) compliance with medications are directly relevant to the context of blood sugar management. Monitoring of blood sugar involves, setting the blood sugar targets, regularly logging the blood sugar levels, and viewing and understanding the trends in the blood sugar levels. Moreover, it is essential to learn about the normal blood sugar levels to set the appropriate blood sugar targets and to make sense of the trends in the blood sugar levels. Also, learning about the normal blood sugar levels, regularly monitoring the blood sugar levels, and compliance with prescribed medication regimen can be viewed as risk-reduction behaviors. Research shows that medication nonadherence remains a common health care problem. Poor adherence causes approximately 33% to 69% of medication-related hospitalizations (Osterberg & Blaschke, 2005). Thus, the task of adding a medication reminder is of critical importance for patients with chronic illnesses such as diabetes. Therefore, we chose to (a) learn about normal blood sugar levels, (b) set blood sugar target levels, (c) log blood sugar levels, (d) view and understand the trends in blood sugar levels, and (e) add a medication reminder, as the five relevant tasks for the research context.

It is important to note that the chosen tasks are representative of the common web and mobile user tasks. Learning about the normal blood sugar levels involves information search task and viewing and understanding the blood sugar trends involves information comprehension task, which are common essential tasks for the web and mobile users. Similarly, setting the blood sugar targets, logging blood sugar information, and adding a medication reminder involve form-filling tasks which are also common essential tasks for the web and mobile users. Therefore, the chosen tasks allow us to produce outcomes that are generalizable across the web and mobile applications beyond healthcare context.

Identification of Relevant eHealth

We identified the relevant eHealth to perform Task-1–Task-5 through a systematic search on the web using the Google search engine. In the context of Task-1, we used the search string "learn about the normal blood sugar levels." We selected the first ten results. The search results are listed in the appendix. All ten eHealth allowed their users to perform Task-1 "learn about normal blood sugar levels," so we randomly selected one of the ten eHealth to perform Task-1. The chosen eHealth was "http://www.webmd.com."

In the context of monitoring blood sugar (Task-2–Task-4), we used two search strings, "websites to log blood glucose" and "websites to log blood sugar" to find the websites which allowed their users to log their blood sugar information. We used two search strings because the terms “blood sugar” and “blood glucose” are often used interchangeably. We selected the first 10 search results for each search string. From those twenty search results, we selected the unique results. Then we removed the results which were not an eHealth. We removed the eHealth which did not provide any interface to add the blood sugar information. We were left with four eHealth. All four eHealth allowed their users to perform Task-2–Task-4; however, we wanted to maximize the diversity of the eHealth design BVI participants interacted with. The rationale to maximize the diversity of the design was to increase the likelihood of capturing broader span of the interaction strategies used by the participants. Therefore, we chose distinct eHealth for each task.

We randomly selected three of the four eHealth. To perform Task-2, we chose “http://www.gomeals.com/glucose-tracker.” To perform Task-3, we chose “https://www.mydiabeteshome.com/marketing/apps/online-glucose-monitoring-tracking-software.” To perform Task-4, we chose “https://sugarstats.com.”

In the context of Task-5, we used the search string “medication reminder websites.” It yielded no results. Therefore, we used the search string “medication reminder.” We selected the first 10 search results. We removed the results which were not an eHealth. We removed the eHealth which did not provide any interface to add the medication information. We were left with only one eHealth. We chose that eHealth “http://www.mymedschedule.com/” to perform Task-5.

Identification of Relevant mHealth

We identified the relevant mHealth to perform Task-1–Task-5 through a systematic search of the Apple app store. In the context of Task-1–Task-4, we used “Diabetes” as the search string. It yielded 100 results. We shortlisted the applications which belonged to either “medical” or “health and fitness” app store categories. Then we removed the applications for which information to determine their purpose was not available, and which were not patient focused. We created two sublists, List-1 and List-2. To create List-1, we selected the applications which provided the functionality to perform Task-1 (see Table 3.2). To create List-2, we selected the applications which provided the functionality to perform either of Task-2, Task-3, or Task4. Then we removed the applications which were last updated before January 2016. We did so to increase the likelihood of the latest user interface technology being used in the application user interfaces and to increase the likelihood of the applications’ compatibility with the latest version of the VoiceOver screen-reader. Then we calculated an index for every application in List-1 or List-2.

The app store provides user rating for the applications in the app store. The number of ratings is a measure of number of individuals who have used the application at least once. The Rating is the measure of goodness of the application. Also, the app store provides customer rating information for the current version and for all the versions of every application. Using that customer rating information, we calculated an index for every application. We used the formula “10 * (rating for the current version *number of ratings for the current version) + (rating for all the versions *number of ratings for all the versions)" to calculate the index for every application. We multiplied the product (rating for the current version * number of ratings for the current version) by 10 to give more weightage to the current version ratings.

Table 3.2

Applications in List-1

Purpose	Name	Updated on	App store category	Current version	All versions	Calculated index
BG information	WebMD – Trusted Health and Wellness Information	Sep-16	health and fitness	850.5	179763.5	188268.5
BG information	AskMD	Nov-16	health and fitness	22.5	1048	1273
BG information	Everyday Health: Health News, Medical Information	Nov-16	health and fitness	NA	609	1374

We chose the first application WebMD – Trusted Health and Wellness Information to perform Task-1.

Some applications in List-2 did not have customer rating available for their current versions. For such applications, we assumed the value of the product (rating for the current version *number of ratings for the current version) to be 150. We did that because, we observed that all the applications for which no customer rating was available for their current version were updated last after September 2016. It suggested that those applications did not get a fair opportunity to accumulate customer ratings for their current versions. Therefore, we calculated the average of the products (rating for the current version (number of ratings for the current version) corresponding to all the applications for which the current version ratings were available. The average was (76.5 + 22 + 85 + 56 + 31.5 + 10 + 42 + 306 + 720) / 9 = 149.88. We rounded it to the nearest whole number (150). We sorted the list of applications according to the calculated indices in the descending order and selected the first ten results in the sorted list as shown in Table 3.3.

Initially, we chose three distinct mHealth to perform Task-2–Task-4. We reviewed the applications, in the order they appeared in the list, to find out which of the five tasks could be performed using those applications. The first application mySugr: Easy to use daily diabetes logbook allowed its users to perform Task-3 “log blood sugar levels.” Therefore, we chose that application to perform Task-3. However, while collecting the pilot data, the application was updated to a newer version and became totally inaccessible to BVI users. Therefore, we chose the third application Glucose Wiz to perform Task-3. The second application GoMeals allowed its users to perform Task-2 “set blood sugar target levels.” Therefore, we chose that application to perform Task-2. The third application Glucose Wiz - Blood Sugar Log & Medication Tracker allowed its users to perform Task-4 “view and understand the trends in the blood sugar levels.” Therefore, we chose that application to perform Task-4.

In the context of Task-5 “add medication reminder,” we used the search string “medication reminder.” We created List-3 by selecting the first five applications in the search results which were either of “medical” or “health and fitness” app store categories and which were last updated after January 2016. We then calculated the index and sorted the applications in List-3 in the descending order of the index value as shown in Table 3.4.

Table 3.3

Top Ten Applications in List-2

Purpose	Name	Last updated	App store category	App store description	Current version	All versions	Calculated index
BG tracking	mySugr: Easy to use daily diabetes logbook	Dec-16	medical	The free mySugr app is your loyal diabetes tracker for your iPhone. From now on, stay in control of your health and say goodbye to manual logging. On a daily basis, mySugr helps you control your blood sugar levels, monitor your carbs, track your insulin use and avoid hypers/hypos to make your diabetes suck less. Data plays a key role in Type 1 or Type 2 diabetes management and mySugr simplifies the diabetic data ecosystem. It's quick and easy to collect your daily therapy data such as meals, diet, meds, blood sugars, insulin, carbs and more. You can use mySugr as a 24-hour tracker, seeing all essential diabetic data at a glance, right on the first screen. Monitor your medical condition with a graph of the day, average blood sugar, standard deviation, amount of insulin, activity levels and more. Based on five-star reviews and ratings, mySugr is the most popular diary app for diabetics in the world.	720	15555	22755
BG tracking	GoMeals	Dec-16	health and fitness	GoMeals includes tools for eating healthy, staying active, and tracking your blood glucose levels.	150	16074	17574
BG tracking	Glucose Wiz - Blood Sugar Log & Medication Tracker	Nov-16	medical	The most comprehensive type 2 diabetes app on the market, designed by a Certified Diabetes Educator. You'll get all the tools plus the most-up-to-date	306	2011.5	5071.5
BG tracking	Diabetes in Check: Blood Glucose & Carb Tracker	Nov-16	medical	The most comprehensive type 2 diabetes app on the market, designed by a Certified Diabetes Educator. You'll get all the tools plus the most-up-to-date information you need to control and manage your condition every day. This app is designed to help you 1) LOWER YOUR BLOOD SUGAR 2) GET ACTIVE 3) EAT BETTER 4) COUNT CARBS 5) MANAGE YOUR WEIGHT.	42	4288	4708

Table 3.3

Cont.

Purpose	Name	Last updated	App store category	App store description	Current version	All versions	Calculated index
BG tracking	Tactio Health: My Connected Health Logbook	Dec-16	medical	Tactio Health App helps you track and manage a wide range of health data from simple manual logging or syncing with connected health apps and medical devices.	10	3458	3558
BG tracking	Sugar Sense - Diabetes App, Blood Glucose Mgmt	Jan-17	health and fitness	A beautiful diabetes app to be in full control of tracking your personal health. Track your blood sugar level, glucose, carbs, weight, and more. The easiest and simplest way to track your health information	31.5	2916	3231
BG tracking	One Drop for Diabetes Management	Jan-17	health and fitness	One Drop | Mobile is a free award-winning app loaded with features to help you manage your diabetes.	150	1424	2924
BG tracking	Daily Carb - Nutrition Counter and Glucose Tracker	Oct-16	health and fitness	This is the app you are looking for if you are a dieter or who want to control your diabetes or weight!	56	2056	2616
BG tracking	Glucose Companion Free	Oct-16	medical	Glucose Companion Free is a handy blood sugar and weight tracker.	85	1467	2317
BG tracking	Diabetes Kit Blood Glucose Logbook	42736	medical	Join people with diabetes, their families, and healthcare professionals from around the world that have tracked MILLIONS of glucose, meds, food, and activity logs with Diabetes Kit!	22	2047.5	2267.5

Table 3.4

Applications in List-3

Purpose	Name	Last updated	App store category	App store description	Current version	All versions	Calculated index
medication reminder	Mango Health - Medicine Manager, Pill Reminder	Jan-17	medical	Mango Health for iPhone and Apple Watch simplifies your daily health routine, to make it fun, easy, and rewarding. App feature highlights include: reminders	207	18733.5	20803.5
medication reminder	Round Health - Medicine reminder and pill tracker	Jan-17	medical	This simple, beautiful app organizes all of your medications and vitamins in one place. It provides subtle, persistent reminders that go beyond awkward phone alarms. By helping you set “reminder windows” tailored to your medicine and schedule, Round accommodates life’s unpredictable distractions and removes the stress of staying healthy.	58.5	20056.5	20641.5
medication reminder	Medisafe Pill Reminder & Medication Tracker (Free)	Jan-17	medical	Never forget to take your meds, vitamins and pills again with the MUST HAVE pill reminder ranked #1 by pharmacists.	365	6435	10085
medication reminder	Pill Reminder - All in One, Medication Reminders	Sep-16	medical	Pill Reminder is an easy-to-use and reliable app that helps you remember to take your medications at the right time. It allows you to create any type of recurring reminders (every X hours, specific times, daily, weekly, monthly, every X days, etc.). It tracks the remaining quantity of each medication and shows a refill alert when running low.	427.5	2673	6948
medication reminder	MedCoach Medication Reminder	Nov-16	medical	MedCoach is an easy-to-use medical app that helps you remember to take your medications and pills at the right time and day.	17.5	3136	3311

The first application, Mango Health - Medicine Manager, Pill Reminder, allowed its users to perform Task-5, “add medication reminder.” Therefore, initially we chose that application to perform Task-5. However, while collecting the pilot data, the application was updated to a newer version and became totally inaccessible to BVI users. Therefore, we chose the next application in the list, Round Health – Medicine reminder and pill tracker, to perform Task-5. Table 3.5 shows the five tasks and the corresponding eHealth and mHealth to perform the respective task.

Table 3.5

The Blood Sugar Information Management Tasks and the Respective eHealth and mHealth

Task	eHealth	mHealth
Learn about normal blood sugar levels	WebMD.com	WebMD
Set blood sugar target levels	gomeals.com	goMeals
Log blood sugar levels	mydiabeteshome.com	Glucose Wiz - Blood Sugar Log & Medication Tracker
View and understand the trends in blood sugar levels	sugarstats.com	Glucose Wiz - Blood Sugar Log & Medication Tracker
Add a medication reminder	mymedschedule.com	Round Health - Medicine reminder and pill tracker

Determination of the Time Required for Performing the Five Tasks

To determine a baseline for the time required to perform each task using the respective eHealth and mHealth, we requested one sighted computer user and one sighted iPhone user to perform the five tasks using the respective eHealth or mHealth. The interaction using a screen-reader is often longer and BVI users take twice as long as the sighted users to complete an online task (Bigham et al., 2007). Additionally, we planned to interact with our participants while they worked on the tasks. Therefore, to allow sufficient time to the participants, we determined 30 mins as a maximum time limit for the participants to perform each task.

Table 3.6

The Task Time Allocation (in Minutes)

Task	Time taken by a sighted computer user to perform the eHealth task	Time allotted to the BVI computer user	Time taken by a sighted iPhone user to perform the mHealth task	Time allotted to the BVI iPhone user
Task-1	9	30	5	30
Task-2	3	30	5	30
Task-3	6	30	7	30
Task-4	1	30	1	30
Task-5	4	30	3	30

Pilot Study to Test the Think-aloud Methodology

Initially, in December 2016, we conducted a pilot study using the think-aloud method with two JAWS screen-reader users. We briefed them about the think-aloud method and what all they should verbalize. We used the exact method used in our earlier studies, Sahasrabudhe and Lockley (2014) and Sahasrabudhe and Singh (2016) to investigate the accessibility and usability problems of BVI technology users. However, we observed that the participants in the pilot study were overwhelmed by the volume of information they were required to verbalize and they could barely complete one task. In fact, couple of participants backed out due to the complexity of the think-aloud method.

The literature informed us that think-aloud verbalizations is an effective method to understand the participant mental models in problem-solving, however, our aim was not to capture the participant mental models and hence we were not required to know every single thought which came to the participants' minds. We went back to the drawing board and simplified the protocol by structuring it like a conversation.

Another rationale to use the conversation-style of observations was to make the participants feel at ease so that they do not deviate from their usual interaction strategies which enabled us to get the rich qualitative data. We were aware that with the conversational approach, we may not capture every strategy used by the participants in a single task. Therefore, to maximize the likelihood of capturing every interaction strategy of the participants, we requested each participant to perform five tasks.

Observation Study

The purpose of the observation study was to create (a) the framework of the eHealth interaction strategies of BVI participants and the respective accessibility and usability problems, (b) the framework of the mHealth interaction strategies of BVI participants and the respective accessibility and usability problems, and (c) to develop the theoretical principles to address the identified accessibility and usability problems.

Participants

We recruited two groups of participants for this study. Group1 comprised five BVI, legally blind, JAWS screen-reader users and Group2 comprised five BVI, legally blind, iPhone VoiceOver screen-reader users. The legal blindness, in the context of this dissertation, is defined as a central visual acuity of 20/200 or less in the better eye with the best possible correction, and/or a visual field of 20 degrees or less (American Foundation for the Blind, 2017). The rationale for the chosen sample size of BVI users was that the Usability literature recommends recruiting at least five participants for usability evaluation studies as five participants are necessary and sufficient to uncover usability issues of technology interfaces (Nielsen, 2000). The rationale to choose the JAWS screen-reader users was that then recent WebAim screen-reader user survey in 2015 had found that the JAWS screen-reader was the most popular screen-reader among BVI computer users (WebAim, 2017). More than thirty percent of the respondents used the JAWS as their primary screen-reader. The rationale to choose the iOS mobile platform users as our participants was that then recent WebAim screen-reader user survey in 2015 had found that the iOS platform was the most popular mobile platform among BVI mobile screen-reader users (WebAim, 2017). More than 69% of the respondents used the iOS platform as their primary mobile platform and the VoiceOver (VO) as the primary mobile screen-reader. To control the variability among the participants in terms of their familiarity with the respective screen-reader (JAWS/VO), we ensured that every participant in Group1 had used the web with the JAWS screen-reader for more than three years and every participant in Group2 had used an iPhone with the VO screen-reader for more than 3 years. All the participants were adult, English-speaking individuals. Participant gender was not a parameter for the participant recruitment. We used snow-ball sampling to reach the BVI computer and iPhone users. We contacted the BVI individuals from the Industries of the Blind-USA, the Industries for the Blind-USA, and the Blind Technology Center at the University of Pune-India. We informed them about the study and requested their participation. We also requested them to spread the word among their BVI friends. We gave $10 as an incentive to every participant.

Procedure

We requested every participant in Group1 to perform the five tasks using the respective eHealth and every participant in Group2 to perform those tasks using the respective mHealth. Using semi-ethnographic method of observation, we engaged in a conversation with the participants while they perform the tasks. To control the learning effects of the order in which the participants perform the tasks, we ensured that no two participants perform the tasks in the same order.

We observed every participant separately. We observed the participants either face-to-face or remotely using Skype. Five participants preferred the face-to-face setting. The remaining five participants preferred remote setting.

On an average, every participant observation took around four hours. It was not realistic to expect the participants to perform all five tasks in a single session. Therefore, we scheduled three-four sessions with each participant to finish five tasks. We started the data collection in February 2017 and finished it in December 2017.

We collected participant concurrent and retrospective verbal protocols by audio-recording (a) the conversation between us and the respective participant, and (b) the respective screen-reader announcements. We chose to collect the concurrent verbal protocols as they contain evidence of the information that participants process to perform a task (Ericsson & Simon, 1984) and concurrent verbalizations are non-reactive and do not alter participants' behavior in tasks (Ericsson & Simon, 1993). This technique is effective for developing an in-depth understanding of human problem-solving (Newell & Simon, 1972) and is a feasible method to trace usability problems in human computer interactions (Cotton & Gresty, 2006).

We asked several questions to the participants to collect their concurrent and retrospective protocols. The questions were as follows.

Concurrent Protocol Questions

- What objective are you trying to achieve?
- What is your strategy to achieve the objective?
- Why do you choose that strategy?
- Do you know any alternative strategies to achieve the objective?
- Are you facing any challenges in executing the strategy?
- How will you overcome the challenge?

Retrospective Protocol Questions

- What aspects of the interface were helpful for using your interaction strategies?
- What aspects of the interface were not helpful for using your interaction strategies?
- What were the most critical accessibility and usability problems for you?
- Could you have used any alternative interaction strategy to achieve better interaction?

- Can you suggest any improvements to the interface to make the interaction better?
- How soon do you generally give-up an interaction?

Chapter Summary

In this chapter, we described the overall goal of our research, and our observation study approach to achieve that goal. In the next chapter, we will describe the methodology to analyze the qualitative data collected through the observation study and the subsequent findings.

CHAPTER IV

ANALYSIS AND FINDINGS

Analysis and Findings

The overall goal of this research is to produce a comprehensive understanding of the BVI web and mobile users' interaction strategies and the respective accessibility and usability problems while executing those strategies, and to use that knowledge to propose ways to resolve the identified accessibility and usability problems. In this chapter, we will articulate the details of the qualitative analysis of the data and the subsequent findings.

Details of the Qualitative Analysis

We transcribed the audio recordings. We decomposed the resulting transcripts into key-commands/touchscreen gestures executed by the participant, screen-reader announcements, participant verbalizations, and researcher verbalizations. We then identified the strategic action sequences. A strategic action sequence is a series of operations in the Web or mobile application interface that a user applies to achieve a goal (Power et al., 2013). We identified the generic objective and the specific objective for every strategic action sequence. The specific objective is the goal the user aims to achieve by executing the respective strategic action sequence. We used the segments denoting participant verbalizations and researcher verbalizations to determine the specific objective of the respective strategic action sequence. To identify the generic objectives, we collected the specific objectives and grouped them according to the respective unit of user interface under operation. Then we assigned one generic objective according to the higher-level function the user aimed to achieve by executing the respective strategic action sequence and the class of the UI unit on which the operation took place. For example, enter the user name and enter the password were two specific objectives which were grouped under the generic objective “edit a textfield.” For every strategic action-sequence, we identified the participant rationale for choice of the respective strategic action-sequence, problems encountered in executing the respective strategic action-sequence, and work-arounds employed to overcome the problems. We also identified the alternative strategic action-sequences to achieve the respective specific objective. This analysis, produced the comprehensive frameworks of BVI participants’ eHealth and mHealth interaction strategies and various accessibility and usability problems the participants face while executing those interaction strategies.

The Theory to Organize the Interaction Strategy Frameworks

Users interact with a technology design with an intention to solve a problem. For example, a diabetes patient uses “myDiabetesHome” website to log their blood-sugar information which forms their interaction goal. During the problem-solving process, users achieve numerous smaller sub-goals which form the task objectives. Every task objective is achieved through operating upon various interface elements such as, a textfield, a drop-down menu, a link, a button, etc. users formulate the overall problem-solving strategy, task completion strategy, and the strategy to operate a respective interface element. BVI users generally maintain a repertoire of strategies to achieve their various generic objectives. According to the contextual factors they choose the strategy to achieve their specific objective.

Often, they face difficulties in executing their strategies. The difficulties can be classified into two types of gulfs: (a) Gulf of execution, and (b) The gulf of evaluation. The gulf of execution represents a mismatch between the user's intentions and allowable actions by the system. This creates problem in translating a psychological goal into a physical action for the user. A measure of this gulf is how well the system allows the user to perform the intended actions directly, without extra effort (Norman, 1988). This gulf gives rise to roadblocks and extra steps that require additional mental and physical effort. The user gets distracted from the task being performed, increasing the chances of failure (Norman, 1988). The gulf of evaluation is the mismatch between the physical representation provided by the system, and the user's ability to perceive and interpret it directly with respect to their expectations and intentions (Norman, 1988). In other words, it is the difficulty of assessing the system state, and how well the system supports the discovery and interpretation of that state (Norman, 1988). This gulf is large if feedback on system state is difficult to perceive and interpret, and is inconsistent with user's expectation of the system (Norman, 1988). These difficulties manifest as the accessibility and usability problems experienced by the users. While the users face an accessibility and usability problem, it can be at the level of overall problem-solving process, or at the level of achieving a specific task objective, or at the level of operating upon a specific interface element. Therefore, in the framework, we organize the interaction strategies at the three levels as described above. This organization enables us to compare between the efficacy of the strategies to achieve the respective goal and to Pin-point the areas of improvement.

Analysis Method to Develop the Design and Interaction Principles

Using the theoretical foundation developed in the second chapter, we further analyzed the data to formulate the design and interaction principles to solve the accessibility and usability problems faced by participants. For each Specific Objective - "SO," as shown in Table 4.1, we classified the data into three sets each and performed the specified analysis to produce the solutions.

Table 4.1

The Data Classification Scheme

Set	Description	Analysis	Expected outcome
Set1	When at least one participant could achieve and at least one participant could not achieve "SO."	1. Identify the interaction strategies that led to the success in achieving "SO." 2. Develop the interaction principles to specify the use of those interaction strategies to achieve "SO." 3. In case of the participants who succeeded, analyze the UI design to understand the relationship between the UI elements and their ability to support the respective interaction strategies. 4. Develop a design principle to specify the use of the identified UI elements to support the respective interaction strategies. 5. Analyze the UI design to find out why some participants faced challenges in executing their interaction strategies. 6. If their interaction strategy was appropriate then develop a design principle to specify the appropriate use of the identified UI elements to support the respective interaction strategy. 7. If the interaction strategy was inappropriate then develop an interaction principle to specify the use of the appropriate interaction strategies to achieve "SO."	● Design principles to improve the accessibility. ● Interaction principles to overcome the accessibility challenges.

Table 4.1

Cont.

Set	Description	Analysis	Expected outcome
Set 2	When none of the participants could achieve the specific objective "SO."	1. Identify the interaction strategies used by the participants to achieve "SO." 2. Analyze the UI design to find out why the participants faced challenges in executing their interaction strategies. 3. If the interaction strategy was appropriate then develop a design principle to specify the appropriate use of the identified UI elements to support the respective interaction strategy. 4. If the interaction strategy was inappropriate then develop an interaction principle to specify the use of the appropriate interaction strategies to achieve "SO."	● Design principles to prevent the accessibility problems
Set 3	When all the participants successfully achieve the specific objective "SO."	1. Identify the interaction strategies used to achieve "SO." 2. Develop an interaction principle that specifies the use of the identified interaction strategies to achieve the specific objective "SO." 3. Analyze the respective UI design to understand the relationship between the UI elements and their ability to support the respective interaction strategies. 4. Develop a design principle that specifies the use of the identified UI elements to support the respective interaction strategies.	● Interaction principles ● Design principles

User-interface Analysis

Using the prevalent web and mobile application accessibility guidelines we analyzed the respective eHealth and mHealth UI design. We used the Web Content Accessibility Guidelines 2.0, Mobile Web Best Practices, and IOS accessibility guidelines to identify (a) the plausible causes of the problems identified in the two frameworks, and (b) the potential remedies to address those problems.

Findings

We now describe the findings of this analysis in terms of design principles (DP), interaction principles (IP), web and mobile interaction strategies and the respective accessibility and usability problems, and the factors influencing BVI user's choice of the interaction strategies. The first sub-section describes the findings in the context of the web and the second subsection describes the findings in the context of the mobile applications.

Findings in the Context of the Web

Table 4.2

The Web Interaction Strategies and the Problems Faced while Executing the Web Interaction Strategies

Objective	Strategy	Accessibility/Usability Problems
Locate the target control or information	Use of screen-reader specific navigation functions	none
	Use of links list	unavailability of the contextual information
Navigate within a table	Use the up and down arrow keys	difficulty in understanding the associated labels
	Use the "table layer"	none
Scan the web page	Using arrow keys	none
	Use of the tab key	propensity to miss the important information which is not focusable
	Use of screen-find function	none

Table 4.2

Cont.

Objective	Strategy	Accessibility/Usability Problems
Open a form field	Hit the enter key	accidental form submission, unexpected shift of the focus
	Hit the spacebar	none
Probe the control under focus	Tab and shift + tab in succession	none
	Up and down arrow keys in succession	none
	Use screen-reader function such as insert + tab in JAWS	none
Work-around the gulf of evaluation	Re-doing the component-level operation	information re-submission
	Restarting the browser and re-doing the entire task-flow	none
Work-around the gulf of execution	Trial and error	accidental form submission

Locate the control or information. While exploring an unfamiliar web page, the participants primarily used the up and down arrow keys to sequentially scan the webpage. They could always successfully locate the desired information/control using the sequential scanning using the arrow keys. They preferred the arrow keys over the tab key because, in their experience, (a) often, the custom controls such as “My Preferences” seen in <Fig> do not receive the keyboard focus, and (b) many times the tab sequence is not logical which reduces their speed of interaction.

They used the JAWS screen-find function to locate the control label when they were unsure of the type of the target control. For example, they used the screen-find function to find “My Preferences” which was a custom control. The strategy was effective to locate the target control only when the participant knew the respective text label.

They also used the screen-reader-specific navigation quick keys to rapidly locate the target control when they knew the type of the target control. For example, they used the quick key “e” to locate the edit fields, the quick key “b” to locate the buttons, etc. The strategy worked effectively when the design exposed the respective role of controls to the screen-reader. Screen-reader could recognize the role of the standard HTML elements such as, input buttons, checkboxes, edit fields. However, the strategy did not work with the custom controls for which no ARIA role was specified. “My Preferences” in <Fig> was an expandable/collapsible menu without the associated “role” attribute. P4 used the quick-key “b,” JAWS list of links, and list of buttons to locate “My Preferences.” However, none of the functions worked as “My Preferences” did not have the role specified. When the quick-keys did not yield expected outcomes, the participants scanned the entire webpage using the arrow keys as the alternative strategy. The following interaction demonstrates it.

<snip>

BVI: I am looking for “my preferences” link.

key:insert+f7

SR: links list dialogue. links list view.

key: m //to move to the link “my preferences.”

SR: Tung sound //no link beginning with “m” was in the list. So, JAWS made the sound.

key: escape.

SR: escape

SR: list

key: escape

SR: escape

BVI: I tried links list but could not find “my preferences” link.

key: ctrl+insert+b

SR: list of buttons dialogue.

key:m

SR: Tung sound //no button with its label starting with “m” was found.

key: escape

SR: escape

SR: list

BVI: I tried the list of buttons but it is not a button.

BVI: I will now search across the entire page using the arrow keys.

</snip>

Participants used the JAWS links list to quickly locate the desired link on a page. The strategy was effective; however, the users could not understand the contextual information for the links while using the links list. Also, JAWS did not distinguish the links from the anchors (same page links) in the links list. When the participants activated the anchor “Hi IS” <fig> they expected a new page. They got confused as the new page did not open.

Navigate within a table. Participants used two strategies to navigate within a table, (1) used the up/down arrow keys and (2) use the “table layer” in JAWS screen-reader. Use of the “table layer” was an effective strategy and it always worked. However, only one of the five participants used the strategy. Two other participants knew about the strategy but they mentioned that they never use it. The remaining two did not knew about the “table layer” functionality the JAWS screen-reader.

Use of the up and down arrow keys was effective in navigating the tables containing information, for example, <Fig>. However, the strategy did not work effectively in case of a table containing form fields as seen in <Fig>. That was a complex table. The first two rows served as the header rows for the table. Each of the following rows contained eight edit fields and two buttons “save” and “cancel.” The first row of the table contained the time-slots viz. breakfast, lunch, supper, bedtime, and night. The second row contained the specific time-points around the time-slots viz. “before,” and “after.” Also, the time-slots “bedtime,” and “night” have only one blood sugar reading associated with each of them; whereas the remaining time-slots viz. breakfast, lunch, and supper had two readings associated with each of them. one reading before the respective time-slot and another reading after the time-slot. The first row contained one set of labels for each of the edit fields and the second row contained the second set of the labels for each of the edit fields. However, the labels were not explicitly associated with the edit fields as prescribed by the WCAG2.0 techniques. Consequently, JAWS screen-reader was not able to associate the appropriate labels with those fields. As the participants moved in the table using the down arrow key, the focus moved to the edit fields one by one. As there was no text/graphic between those fields JAWS announced “edit” on every press of the down arrow key. It was confusing and annoying for the participants. One participant wrongly interpreted the screen-reader response and inferred that he was trapped inside an edit field. The following interaction demonstrates the problem.

<snip>

i: you are supposed to add the information for May 1st.

BVI: ok

key: down arrow

SR: edit

key: down arrow

SR: edit

key: down arrow

SR: edit

key:escape

SR: escape.

SR: edit

key:capslock+semicolon

SR: virtual pc

key:down

SR: edit

i: are you still using the arrow keys?

key: escape

SR: escape

key: escape

SR: escape

BVI: I am trapped here in the form field. I pressed the escape key. Still it remained trapped in the field.

</snip>

Open a form field. Participants used two strategies to open the form fields for editing namely. (1) hit the enter key on the form field and (2) hit the spacebar on the form field. The strategy to hit the enter key was not a reliable strategy. It yielded inconsistent outcomes when used with two edit fields on a same webpage. In one case, the strategy resulted in an unexpected shift of the focus. Participants also noted that hitting the enter key sometimes results into an accidental form submission.

Probe the control under focus. Participants used three strategies to probe the control under focus, namely, (a) press the tab and shift + tab in succession, (b) press the up and down arrow in succession, and (c) use the JAWS keystroke “insert tab.” All three strategies always worked across all eHealth used in this study.

Work-around the gulf of execution. When participant could not perceive if an element could be activated they faced the gulf of execution. To work-around the gulf of execution, participants often used the trial-error strategy and tried activating the respective element. However, in some instances, the strategy resulted in an accidental submission of information.

Work-around the gulf of evaluation. When there was no system response on participants action such as, hitting the enter key, they faced the gulf of evaluation. To work-around the situation, they either (a) re-did the component level action such as hitting the enter key, or (b) restarted the entire task. However, re-doing the component-level operation can result into unwanted information re-submission.

Findings in the Context of Mobile Applications

Table 4.3

The Mobile Interaction Strategies and the Problems Faced while Executing the Mobile Interaction Strategies

Objective	Strategy	Accessibility/ Usability problems
Locate the controls or information	Sequential scanning	none
	Gambling scanning	propensity to miss the important information
	Direct-touch scanning	propensity to lose the place on the screen
Probing	Read character-by-character	none
	Read word-by-word	none
	Read line-by-line	none
	Skim through headings	none
	Flick left and flick right in succession	none
Seeking where am I information	Flick left and flick right in succession	none

Table 4.3

Cont.

Objective	Strategy	Accessibility/ Usability problems
Typing the information	Use of handwriting	none
	Use of braille screen input	none
	Use of direct-touch typing	Difficulty locating the desired character Accidental typing
	Use the dictation feature	none
	Use of an external keyboard	none
	Use of standard typing	difficulty locating the desired character
	Use of touch typing	Difficulty locating the desired character Accidental typing
Work-around the gulf of evaluation	Re-doing the component-level operation	information re-submission
	Moving one step back and re-tracing the path	none
	Restarting the application and re-doing the entire task-flow	none
Work-around the gulf of execution	Trial and error	Accidental form submission

BVI Users' iPhone Interaction Using VoiceOver (VO) Screen-reader

The BVI users' iPhone interaction using the VO screen-reader is significantly different from those of the sighted users' iPhone interaction. If a BVI user swipes to the left the user's focus shifts to the previous element. The gesture is known as "left flick." If they swipe to the right the focus shifts to the next element. The gesture is known as “right flick.” If they touch an element on the screen then VO announces that element. the gesture is known as “single tap.” If they perform the single tap gesture twice in a quick succession then that element is activated. the gesture is known as “double tap.” The detail list of gesture is available on the Apple.com website.

Locate the target control or information. Participants used four strategies to locate the target control or information, namely (a) sequential scanning, (b) gambling scanning, (c) direct-touch, and (d) use of the Rotor function.

Sequential scanning. Participants sequentially scanned the screen by performing the right flick or left flick gesture. Usually, they flicked to the left until they reached the left top of the screen and then flicked to the right until they found the target information. The strategy always worked, however, it was time consuming. Participants mentioned that they use the strategy when they are not familiar with the application. This strategy is analogous to the tab key navigation used in computer interaction. It is prone to the same problems experienced while using the tab key navigation. Users may encounter the screen elements in an order which does not make sense. Also, as the participants encountered the text and fields separately, it was difficult for them to associate the appropriate labels with the edit fields.

Also, when the users scan the screen sequentially, they cannot grasp the visual organization of the controls on the screen. While interacting with the calendar control in the GlucoseWiz application, the participants encountered the constituents of the calendar sequentially. They could not understand that the individual elements were part of the same control. Consequently, they could not perceive the calendar as one control. The following evidence demonstrates the problem.

<snip>

v: default profile

GRS

v: nav btn info

GRS

v: nav btn camera

GRS

v: arrow left button.

GRS

v: October fifteenth two thousand seventeen.

GRS

v: hyphen

GRS

v: October fifteenth two thousand seventeen.

GRS

v: arrow right button

GRS

v: selected. btn select day button. one of four.

GRS

v: btn week button. two of four.

GRS

v: btn month button

GRS

v: btn year button.

</snip>

The calendar functionality comprised the start date and the end date of the selected time frame, left and right arrow buttons to shift the calendar back and forth, and four more buttons to select the unit of the calendar movement. However, the design did not contain any information about that composition of the calendar functionality. due to the lack of that information, the participants could not perceive the inter-relationships between the individual elements which composed the calendar functionality. Consequently, the participants could not use the functionality.

Gambling scanning. Participants often used the gambling scanning strategy. They simply move one finger on the screen until they heard something relevant to what they were looking for. This strategy does not guarantee that the user visits every element on the page. Hence, the users may miss the important information while using the strategy.

Direct-touch scanning. Participants used the direct-touch scanning strategy to locate the target element on the screen. They used the strategy when they had a good sense of the place of the elements on the screen. All participants had a very good sense of the placement of the standard controls such as “back” button, page-tab bar, and on-screen keyboard, etc. When they used the direct-touch strategy, it often resulted in losing their place on the screen. However, the participants missed the target with a very small error. Usually, they could find the target by swiping once to the left or right. Generally, all the participants acquired a very good sense of the placement of various controls on the screen in a single exploration pass.

Use of the Rotor function. Participants also used the Rotor function in VO screen-reader to skim through the information to locate the target control or information. The function allows users to set the type of the element they want to skim through. Once a user sets the type of the element on the rotor, the user can skim back and forth through the elements of the chosen type using the single finger swipe up and single finger swipe down gestures. The roter can contain options such as "characters," "words," "lines," "links," "headings," "form fields," etc. The strategy is effective only if the user knows the type of the target element.

Probe the control under focus. Participants used various strategies to probe the screen. Using the roter function, they read the information character-by-character, word-by-word, or line-by-line to probe the element under focus. They also performed the flick left and flick right gestures in succession to probe the element under focus. This strategy is analogous to the use of the tab and shift+tab in succession in web-interaction using a computer screen-reader. Participants used the same strategy to understand their position on the screen.

Type the information. VO allows its users to use six strategies to type the information, namely. "standard typing," "touch typing," "direct touch typing," "handwriting," "braille screen input," and "dictation." Participants mostly used the standard typing. Participants faced difficulty locating the desired character using the on-screen keyboard. It is the safe strategy and rarely results into an accidental typing. Only one participant mentioned that sometimes he uses the touch-typing strategy. However, he mentioned that he faces the difficulties locating the desired character. The participants rarely used the direct-touch typing. To use the strategy effectively, the users should precisely know the location of every alphabet on the screen. The strategy is error-prone and often results in accidental typing. Only one participant used the handwriting feature and the Braille screen input mode. To use the Braille input the user should be aware of the Braille notations. Also, only one participant used the dictation feature to type information. One participant also mentioned that they use the external Bluetooth keyboard to type information.

Work-around the gulf of execution. When participants could not perceive if an element could be activated they faced the gulf of execution. Participants often encountered unlabeled buttons in all the applications. When they encountered the unlabeled buttons, they could not understand the purpose of those buttons. Consequently, they perceived the affordance incompletely. There also they faced the gulf of execution. To work-around the gulf of execution, participants often used the trial-error strategy and tried to activate the respective element. However, in some instances, the strategy resulted in an accidental selection of options. The strategy can also result in accidental submission of information or accidental cancelation of a transaction. Also, in some instances the design did not inform the users of the outcomes of their action and then they experienced the gulf of evaluation.

Work-around the gulf of evaluation. When there was no system response on participants action such as, performing the double-tap gesture, they faced the gulf of evaluation. To work-around the gulf of evaluation, the participants often re-did the component-level operation such as, performing the double-tap gesture on a button. However, it can result in the information re-submission. They also chose to move one step back in the application and then re-traced the path to visit the interface where they had faced the gulf of evaluation. In some cases, they opted to restart the application and re-did the entire task-flow.

Table 4.4

Factors Influencing the Choice of the Interaction Strategy

Personal factors	• Available time. • Degree of user expertise in using the web/mobile with a screen-reader. • Self-efficacy beliefs. • Perceived importance of the task.
Technological factors	• Availability of interface elements such as headings, and labels. • Navigability of the interface using a keyboard. • Use of complex layout tables
Task context	• Complexity of the task. • Background knowledge about the task.

Chapter Summary

In this chapter, we described the analysis of the qualitative data and the subsequent findings in form of the interaction strategies and the respective problems. In next chapter, we will discuss the findings in detail to generate the design and interaction principles.

CHAPTER V

DISCUSSION

Chapter I explained that the purpose of this research is to develop an understanding of the interaction strategies and the respective accessibility and usability problems of blind and visually impaired (BVI) web and mobile users and to develop the design and interaction principles to resolve those problems. Chapter II identified a critical gap in existing literature about an accurate and in-depth understanding of the interaction strategies, and explained the inadequacies in existing research approaches to develop this understanding. Chapter III explained our novel user-centered, task-oriented and cognitive approach to develop an in-depth, contextually-situated, observational and experiential knowledge of the BVI users' interaction strategies and outlined the research design using which we implemented the novel approach. Chapter IV described the qualitative analysis of the observational data and subsequent findings. In this chapter, we conclude this dissertation by presenting a discussion of our findings, limitations, and future research plans.

Theoretical Contributions

Interaction Strategy Construct

We define the construct "interaction strategy" as a coordinated sequence of user interactions with online resources that is intended to achieve an interaction goal. BVI users interact with a technology design with an intention to solve a problem. For example, a diabetes patient uses “myDiabetesHome” website to log their blood-sugar information which forms their interaction goal. During the problem-solving process, users achieve numerous smaller sub-goals which form the task objectives. Every task objective is achieved through operating upon interface elements such as, an edit field, a drop-down menu, a link, a button, etc. users formulate the overall problem-solving strategy, task completion strategy, and the strategy to operate on a respective interface element. BVI users generally maintain a repertoire of strategies to achieve their objectives. According to the contextual factors they choose the strategy to achieve their objective. An interaction goal is a high-level affordance intended by the design. An affordance is defined as an action potential that emerges through the interaction between the capabilities of a user and the properties of the design. Every technology design intends various affordances and conveys the existence of those affordances through the properties of the design. When the users perceive any of those intended affordances, they follow a coordinated sequence of steps to realize that perceived affordance. In other words, they execute an interaction strategy to realize the intended affordance which is the interaction goal.

BVI users may succeed or face challenges in executing their interaction strategy. When the users cannot perceive that intended affordance then two things can happen: (1) they face gulf of execution; they do not know how to proceed. They are stuck; they cannot realize the intended affordance, or (2) to deal with the gulf of execution, based on their experiences of interacting with similar designs, they assume the existence of certain affordance and then execute an appropriate interaction strategy to realize that assumed affordance. Sometimes the assumed affordance exists and the users realize it. Sometimes the assumed affordance does not exist and the users do not get the results they expected. It results in gulf of evaluation. Those gulfs denote the accessibility and usability problems experienced by the BVI users of the web and mobile applications. The construct "Interaction Strategy" is useful to comprehend a BVI user's interaction, the respective accessibility and usability problems, and the approaches employed by BVI users to work-around those problems.

The prevalent approaches to ensure the accessibility and usability for BVI, view the accessibility and usability as the responsibility of the interface design alone. They tend to believe that the accessibility and usability problems arise solely due to the inappropriate interface design. Consequently, they tend to develop new technologies or improve the existing technologies. The approaches are around for two decades yet BVI users face frequent accessibility and usability problems in their web and mobile interactions. This constant presence of the accessibility and usability problems suggest that the prevalent approaches are not enough to ensure reasonable accessibility. The missing piece of the puzzle is the BVI user. The accessibility and usability problems arise from both the interface design as well as from the user strategies to interact with that design. Conceptualization of the interaction as a process to realize an affordance enabled us to distinguish the role of the design and the role of the BVI user in the success or failure of the respective interactions.

This research revealed various interaction strategies of the BVI participants to achieve their specific interaction objectives in their web and mobile interactions.

The Web interaction strategies were

- Use of screen-reader specific navigation functions
- Use of links list
- Use the up and down arrow keys
- Use the “table layer”
- Using arrow keys
- Use of the tab key
- Use of screen-find function
- Hit the enter key
- Hit the spacebar
- Tab and shift + tab in succession
- Up and down arrow keys in succession
- Use screen-reader function such as insert + tab in JAWS
- Re-doing the component-level operation
- Restarting the browser and re-doing the entire task-flow
- Trial and error

The mobile interaction strategies were

- Sequential scanning
- Gambling scanning
- Direct-touch scanning
- Read character-by-character
- Read word-by-word

- Read line-by-line
- Skim through headings
- Flick left and flick right in succession
- Flick left and flick right in succession
- Use of handwriting
- Use of braille screen input
- Use of direct-touch typing
- Use the dictation feature
- Use of an external keyboard
- Use of standard typing
- Use of touch typing
- Re-doing the component-level operation
- Moving one step back and re-tracing the path
- Restarting the application and re-doing the entire task-flow
- Trial and error

The web interaction strategies were very similar to the mobile interaction strategies. The participants often develop multiple strategies to achieve their objectives and then choose to execute one or more of the strategies considering various contextual factors. The strategies can be broadly classified as exploration or exploitation. The strategies in the exploration category intend to gather the information about the interface. The strategies in the exploitation category intend to use the properties of the interface without exploring the interface. The participant often exhibited the use of combination of exploration and exploitation strategies depending upon the context.

Organization of the Interaction Strategy Frameworks

The strategies execute at three different levels of interaction, namely. problem level, task level, and component level. While the users face an accessibility and usability problem, it can be at the level of overall problem-solving process, or at the level of achieving a specific task objective, or at the level of operating upon a specific interface element. Therefore, in the framework, we organize the interaction strategies at the three levels as described above. This organization enables us to compare between the efficacy of the strategies to achieve the respective goal and to Pin-point the areas of improvement.

Novel Data-collection Methodology

We developed a novel semi-ethnographic, conversation-style data-collection methodology to study human technology interactions. We implemented the methodology to study the BVI users' web and mobile interactions using a screen-reader. However, the methodology is applicable to produce rich qualitative data about the technology interactions of BVI users who do not use screen-readers but use other assistive Technologies like screen-magnifier. Also, the methodology is applicable in the context of the BVI users' interactions with the technologies other than the web and mobile applications. Additionally, the same methodology can be used to study the interactions of any technology user who can engage in a verbal conversation with the researcher.

Method to Develop the Theoretically Validated Design and Interaction Principles

We developed the theoretical analysis methodology to identify the areas of improvement in the BVI users' web or mobile interactions. We take a position that creating an accessible interaction experience is a joint responsibility of all the stakeholders in the accessibility equation. The onus of the successful interaction should be shared by all the stakeholders and not shifted to any one of them. Current approaches to accessibility tend to put the onus of ensuring the accessibility on the design alone. However, our research demonstrated that the design is not always the only culprit sometimes users need to improve their strategies. It was important for us to precisely identify where the design was faulty and where were the users. Therefore, we developed the novel methodology to identify the stakeholder which needs improvement. Using that methodology, we developed the design principles and the interaction principles to address the accessibility and usability problems faced by the BVI participants. Although, we develop the interaction principles to inform the training given to the BVI users so that they could prevent or work-around the accessibility problems identified in this study, we do not suggest that let the problems in the design persist. The problems in the design must be fixed by adhering to the design principles in addition to the prevalent web and mobile accessibility standards. At the same time, BVI users can also improve their interaction strategies to achieve better accessible and usable interaction.

The last but not the least contribution of our research is the design and interaction principles thus generated. In this section, we demonstrate the use of the method and generate the design and interaction principles.

Generation of the Design and Interaction Principles

We now describe the design and interaction principles, and the factors influencing BVI users' choice of interaction strategies. The first two subsections describe the principles in the context of the web and the third and fourth subsections describe the principles in the context of mobile applications.

Design Principles for the Web

Table 5.1

Design Principles for the Web

Design Principle	Design Principles for the Web
DP1	Convey the affordances of non-standard controls to screen-readers using ARIA techniques.
DP2	Whenever a page is dynamically updated notify the user and provide explicit instructions to reach the modified part of the page.
DP3	If Any part of the page is not required; remove the respective HTML from the document Object; do not camouflage.
DP4	In case of a combo box, advice the screen-reader users of the correct interaction strategy.
DP5	Notify the users about the outcomes of their form submission actions using an explicit text message on the page.
DP6	Programmatically associate the table cells with the respective headings.
DP7	Provide the focal information on a webpage using text. If use of any non-text such as graphs, charts, videos, or colors is essential then the appropriate text equivalent must be provided.
DP8	Include the category of the information in the section heading.

DP1: Convey the affordances of non-standard controls to screen-readers using ARIA techniques. In Task-2, the participants were required to expand the menu "My Preferences" by activating the clickable text "My Preferences" shown in Figure 5.1. No participant could achieve the objective. It meant either no participant used the appropriate interaction strategy or the interface did not support their interaction strategies. All the participants could locate the text "My Preferences," however, they could not determine whether the text was clickable. The affordance that the text could be clicked and the menu could be expanded was not perceivable to them. It was an instance of the gulf of execution experienced by the BVI users. All the participants dealt with the problem using the trial-error strategy and hit the enter key to activate the text. The "My Preferences" menu expanded, however, there was no response from the system. Consequently, they were not sure of the outcomes of their action. They experienced the gulf of evaluation. The strategies used by the participants were reasonable and were effective on many other webpages they had interacted with. However, this interface did not support those strategies. Therefore, the design should improve.

The text "My Preferences" was not a HTML hyperlink, or a HTML button; it was a custom control created using the HTML "div" element. The information that the text could be clicked was not exposed to the screen-reader. Also, it is not enough to merely convey that the text can be clicked. The information about the state of the control such as "collapsed," or "expanded" should also be conveyed to the screen-readers. Without that information, BVI users will not be able to perceive the affordance completely. Thus, the design principle, DP: Convey the affordances of non-standard controls to screen-readers using ARIA techniques

Figure 5.1. My Preferences—Collapsed.

DP2: Whenever a page is dynamically updated notify the user and provide explicit instructions to reach the modified part of the page. The participants were required to activate the anchor "Hi IS" shown in Figure 5.2. Participants could successfully locate the anchor and hit the enter key to activate it. However, there was no system response on their hitting the enter key. They could not understand the outcomes of their action. They faced the gulf of evaluation. They wondered if the anchor was activated or not.

When the participant activated the anchor, the relevant user options became available just below the anchor as seen in Figure 5.2. However, the participant had no clue about that dynamic change on the page. It is important to inform the screen-reader users whenever part of the page is updated dynamically. Also, it is important to inform the BVI users how to reach that part of the page. It can be easily done using ARIA techniques such as, ARIA alerts. Thus, the design principle,

DP: Whenever a page is dynamically updated notify the screen-reader user and provide explicit instructions to reach the modified part of the page.

Figure 5.2. Activated Hi, IS.

DP3: If Any part of the page is not required; remove the respective HTML from the document Object; do not camouflage. While attempting to expand "My Preferences," P2 encountered the fields shown in the Figure 5.3. P2 thought, "My Preferences" were already expanded. The fields were present on the webpage; however, they were camouflaged using UI formatting techniques as seen in Figure 5.1. Consequently, visual users could perceive the fields shown in Figure 5.3 only when they expanded "My Preferences." However, screen-reader reads the webpage from the HTML source in the document object model (DOM). It can access the parts of the page which are hidden just using visual formatting tricks. Consequently, BVI users could perceive those fields even when the “My Preferences” were collapsed. It is not an accessibility problem per se, but it could lead to confusion and unexpected system state as BVI users will interact with the interface which is not meant to be available to the users. Design should pre-empt such situations. Thus, the design principle,

DP: If Any part of the page is not required; remove the respective HTML from the document Object; do not camouflage.

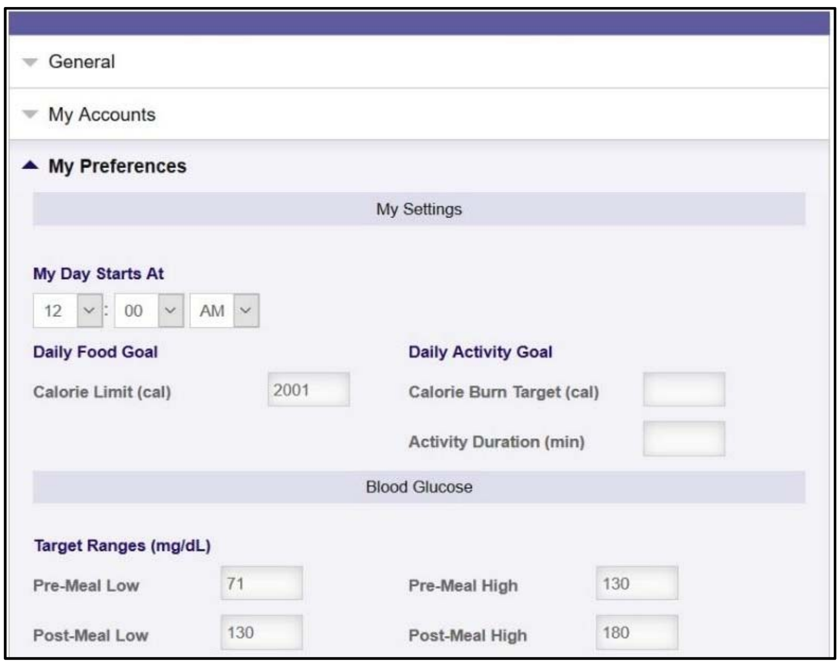

Figure 5.3. My Preferences—Expanded.

DP4: In case of a combo box, advice the screen-reader users of the correct interaction strategy. Participants faced challenges while interacting with the drop-down combo box shown in Figure 5.4. The onchange event was associated with the combo box. When the user used the arrow key without opening the combo box, the event was triggered and initiated the change of context. The design did not advise the users of the correct interaction strategy. It is a failure of the WCAG 2.0 Success Criterion 3.2.2. Although, the accessibility problem can be avoided if the users improve their interaction strategy, our observations indicate that even the participants with substantial experience of using a screen-reader did not know the correct interaction strategy. Therefore, the design should advise the BVI users of the correct interaction strategy to avoid this problem. Thus, the design principle

DP: In case of a combo box, advice the screen-reader users of the correct interaction strategy.

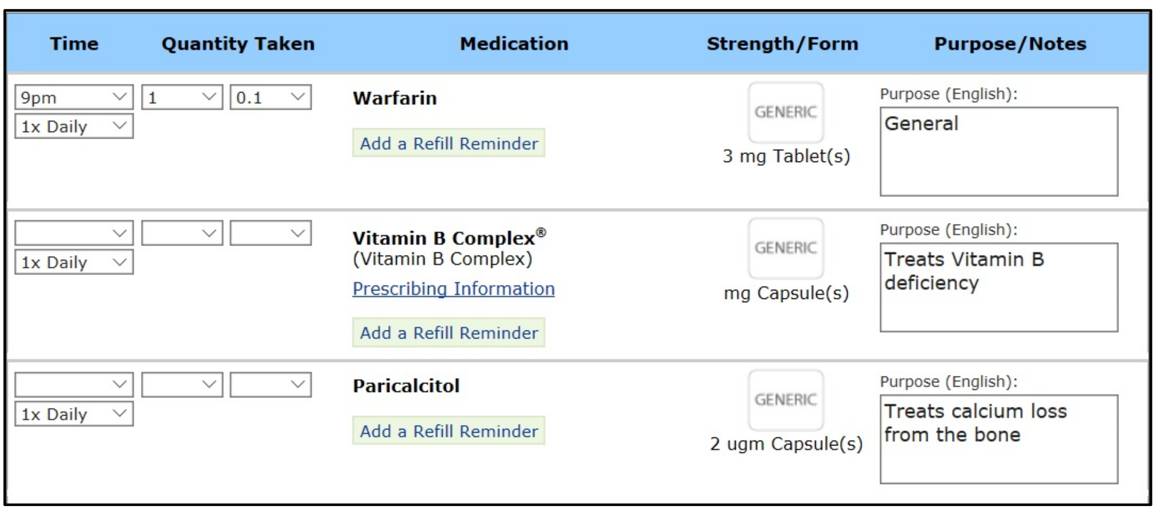

Figure 5.4. Add Medication Screen.

DP5: Notify the users about the outcomes of their form submission actions using an explicit text message on the page. Some participants faced challenges in saving the information using the interface shown in Figure 5.5. The participant strategies to locate and activate the save button were supported by the design; hence, the participants could successfully activate the button.

Figure 5.5. Table to Add the Sugar.

However, there was no system response on their activating the save button. Participants scanned the page from the top to bottom; however, there was no explicit notification message on the webpage. They could not understand the outcomes of their actions. They faced the gulf of evaluation. This problem was also present on other eHealth used in this study. Participants mentioned that they face that problem regularly in various websites. It indicates that it is a common web accessibility problem. The problem can be resolved by providing the appropriate notification. Moreover, participants indicated their preference for an explicit text message as opposed to an audio cue because an audio cue is transient and they may miss it. Hence the explicit notification message must be provided in the text form. Thus, the design principle,

DP: Notify the users about the outcomes of their form submission actions using an explicit text message on the page.

DP6: Programmatically associate the table cells with the respective headings. All participants faced challenges using the interface shown in Figure 5.5. As the participants probed the interface, JAWS announced “edit” whenever they pressed the down arrow key. Consequently, they could not understand which textfield was associated to which column header. P4 did not understand that it was a table. P4 thought that he was trapped inside an edit field and therefore JAWS announced “edit” on his pressing the down arrow key.

The column headings were denoted using the <th> but the appropriate headers were not associated with the edit fields using the “headers,” and “id” attributes. Consequently, JAWS screen-reader could not programmatically associate the appropriate labels with the edit fields. The fields were laid out in adjacent columns. There was no text or graphics between the adjacent fields. Consequently, on every press of the down arrow key the focus moved to the next edit field and JAWS announced “edit.” This problem can be resolved by improving the design. Thus, the design principle,

DP: Programmatically associate the table cells with the respective headings.

DP7: Provide the focal information on a webpage using text. If use of any non-text such as graphs, charts, videos, or colors is essential then the appropriate text equivalent must be provided. The Task-1 required the participants to find the information about the normal blood sugar levels for the adults with diabetes using the WebMD (https://www.webmd.com/default.htm) website. The participants were given an initial link to initiate the task. They were told that the information may or may not be on the initial link. They demonstrated two competing strategies to find the information using the initial link. Those were (a) browse through the webpage looking for the relevant text or links and to follow the links which seem relevant to the focal search task, or (b) use the website search function to find the relevant web pages. Participants heavily relied on the screen find function in the JAWS screen-reader to identify the relevant links. The screen-find function allows its users to find a text string on the computer screen. Participants also probed the webpages using heading navigation, up and down arrow keys, and tab navigation. The participants could reach the target article using the above strategies, however, none of them could understand the information in the article. It was because, the chart provided the information only in a graphical form as seen in Figure 5.6. There was no text equivalent accompanying the chart. Also, the use of screen-find function can be successful only if the information is available in the text on a webpage.

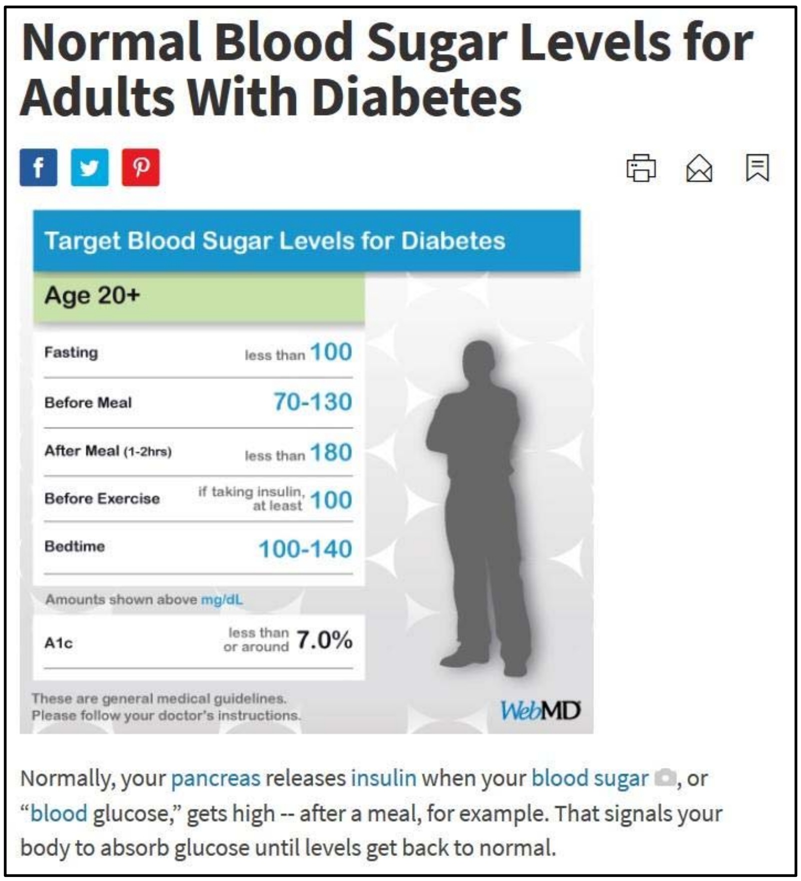

Figure 5.6. Chart of Normal Blood Sugars for the Adults with Diabetes.

It is important to note that this is a fundamental accessibility principle. Web-accessibility standards have advocated this principle since two decades. Worldwide, numerous legislatures have prescribed this principle to ensure an equitable information access to the people with disabilities. Yet there are incidences of the violation of this fundamental requirement even today. It strongly indicates that the present efforts to ensure accessibility are not adequate and we need more thought and effort towards making the web-accessibility a reality. Thus, the design principle,

DP: Provide the focal information on a webpage using text. If use of any non-text such as graphs, charts, videos, or colors is essential then the appropriate text equivalent must be provided.

Moreover, participants mentioned that their preferred interaction strategy was to find the information using the Google search engine instead of looking for the information on a specific website. It is because, Google search results provide the deep links to the required information. A deep link is the URL which contains all the information needed to point to an item, in this case the article about normal blood sugar levels for the adults with diabetes.

DP8: Include the category of the information in the section heading. P2 activated the link “blood sugar test.” On the resultant page, P2 found a heading “find information about.” P2 expected to find the information about Diabetes and blood sugar following the heading. However, the information was about the Diabetes drugs. This is an instance of a usability problem. Technically the heading was provided; but the heading text was ambiguous. It did not convey the category of the information following it. Consequently, the user might miss such information or will land on irrelevant information. BVI users of screen-reader are often not aware of the context of the headings. Often, only based on a heading text, they determine the purpose of the information following that heading. This problem can be resolved by including the category of the information in the heading text. Thus, the design principle,

DP: Include the category of the information in the section heading.

Interaction Principles for the Web

Table 5.2

Interaction Principles for the Web

Interaction Principles	**Interaction Principles for the Web**
IP1	Do not hit the enter key to activate a button, use the spacebar instead.
IP2	Do not hit the enter key to open the forms mode, use the spacebar instead.
IP3	Do not use arrow key navigation when dealing with the form fields in a table; use the table-specific navigation keys instead.
IP4	To expand the drop-down combo box before navigating it using the arrow keys or first letter navigation.
IP5	**If the buttons to save the information are not present and the options to edit/delete the information are present then the information is saved successfully.**
IP6	While in a forms mode, do not use CTRL home to go to the top of the page.
IP7	When unsure about the type of the target control, locate the control using arrow keys or the screen-find function; do not use tab.
IP8	**If the link to log out is available and the login fields are not available then you are in.**
IP9	If you know the exact on-screen text for a link then use the JAWS links list and the first letter navigation; it is the quickest.

IP1: Do not hit the enter key to activate a button, use the spacebar instead. Participants used two strategies to activate a button. The strategy to hit the spacebar while on the button always worked successfully and the cursor focus remained on the button. The strategy worked successfully across all the study participants and across all the eHealth used in this study. However, hitting the enter key to activate a button was not a reliable strategy. In the table Figure 5.5 to add the sugar, P2 hit the enter key to activate the "save" button. The button was activated, however, the cursor focus shifted away from the table. This unexpected system behavior disoriented the participant. It indicates that hitting the enter key to activate a button may result into the user losing their place on the page. It is very frustrating and disorienting especially while working with the forms containing several fields. Additionally, the problem is intensified if the form lacks reasonable accessibility. BVI users, therefore, are advised to use the spacebar instead. Thus, the interaction principle,

IP: Do not hit the enter key to activate a button, use the spacebar instead.

IP2: Do not hit the enter key to open the forms mode, use the spacebar instead. JAWS screen-reader allows its users to interact with the webpage in two modes namely. browse mode and forms mode. The form fields can be edited only when the forms mode is on. Two participants had configured their screen-reader to open the forms mode automatically on the field receiving the focus. Other three participants had to open the forms mode explicitly. They used two strategies to open the forms mode explicitly (1) hit the enter key while on the form field, and (2) use the spacebar while on the form field. The strategy to hit the spacebar while on the form field always worked successfully and the cursor focus remained in the form field. The strategy worked successfully across all the study participants and across all the eHealth used in this study. However, hitting the enter key to open a form field was not a reliable strategy. P3 used the strategy with two text-fields on the same webpage. However, the outcomes of the strategy in both the cases were different. When P3 hit the enter key to open the pre-meal low field (Figure 5.4) it worked successfully. The field opened and the cursor focus remained in it. However, when P3 hit the enter key to open the pre-meal high textfield, instead of opening the forms mode the focus shifted to the save button. This unexpected behavior was disorienting for the participant. It created confusion for the participant as she lost her place on the page. It also created an annoyance for the participant as she had to spend time/effort to return to her original place on the page. Moreover, forms mode is a feature in the screen-reader technology. The likelihood of the design being responsible for the inconsistent outcomes of the interaction strategy is very low. Hence, we should inform the user behavior and not the design. Thus, the interaction principle,

IP: Do not hit the enter key to open the forms mode, use the spacebar instead.

IP3: Do not use arrow key navigation when dealing with the form fields in a table; use the table-specific navigation keys instead. Participants faced challenges while interacting with the edit fields laid out using the table shown in Figure 5.5. As discussed previously, the design needs an improvement. However, it is also worth noting that the participants used various strategies to overcome the problem. Some strategies worked and some did not. P4 thought that he was trapped inside an edit field and therefore JAWS announced “edit” on his pressing the down arrow key. He pressed the escape several times to get out of the edit field, and then used the down arrow key. However, he did not hear anything beyond “edit.” Finally, he gave up. To find out if there were any text near the edit fields, P5 used the optical character recognition (OCR) function followed by the smart navigation function in JAWS. The JAWS Screen-reader reads the webpage in a linear fashion, whereas the OCR function reads the webpage as it appears on the screen. As he used the OCR function, JAWS announced sequence “before,” “after” in a single line. It confused the participant even more. Then he used the smart navigation in JAWS and got the same result. He blamed the design and gave up.

Two participants succeeded despite of the challenges. Participants were required to enter the information for the time-slots viz. before lunch, after lunch, and so on up to nighttime. Using that background information, P2 just assumed that the edit fields were laid out in the chronological order of the meals and entered the information accordingly. P3 used the “table layer” feature in JAWS and entered the information successfully. Thus, the interaction principle,

IP: Do not use arrow key navigation when dealing with the form fields in a table; use the table-specific navigation keys instead.

The observation was intriguing for one more reason. Literature has demonstrated that BVI users often blame their lack of technology skills when they encounter an accessibility problem. However, our study revealed a contradictory finding. The participants who had some knowledge of the technologies to create the web interfaces were inclined to be impatient and frequently blamed the interface design for the accessibility and usability problems they faced. The two participants who chose to give-up were knowledgeable about the Hyper Text Mark-up Language (HTML). They got quickly frustrated with the web interfaces with accessibility glitches. They were more judgmental and less open for exploration. They were over-confident about their strategies and were less likely to find alternative strategies to overcome the accessibility or usability problems. On the contrary, participants who had no exposure to HTML, considered accessibility glitches as inevitable. They believed that the design is rarely perfectly accessible and they need to be patient in their interactions to find the alternative strategies. This finding was personally enlightening to me because I used to get quickly frustrated when faced with the accessibility glitches in the web design. One participant gave-up when none of his usual strategies worked. He was also more likely to use advanced screen-reader functions to overcome the accessibility problems even when the problems could be resolved using simpler screen-reader functions. This suggests that the training imparted to the BVI users of screen-readers should focus on teaching the interaction strategies along with the screen-reader functions.

IP4: expand the drop-down combo box before navigating it using the arrow keys or first letter navigation. As noted in DP4, some participants could not successfully select the value in the drop-down combo box shown in Figure 5.4. It was partly due to their inappropriate interaction strategy. They did not open the combo box before selecting an option. As P4 used the arrow key to select an option, the interface was dynamically updated and he got disoriented. P2, on the other hand, first opened the combo box using the alt + down arrow key and then used the arrow key to select the required option. It did not create any disorienting outcome. Even some expert participants did not know this strategy and faced problems. Therefore, it is essential to improve the BVI users' strategy. Thus, the interaction principle,

IP: expand the drop-down combo box before navigating it using the arrow keys or first letter navigation.

IP5: If the buttons to save the information are not present and the options to edit/delete the information are present then the information is saved successfully. When there was no explicit notification indicating the outcomes of hitting the save button, the participants used two heuristics to find out if the information was saved. They inferred that the information was not saved when "save" button was present. They inferred that the information was saved when the options to edit the information were present. Although, the design must explicitly inform the users if the information was saved, there is a value in informing the BVI users of the heuristics. Thus, the interaction principle,

IP: If the buttons to save the information are not present and the options to edit/delete the information are present then the information is saved successfully.

IP6: While in a forms mode, do not use CTRL+home to go to the top of the page. Often the participants used the ctrl+home to jump to the top of the page. When the strategy was used while in the forms mode, it moved the cursor to the beginning of the respective form field and not to the beginning of the page. It created confusion for some of the participants. Thus, the interaction principle

IP: While in a forms mode, do not use CTRL+home to go to the top of the page.

IP7: When unsure about the type of the target control, locate the control using arrow keys or the screen-find function; do not use tab. The participants were requested to activate "My Preferences" in Figure 5.1; however, they were not told the type of the target control. Participants located the control using the JAWS screen-find function or using the sequential scanning using the down arrow key. They did not rely on the tab key navigation as their experience suggested that often non-standard controls do not receive keyboard focus. It was also observed that when the text identifying the control was known then the use of screen-find function was quicker than the sequential scanning using the arrow keys. Thus, the interaction principle,

IP: When unsure about the type of the target control, locate the control using arrow keys or the screen-find function; do not use tab.

IP8: If the link to log out is available and the login fields are not available then you are in. To infer if the login attempt succeeded or failed, participants used two heuristics. They inferred that the login attempt was successful when the link to log out was available. They inferred that the login attempt failed when the user name and password fields were present. It is useful to teach such heuristics to BVI users. Thus, the interaction principle,

IP: If the link to log out is available and the login fields are not available then you are in.

IP9: If you know the exact on-screen text for a link then use the JAWS links list and the first letter navigation; it is the quickest. When the participants knew the exact link text, they used the first letter navigation to locate the link in the list of links. This strategy was most efficient when the first letter of the link text was known.

However, the users are unaware of the context of the links while using this strategy. Moreover, the screen-reader used by the participants did not distinguish between the links and anchors while browsing the list of links. Consequently, they expected a new page to load even on activating the anchors. They got confused when there was no change on the page. Thus, the use of this strategy is, may not be very effective for a first-time visitor of the webpage. Thus, the interaction principle

IP: If you know the exact on-screen text for a link then use the JAWS links list and the first letter navigation; it is the quickest.

Design Principles for Mobile Applications

Table 5.3

Design Principles for Mobile Applications

Design Principle	Design Principles for Mobile Applications
DP1	Expose the intended affordance to screen-readers using the respective accessibility APIs.
DP2	Provide explicit textual messages to indicate the success or the validation errors in the information save/delete process.
DP3	Inform the users through a spoken instruction about the position of the controls which dynamically appear on the screen.
DP4	When the picker control closes, restore the user’s focus to the relevant screen position.
DP5	Provide clear instructions about any format restrictions for edit fields.
DP6	provide clear instructions on how to use the functionality in cases when the users should follow a specific procedure to use the functionality.

Table 5.3

Cont.

Design Principle	Principles for Mobile Application Design
DP7	If a composition of inter-related controls is used to achieve a specific functionality then provide clear information on how the constituent controls are related to each other.
DP8	Label the buttons and page-tabs such that the mobile screen-readers can read them
DP9	The text label for a button must convey the function of the respective button.
DP10	When the selection status of a button indicates a specific state of the system, the label of the button must convey the meaning of the state of that button.

DP1: Expose the intended affordance to screen-readers using the respective accessibility APIs. In the interface shown in Figure 5.7, the text “Jun 20, 2018 at 11:52 PM” could be activated to open the date-time picker control. However, the participants did not understand that the text could be activated. The participants could not perceive the intended affordance. They experienced the gulf of execution. The information that the text could be activated was not exposed to the screen-reader. The problem should be resolved by improving the design. Thus, the design principle,

DP: Expose the intended affordance to screen-readers using the respective accessibility APIs.

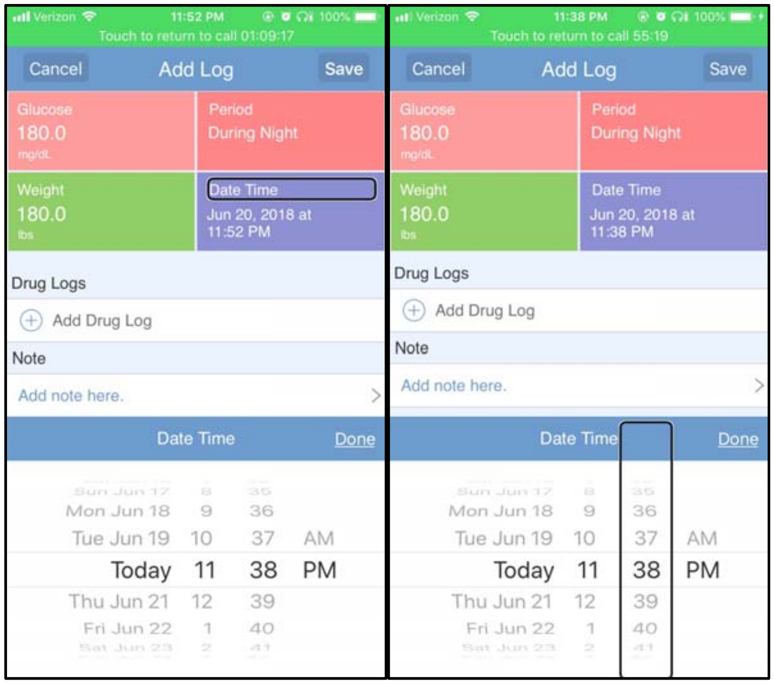

Figure 5.7. Log the Blood-Sugar Information for Specific Day.

DP2: Provide explicit textual messages to indicate the success or the validation errors in the information save/delete process. Three of the five tasks, required participants to enter and save relevant information. When the participants activated the respective button to save the information, they did not receive any spoken response indicating the outcomes of their action. They experienced gulf of evaluation. Participants faced this problem across all the respective applications used in this study. It is a strong indication that lack of spoken messages indicating the success or validation errors in mobile applications is a common accessibility problem. Either there is no message displayed on the screen or the messages are displayed at the top of the screen. Screen-readers cannot read those messages aloud unless the proper accessibility announcement notification method is implemented within that application. Every mobile

OS has a set of accessibility APIs to implement the notifications. This problem should be resolved by changing the design. Thus, the design principle,

DP: Provide explicit textual messages to indicate the success or the validation errors in the information save/delete process.

DP3: Inform the users through a spoken instruction about the position of the controls which dynamically appear on the screen. When faced with the gulf of execution, participants always used the trial-error strategy to deal with the problem. They performed the double-tap gesture on ‘Date Time’ as seen in Figure 5.7. However, there was no system response. Consequently, the participants could not understand the outcome of their double-tap action. They faced the gulf of evaluation. To deal with the situation, they swiped once to the right to check if the date-time picker had appeared there. However, they didn’t find any date-time picker. It was confusing and annoying for the participants. The date-time picker control appeared at the bottom of the screen as seen in Figure 5.7. However, the design did not inform the users about it. This problem should be resolved by improving the design. Thus, the design principle,

DP: Inform the users through a spoken instruction about the position of the controls which dynamically appear on the screen.

DP4: When the picker control closes, restore the user’s focus to the relevant screen position. In Figure 5.7, the participants selected the date-time using the picker control and closed the picker control by double-tapping the “done” button. The picker control disappeared, however, the focus did not return to its earlier position. It was disorienting and annoying for the participants. The problem can be easily prevented by handling the user focus. Thus, the design principle,

DP: When the picker control closes, restore the user's focus to the relevant screen position.

DP5: Provide clear instructions about any format restrictions for edit fields. In the interface Figure 5.7, the Glucose edit field by default considered the last digit to be after the decimal point. e.g. when a user types "123" it is typed as "12.3." No participant expected the application to demonstrate this behavior. The design did not inform the users of this non-standard behavior. Consequently, no participant could successfully enter the information. The design needs an improvement to resolve this problem. Thus, the design principle,

DP: Provide clear instructions about any format restrictions for edit fields.

DP6: Provide clear instructions on how to use the functionality in cases when the users should follow a specific procedure to use the functionality. Task-4 expected the participants to shift the calendar seen in Figure 5.8, backwards by a week. However, no participant could do it. They could not understand how to use the functionality. The process to select the desired time-frame involved two steps, (1) select the unit by which the calendar shifts backwards or forwards, and (2) shift the calendar in the desired direction using the left and right arrows on the calendar.

Figure 5.8. Calendar Control to View the Blood-sugar Information for a Specific Timeframe.

Activating the left arrow shifted the calendar backward and activating the right arrow shifted it forward by the selected unit. This two-step process is not intuitive for BVI users. Research suggests that often the web-technologies are sight-centric and favor non-sequential access. The calendar functionality is an example of the sight-centricity in the mobile application arena. Designers should improve the design to make it intuitive to BVI users as well. Thus, the design principle,

DP: Provide clear instructions on how to use the functionality in cases when the users should follow a specific procedure to use the functionality.

DP7: If a composition of inter-related controls is used to achieve a specific functionality then provide clear information on how the constituent controls are

related to each other. No participant could use the calendar functionality as seen in Figure 5.8. It comprised the start date and the end date of the selected time frame, left and right arrow buttons to shift the calendar back and forth, and four more buttons to select the unit of the calendar movement. As the participants scanned the screen from the left top to the right bottom corner, they encountered those constituents sequentially. However, they could not comprehend the inter-relationships between them because the design did not contain any information about that composition. Consequently, they failed to perceive the presence of the calendar functionality. It was the failure of the WCAG 2.0 SC 1.3.1. The design should improve to resolve this problem. Thus, the design principle, DP: If a composition of inter-related controls is used to achieve a specific functionality then provide clear information on how the constituent controls are related to each other.

DP8: Label the buttons and page-tabs such that the mobile screen-readers can read them

The labels of the buttons to choose the unit of the calendar movement as seen in Figure 5.8 were not readable to the VO screen-reader. Consequently, the participants could not understand the purpose of the buttons. Similarly, the icons used to label the page tabs in Figure 5.8 were not readable to the screen-reader. Consequently, the participants could not identify the desired page-tab. It is a violation of the WCAG 2.0 SC1.1.1. Moreover, the lack of accessible labels was a common problem across all applications used in this study.

Participants used the trial-error strategy and activated the unlabeled buttons to understand their purpose. This strategy may result into undesirable system state such as, accidental information submission, unwanted option selection, accidental cancelation of a transaction, etc. Therefore, the problem must be resolved through a design improvement. Thus, the design principle,

DP: Label the buttons and page-tabs such that the mobile screen-readers can read them.

DP9: The text label for a button must convey the function of the respective button. The arrow buttons in Figure 5.8 had the labels “arrow left” and “arrow right.” The labels described the shape of the icons, but did not convey the function of those buttons. Consequently, the participants could not understand the meaning of those buttons. It is an instance of the accessibility technique implementation without considering its usefulness to the intended audiences. The problem should be resolved by a design improvement. Thus, the design principle,

DP: the text label for a button must convey the function of the respective button.

DP10: When the selection status of a button indicates a specific state of the system, the label of the button must convey the meaning of the state of that button. As the participants activated the buttons to select the unit of the calendar movement as seen Figure 5.8, only the state of the buttons changed to “selected.” It did not help the participants to understand that the unit of the calendar movement had changed. This problem must be resolved by improving the design to include appropriate labels which convey the meaning of the change of the status. For example, the label can read “selected, shift the calendar by week.” Thus, the design principle,

DP: When the selection status of a button indicates a specific state of the system, the label of the button must convey the meaning of the state of that button.

Interaction Principles for Mobile Applications

Table 5.4

Interaction Principles for Mobile Applications

Interaction Principles	Interaction Principles for Mobile Applications
IP1	If there is no save notification, review the saved information.
IP2	**In the context of the dynamically appearing picker controls, probe the bottom portion of the screen to find the relevant picker control.**
IP3	If an interface contains left and right arrow buttons then it is highly likely that the buttons are useful to move back and forth in the given context and the arrow-head indicates the respective direction in which the user will move.
IP4	If the page-tabs are not labeled then sequentially visit each tab and probe the respective screen to identify the desired page-tab.

IP1: If there is no save notification, review the saved information. When there was no explicit notification indicating the outcomes of hitting the save button, the participants used two heuristics to find out if the information was saved. In Task-3 and Task-5, They inferred that the information was saved by reviewing the application tab which showed the saved information. In Task-2, they inferred that information was saved when the options to save the information were not present. We recommend adopting the first heuristic as it is deterministic as opposed to the second which is probabilistic. Ideally, the problem must be resolved using the design principle DP2. Nevertheless, BVI

users can adopt the heuristic approach to manage the contingency. Thus, the interaction principle,

IP: If there is no save notification, review the saved information.

IP2: In the context of the dynamically appearing picker controls, probe the bottom portion of the screen to find the relevant picker control. To deal with the gulf of evaluation described in DP3, two participants probed the bottom portion of the screen and found the date picker control. They had learnt by experience that the dynamic picker controls appear at the bottom of the screen. They could thus successfully set the date and time as required. Other participants could not overcome the problem. Hence, there is scope to improve the BVI users' interaction skill. Thus, the interaction principle,

IP: In the context of the dynamically appearing picker controls, probe the bottom portion of the screen to find the relevant picker control.

IP3: If an interface contains left and right arrow buttons then it is highly likely that the buttons are useful to move back and forth in the given context and the arrowhead indicates the respective direction in which the user will move. One participant had interacted with the computer before she became blind. In some applications, she had used left and right arrow icons to move back and forth. Based on that experience, she speculated that the calendar as seen in Figure 5.8 can be moved back and forth using the left and right arrow buttons. Evidence suggests that despite of the accessibility guidelines and disability laws, incidences of accessibility glitches is a fact. Therefore, there is a value in informing the BVI users about the meaning of such standard icons. Thus, the interaction principle, IP: if an interface contains left and right arrow buttons then it is highly likely that the buttons are useful to move back and forth in the given context and the arrowhead indicates the respective direction in which the user will move.

IP4: If the page-tabs are not labeled then sequentially visit each tab and probe the respective screen to identify the desired page-tab. The participants used an alternative strategy to overcome the unlabeled page-tab problem described in DP8. They sequentially selected each tab and probed just below the top-portion of the respective screens to identify the desired page-tab. They knew by experience that the title for the page is usually just below the top of the screen. They used same strategies in other applications when they were required to select a page-tab. This strategy is time-consuming and an unnecessary burden on the BVI users. Designers, must follow DP8 and should not compel BVI users to use this interaction principle. Thus, the interaction principle,

IP: If the page-tabs are not labeled then sequentially visit each tab and probe the respective screen to identify the desired page-tab.

Limitations and Future Research Directions

The limitation of this study is that all the participants had substantial (more than three years) experience of using the web and mobile screen-readers. It limits the generalizability of the findings to the BVI users who have minimum three years of experience of using the screen-readers. The interaction strategies employed by the novice users of screen-readers could be different than those revealed by this study. To overcome this limitation, we plan to replicate this research with the novice users of screen-readers.

Also, we plan to utilize the in-depth knowledge of BVI users' interaction strategies to create a smart interaction assistant. It would facilitate the BVI users' interaction by suggesting the appropriate strategies for the given context.

It is important to note that the methodology to identify the areas of improvement is generalizable beyond the interactions of blind users of screen-readers. It can be employed in studying the interactions of users who do not use screen-readers. We plan to expand the scope of this methodology beyond the BVI users and use it to improve the technology interactions of diverse user-groups such as sighted users, visually impaired users of screen-magnification technology, web and mobile users with hearing disabilities, and elderly users of the web and mobile technologies, etc.

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APPENDIX A

RESULTS FOR SEARCH STRINGS

Results for the search string "learn about the normal blood sugar levels"

https://www.diabetesselfmanagement.com/blog/what-is-a-normal-blood-sugar-level/

http://www.diabetes.org/living-with-diabetes/treatment-and-care/blood-glucose-control/checking-your-blood-glucose.html

http://www.webmd.com/diabetes/guide/blood-glucose#1

http://www.webmd.com/diabetes/guide/normal-blood-sugar-levels-chart-adults

https://medlineplus.gov/bloodsugar.html

http://bloodsugarbasics.com/about-blood-sugar

https://www.niddk.nih.gov/health-information/diabetes/overview/managing-diabetes/know-blood-sugar-numbers

https://www.niddk.nih.gov/health-information/diabetes/overview/what-is-diabetes/gestational

http://www.phlaunt.com/diabetes/16422495.php

https://chriskresser.com/when-your-%E2%80%9Cnormal%E2%80%9D-blood-sugar-isn%E2%80%99t-normal-part-2/

Results for the search string "websites to log blood glucose"

https://sugarstats.com/

http://www.diabetesforecast.org/2014/feb/tech-tools-manage-your-blood.html

https://www.mydiabeteshome.com/marketing/apps/online-glucose-monitoring-tracking-software

https://www.mydiabeteshome.com/marketing/apps/online-daily-blood-sugar-log-chart-software

http://www.gomeals.com/glucose-tracker

http://www.mynetdiary.com/diabetes.html

www.mynetdiary.com/tracking-diabetes-with-mynetdiary.html

https://itunes.apple.com/us/app/glucose-buddy-diabetes-logbook/id294754639?mt=8 https://play.google.com/store/apps/details?id=com.skyhealth.glucosebuddyfree&hl=en

http://download.cnet.com/Free-Glucose-Tracker/3000-2129_4-10454535.html

Results for the search string "websites to log blood sugar"

https://sugarstats.com/

http://www.gomeals.com/glucose-tracker

http://www.diabetesforecast.org/2014/feb/tech-tools-manage-your-blood.html

https://www.mydiabeteshome.com/marketing/apps/online-glucose-monitoring-tracking-software

http://www.mynetdiary.com/diabetes.html

https://itunes.apple.com/us/app/glucose-buddy-diabetes-logbook/id294754639?mt=8

http://www.besthealthmag.ca/best-you/diabetes/how-to-track-your-blood-sugar-levels/

https://www.toujeo.com/blood-sugar-log

http://www.diabetes.org/living-with-diabetes/treatment-and-care/247.html?loc=checking-your-blood-glucose

https://play.google.com/store/apps/details?id=com.skyhealth.glucosebuddyfree&hl=en

Results for the search string "medication reminder"

http://www.healthline.com/health/best-medication-reminders

http://www.epill.com/

https://play.google.com/store/apps/details?id=com.medisafe.android.client&hl=en

https://itunes.apple.com/us/app/medisafe-pill-reminder-medication/id573916946?mt=8

http://www.mymedschedule.com/

https://www.alert-1.com/blog/general/the-benefits-of-a-medication-reminder-and-organizer/3970

https://www.alert-1.com/products/medication-dispenser-reminder-and-organizer/206

http://www.caregiver.com/channels/medication/articles/medication_reminder_system.htm

https://www.amazon.com/MedCenter-70942-Talking-Alarm-Clock/dp/B00CEZQ9U4 https://www.activeforever.com/shop-by-category-c-af/independent-living/medication-management/medication-reminders

Set theoretic analysis