AIS Transactions on Human-Computer Interaction

Volume 2 | Issue 3 Article 1

Fall 9-29-2010

Understanding Blind Users' Web Accessibility and Usability Problems

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Original Research

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Abstract

Our motivation for this research is the belief that blind users cannot participate effectively in routine Web-based activities due to the lack of Web accessibility and usability for non-visual interaction. We take a cognitive, user-centered, task-oriented approach to develop an understanding of accessibility and usability problems that blind users face in Web interactions. This understanding is critically needed to determine accessibility and usability requirements for non-visual Web interaction. We employ verbal protocol analysis for an in-depth examination of difficulties participants face in completing an online assessment through a course management system. We analyze the problems that hinder accessibility and usability and explain the nature of these problems in terms of design principles. Our study contributes an effective method for qualitative evaluation of Web accessibility and usability. Our findings will guide future research to develop more accessible and usable Web applications for blind users.

Keywords: Accessibility, Usability, Blind User, Verbal Protocol Analysis, Online Task

Eleanor Loiacono was the accepting Senior Editor. This article was submitted on 11/12/2009 and accepted on 6/11/2010. It was with the authors 8 weeks and 3 days for 1 revision.

Babu, R., R. Singh, and J. Ganesh (2010) "Understanding Blind Users' Web Accessibility and Usability Problems," A*IS Transactions on Human-Computer Interaction*, (2) 3, pp. 73-94.

INTRODUCTION

For the 45 million blind people around the world, interacting with Web sites and Web applications is a challenging task (Theofanos and Redish, 2003; Erin, 2006; Brophy and Craven, 2007; Lazar et al., 2007). This is primarily due to a lack of accessibility and usability in current Web technology (Gerber and Kirchner, 2001; Theofanos and Redish, 2003; Di Blas et al. 2004; Correani et al., 2004; Leuthold et al., 2008; American Foundation for the Blind, 2008). Accessibility allows users access to system functionality (Goodhue, 1986). An accessible Web will allow a blind user access to all its functionality. Usability is the degree to which a system conforms to users' cognitive perceptions of accomplishing a task using the system (Goodwin, 1987). A usable Web will fit with blind users' notion of performing online tasks. Although lack of Web accessibility and usability is undesirable for all, it creates additional problems for the blind in completing online tasks (Correani et al., 2004). This places the blind at a disadvantage in the information society where online tasks are integral parts of education, commerce, social interaction, communication and work.

Extant literature recognizes that blind users' Web interaction problems are multi-dimensional, but does not clearly explain their nature. Blind users interact with the Web through screen-reader software, which reads the textual content of a Web page in a sequential manner (Leuthold et al., 2008). This interaction is constrained by factors such as high cognitive load (Theofanos and Redish, 2003), inefficiency (Lazar et al., 2007), and loss of graphical information (Harper et al., 2006; Leuthold et al., 2008). Often, ignorance of developers and designers about non-visual Web interaction impedes design of accessible and usable Web sites (Lazar et al., 2004). Although the Web Content Accessibility Guidelines (WCAG) exist to help developers and designers overcome this impediment, conformity does not guarantee effective accessibility for the blind (Clark, 2006; Di Blas et al., 2004). Research that specifically examines blind users' online experience is very scarce (Leuthold et al., 2008). This creates a gap in literature addressing where and why blind users face problems during Web interaction; this understanding is necessary for determining accessibility and usability requirements for these users. Our research develops this understanding. Through this research, we answer the question: *What is the nature of accessibility and usability problems blind users face in performing a Web-based task*?

A task-oriented approach helps us examine the complete interaction between a blind user and the Web (Hersh et al., 1996) and provides a complete picture of the problem (Goodwin, 1987). We chose online assessment as the context of our investigation and employed verbal protocol analysis, which is an effective technique for studying users' experience with a system (Todd and Benbasat, 1987). We asked blind participants to complete a representative online assessment while simultaneously verbalizing their thoughts out loud. Audio-recordings of these verbalizations captured participants' thoughts, perceptions and actions. Analysis of this qualitative evidence revealed four aspects of Web design that present accessibility and usability problems to blind users completing an online assessment. We discuss where and why these problems occur, the characteristics of these problems, and possible solutions.

Our study makes two important contributions to HCI research. First, it provides a holistic understanding of the accessibility and usability problems blind users experience in completing LMS assessments. Existing literature lacks this understanding about blind users' Web interaction problems. This understanding is critically needed to develop effective solutions. Our study also provides an effective and feasible technique for qualitative and subjective evaluation of Web accessibility and usability. It demonstrates how to trace accessibility and usability problems from the perspective of blind users and characterize these problems with the help of extant design principles. Our findings have implications for the design of online assessment tools as well as other commonly used applications, such as interactive forms and questionnaires.

We organize the remainder of this paper as follows: In the next section, we present the theoretical foundation to develop an in-depth understanding of blind users' Web accessibility and usability problems in online tasks. Following that, we describe our methodology and research design. Next we provide a detailed discussion of our results and findings. We then present concluding remarks on our study including its contribution and implications, and conclude our paper by identifying the limitations of our study and discuss our plans for future research.

THEORETICAL FOUNDATION

The blind comprise a significant user group that interacts with the Web in an entirely different way from sighted users. The global blind population exceeds 45 million (World Health Organization, 2009), 2 million of which resides in the US (American Foundation for the Blind, 2008). Existing literature recognizes that the Web lacks accessibility and usability for the blind; however, it does not clearly explain the nature of the problems they face in web interactions. In this section, we lay the foundation for developing this missing knowledge. In the first subsection, we define key concepts. The second summarizes our current knowledge about the problem based on an extensive literature analysis to identify the gap in our understanding. In the third subsection, we discuss theories of HCI and cognitive science that help us develop the required understanding. In the final subsection, we identify extant design principles that characterize this understanding. These provide the design principles that we adopt in our study to shape our understanding of the nature of accessibility and usability problems that blind users face in Web interaction.

Definition of key concepts

In our study, a "blind user" refers to an individual who lacks the functional vision necessary to see information presented on a computer screen. Although text-to-Braille assistive technology (AT) is available, blind users predominantly rely on text-to-speech AT, called screen-readers, to interact with computers and the Web (Lazar et al., 2007). A screen-reader identifies and interprets textual content on the screen and presents this aurally through a synthetic voice (Di Blas et al., 2004). This study is concerned with the Web interaction of blind users who rely on a screen-reader assistive technology.

Accessibility allows users access to system functionality (Goodhue, 1986). For users with disabilities, accessibility is treated as a technical construct that allows ATs, such as 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 et al., 2004). Effective user-system interaction requires both technical accessibility and cognitive usability (Norman, 1988).

In this study, we develop an understanding of both the accessibility and the usability problems that blind users face in Web interactions for common online tasks.

Web interaction for a blind user

For blind users, interacting with the Web is a listening activity. Screen-readers read information presented on a Web page aloud from top left to bottom right (Leuthold et al., 2008). This interaction is characterized by sequential access to Web content instead of direct access as in sighted interaction. Blind users provide input exclusively through the keyboard, with continual guidance from the screen-reader's typing echo. Although screen-reader functionality includes innumerable key commands corresponding to various operations (Harper et al., 2006), most users know or use only a handful of these (Theofanos and Redish, 2003). Such a unique interaction strategy demands accessibility and usability requirements distinct from typical users (Bornemann-Jeske, 1996).

Extant research recognizes that the Web lacks the accessibility and usability needed by blind users (Hailpern et al., 2009; American Foundation for the Blind, 2008; Leuthold et al., 2008; Lazar et al., 2007). Research shows that 80% of Web sites do not meet basic accessibility requirements (Loiacono and McCoy, 2004; Sullivan and Matson, 2000; Klein et al., 2003). Web sites that comply with existing accessibility requirements still present access barriers for the blind (Correani et al. 2004; Petrie et al., 2004). What's worse, Web accessibility and usability has declined recently as measured by evaluation tools (Leuthold et al., 2008). Although lack of accessibility and usability is undesirable for all, it creates additional problems for the blind (Di Blas, 2004). These users are half as likely to complete online tasks as their sighted counterparts (Correani et al., 2004).

Current research (Takagi, 2004; Tonn-Eichstädt, 2006; Lunn et al., 2009; Mikovec et al., 2009) focuses on accessibility without addressing usability for the blind. A common perception is that blind users' Web accessibility and usability problems result from the graphical user interface (GUI) (Mynatt and Weber, 1994; Alty and Rigas, 1998; Franklin and Roberts, 2003; Brewster, 2003; Jacko et al., 2003; Zajicek et al., 2004; Yu et al. 2006; Harper et al., 2006; Mahmud, 2007). The contention is that screen-readers do not recognize graphics, and therefore fail to convey information embedded in graphical elements to a blind user (Leuthold et al., 2008). These studies assume that the blind are typical users, except they perceive information non-visually. They focus on how to improve interface design (accessibility) without addressing critical elements of user cognition for the task being performed (usability). In spite of much extant research, guidelines and laws, web accessibility and usability challenges for the blind remain (Hailpern et al., 2009; Mikovec et al., 2009). It is important to consider both the technical accessibility and the cognitive usability of Web interaction while addressing blind users' problems. Without understanding blind users' Web experiences, we cannot accurately understand the nature of their accessibility and usability problems, and therefore cannot develop effective solutions.

The scant research on blind users' Web experience informs us that Web interaction as a listening activity is constrained in several ways. We identify the following problems with non-visual Web interaction based on analysis of this literature:

- The sequential nature of Web interaction means that at any given point, the user perceives only a snippet of the content, losing all contextual information (Lazar et al., 2007).

- Inability to quickly scan a page means that the user has trouble locating goal-relevant information on the Web (Di Blas, et al, 2004). For example, input fields are not apparent to them on a Web page (Theofanos and Redish, 2003).

- When Web pages have a complex layout, the screen-reader's feedback becomes ambiguous (Lazar et al., 2007). Screen-readers also mispronounce many words (Theofanos and Redish, 2003). These shortcomings make it difficult for the user to understand the information being conveyed.

- The wide range of screen-reader functionality makes it difficult for a user to remember and use the appropriate commands and functions during Web interaction (Theofanos and Redish, 2003).

- Cognitive resources are split three ways; the user is trying to understand the web browser, the web site, and the screen-reader (Theofanos and Redish, 2003) simultaneously. This contributes to cognitive overload during Web interaction (Millar, 1994; Thinus-Blanc and Gaunet, 1997).

Literature reveals only glimpses of the problem. It does not explain where and why blind users face problems during Web interaction, nor does it provide insight into blind user's cognition and behavior under a problem situation. This kind of insight is important to understand the nuanced nature of the problem (Foley et al., 1984). In addition, the few studies with a user-centered focus (e.g. Theofanos and Redish, 2003; Lazar et al., 2007) rely on users' reporting of problems. However, research shows that most users report a positive online experience even when they fail to accomplish their goal (Nielsen, 2001). This is particularly true for blind users since they are accustomed to lack of Web accessibility (Gerber, 2002). When faced with a usability problem, people normally blame their own lack of proficiency (Norman, 1988). These unique characteristics of blind users render the overall findings of studies questionable and point to a need for a closer examination of their cognition and behavior during web interaction.

Understanding the blind user's cognition and behavior in web interaction

It is our contention that understanding the nature of accessibility and usability problems of blind users requires examination of their cognitions and behavior during Web interaction. Web interaction, like other human behavior, involves three types of basic processes: perception, cognition, and action. Problems arise when Web design forces the user to spend extra physical and mental effort in these processes (Foley et al., 1984). To evaluate system usability, we need to know how users think, perceive, and act during their interaction (Norman, 2001). This requires a close examination of the user-system interaction process (Zhang et al., 1999). The seven-staged action model helps us examine the complete interaction between a user and a system (Norman, 1988). Next, we discuss how this model guides our research. The theory of cognitive dissonance helps us understand how users think and act when they observe discrepancy between their expectation and reality (Festinger, 1957). Following this, we explain how this theory informs us about thoughts and actions of a blind user dealing with a problem.

Seven Stages of Action

Norman (1988) proposed the seven-staged action model to explain the interaction process between a user and a system, and identify conditions that give rise to usability problems. He emphasizes the need to understand the perception, cognition, and motor functions of a user during interaction. This approximate psychological model accounts for both cognitive and physical activities (Zhang et al., 1999). Norman's model characterizes the complete interaction process between a user and a system into seven stages (Norman, 1988):

1. **Goal identification**: The interaction begins with the user identifying the outcome of the task (i.e., the goal to be achieved). For instance, if the task is to complete an online assessment, the user may identify answering a question as her goal.

2. **Intention**: Once the user identifies a goal, the next step is to form an intention of accomplishing the goal. For instance, the user will intend to answer a question by reading the question; providing a response; and submitting the answer.

3. **Plan of action**: To translate the intention into action, the user identifies an action sequence or series of steps leading to the goal. For instance, the user may identify a four-step plan – (a) locate and read the question text; (b) locate the input field; (c) type a response; and (d) locate and activate the submit button for answering a question.

4. **Execution**: The user will execute the planned action by physically interacting with the system (e.g. online assessment environment). A blind user relies exclusively on key commands guided by audio feedback of the screen-reader to execute an action. For instance, to locate question text, an input field, or any component of

the assessment environment, she would use the arrow keys.

5. **Perceive system response**: After executing an action, the user perceives a change in system state. A blind user perceives system response aurally based on an announcement made by the screen-reader. For instance, the user will detect a new page only if the screen-reader provides some kind of audio feedback.

6. **Interpret the results**: After perceiving the system's response, the user will try to make sense of its meaning with respect to the goal. For instance, she will try to interpret the meaning of screen-reader feedback with respect to answering a question.

7. **Goal accomplishment**: Based on her interpretation, the user will decide if she has succeeded in accomplishing the intended goal. For instance, a blind user will decide if she successfully answered a question based on her interpretation of screen-reader feedback.

We use this action model to conduct online assessments that guide us in understanding the complete interaction between a blind user and the Web in performing an online task.

The most insightful aspect of the seven-stage action model is its ability to identify sources of problem during user-system interaction. Norman (1988) asserts that people face problems when they fail to: (1) determine the relationship between intended actions and system mechanisms, (2) determine the functions of a control; (3) perform adequate mapping between controls and functions; and (4) provide adequate feedback for verifying outcome of actions (Norman, 1988). In other words, the difficulty is solely because they fail to map intentions to interpretations and physical actions to system states. These inconsistencies correspond to two types of gulfs (Norman, 1988):

Gulf of execution: 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).

Gulf of evaluation: 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 her expectation and intention (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, 2001). 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).

The gulfs of execution and evaluation are both associated with roadblocks and extra cognitive effort, making it difficult for the user to accomplish her goal. In online assessment, a gulf of execution will occur when the user hits spacebar on the submit button with the goal of submitting the answer, but the system does not accept this action as a legitimate operation. The user will fail to move ahead and complete the assessment. A gulf of evaluation will occur if the system presents an assessment such that the user has difficulty identifying a sequence of action that will help her answer a question. Another example is when the user fails to derive that she has moved closer to completing the assessment after hitting enter on the submit button. In such a situation, the user exerts additional cognitive effort interpreting the system state to decide if she was successful in answering the question. This makes completing the assessment a difficult task. We use this knowledge about the gulf of execution and gulf of evaluation to trace accessibility and usability problems of blind users in online assessment environments.

Cognitive dissonance

Cognitive dissonance is a state of mental conflict resulting from a discrepancy between previous knowledge or belief, and current reality in the form of new information or interpretation (Atherton, 2005). By nature, we tend to seek consonance among various cognitions, including beliefs, affect, opinion, values, and knowledge of the environment (Festinger, 1957). Discovery of discrepancy in a new cognition challenges this consonance; the two cognitions fail to coexist "peacefully" (Festinger, 1957). The resulting unpleasant psychological tension is cognitive dissonance (Neighbor, 1992). Cognitive dissonance increases with the importance and impact of a decision, along with the difficulty of reversing it (Aronson, 1969).

Dissonance arises due to a need for accommodating a new idea. When it exceeds the threshold to overcome the resistance of a particular cognition, we change or eliminate that cognition (Festinger, 1957). This dissonance also motivates us to change our future actions and behavior for achieving consonance (Aronson, 1969). While using an information system, a user is likely to experience dissonance when observing inconsistency between expected and actual system behavior (Bhattacherjee, 2001). This motivates her to change either her cognition or her behavior (Festinger, 1957) to reduce dissonance. We use this knowledge to understand how cognitive dissonance caused by a problem during Web interaction impacts a blind user's cognition, perception and action in online assessments. We expect that blind users will experience dissonance when they observe a gulf of execution or gulf of evaluation. This is likely to induce a change in their plan of action.

Understanding the problem from a design perspective

In this section, our goal is to develop a set of evaluation criteria to help us characterize accessibility and usability problems. The Web Content Accessibility Guidelines (WCAG) provides four principles of Web accessibility. In section 2.3.1, we discuss how we use these WCAG principles to characterize a blind user's accessibility problems during Web interaction. HCI Scholars have proposed several principles for evaluating system usability. In section 2.3.2, we present a set of usability criteria synthesized from multiple sources that we can use to characterize a blind user's usability problems during Web interaction.

Criteria for Accessibility Evaluation

The WCAG is the de facto standard on Web accessibility. 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 (Trace Center, 2008), represent the primary source of guidance for developers and designers on accessible Web design (Kelly et al., 2005). 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).

The current version of WCAG guidelines (World Wide Web Consortium, 2008) includes a hierarchy of four guidelines and 18 checkpoints. The four guidelines correspond to four principles of Web accessibility: *perceivability*, *operability*, *understandability*, and *robustness*. The 18 checkpoints are considered normative and include definitions, benefits, and examples. In Table 1, we summarize the main ideas of the four guidelines, along with the corresponding checkpoints.

Table 1: WCAG 2.0 Guidelines and Checkpoints (adapted from W3C: www.w3.org/TR/WCAG20/#guidelines)

Guideline	Checkpoints
Perceivable	• All non-text content that can be expressed in words should have a text equivalent of the function or information that the non-text content was intended to convey. • Synchronized media equivalents must be provided for time-dependent presentations. • Information/substance and structure must be separable from presentation. • All characters and words in the content should be unambiguously decodable. • Structure must be made perceivable to more people through presentation(s), positioning, and labels. • Foreground content must be easily differentiable from background for both auditory and visual default presentations.
Operable	• All functionality must be operable at a minimum through a keyboard or a keyboard interface. • Users should be able to control any time limits on their reading, interaction, or responses unless control is not possible due to nature of real time events or competition. • User should be able to avoid experiencing screen flicker. • Structure and/or alternate navigation mechanisms must be added to facilitate orientation and movement in content. • Methods must be provided to minimize error and provide graceful recovery.
Understandable	• Language of content must be programmatically determined. • Definition of abbreviations and acronyms must be unambiguously determined. • Content must be written to be no more complex than is necessary and/or supplemented with simpler forms of the content. • Layout and behavior of content must be consistent or predictable, but not identical.
Robust	• Technologies must be used according to specification. • Technologies that are relied upon by the content must be declared and widely available. • Technologies used for presentation and user interface must support accessibility, or provide alternate versions of content that support accessibility.

Our literature analysis informs us that WCAG is necessary but not sufficient for evaluation of Web accessibility for the blind. Many experts doubt that WCAG recommendations accurately represent accessibility and usability needs of blind users (Di Blas et al., 2004; Clark, 2006; Kelly et al., 2005). For instance, recommendations on perceivability prescribe modifying graphical interface to facilitate screen-reader access (Leuthold et al., 2008). This will be ineffective as content readability for the blind requires aural presentation strategy (Di Blas et al., 2004). Recommendations on understandability ignore design principles and semantics that are critical for understanding content (Di Blas et al., 2004). These do not address complexity of content layout or navigation patterns that cause disorientation among blind users (Kelly et al., 2007). Recommendations on robustness do not address accessibility due to enhancement in screen-reading technology (Di Blas et al., 2004).

Acknowledging its value, along with its limitations, we believe WCAG compliance is a good starting point in achieving Web accessibility for the blind. For our research, we adopt the four top-level WCAG principles: perceivability, operability, understandability, and robustness as accessibility evaluation criteria. We conceptualize the four criteria in the context of a blind user's Web interaction as follows:

1. **Perceivable**: It is possible for the blind user to perceive all Web content.

2. **Operable**: It is possible for a blind user to operate all interface elements.

3. **Understandable**: It is possible for a blind user to understand all content and controls.

4. **Robust**: It is possible for the screen-reader to interoperate with every aspect of the Web.

Criteria for Usability Evaluation

Usability is a qualitative attribute for assessing how easy it is to use a system (Dumas and Redish, 1993). Although there are several guidelines for evaluating the usability of a system, we adopt an integrated set of usability criteria for evaluation of an online assessment environment. This is a synthesis of design principles put forth by three renowned usability experts: Jacob Nielsen's Web usability criteria (Nielsen, 1993); Donald Norman's principles of good design (Norman, 1988); and Shneiderman and Plaisant's golden rules of interface design (Shneiderman and Plaisant, 2004). The ten criteria we adapt for our study are:

A. **Web Usability Criteria** (Nielsen, 1993)

   1. *Learnability*: If first-time users can become productive quickly in terms of finding information and using functionality on the Web site.

   2. *Efficiency*: If Users can accomplish online tasks quickly, without much cognitive effort, after learning the Web site.

   3. *Errors*: If users are prone to committing errors, and if they recover quickly.

   4. *Satisfaction*: If users are satisfied with how the website works.

   5. *Memorability*: If returning users have to relearn how to use the Web site.

B. **Principles of Good Design** (Norman, 1988)

   6. *Visibility*: If users can tell what is going on with the system, and derive alternatives for action by observation.

   7. *Good mappings*: If users can determine the relationships between actions and results, between the controls and their effects, and between the system state and what is visible.

   8. *Feedback*: If users receive full and continuous feedback about the results of actions.

C. **Golden Rules of Interface Design** (Shneiderman and Plaisant, 2004)

   9. *Consistency*: If the sequence of action is consistent in similar situations; if labeling, order and effects of user interface elements are consistent.

10. *Working memory load*: If displays are kept simple, multiple page displays are consolidated, and window-motion frequency is reduced.

These principles were developed for accessibility and usability of systems for sighted user interaction and represent our best knowledge of accessible and usable systems interface design. We adopt and apply these principles to study the accessibility and usability problems that blind users face in Web interaction. They provide a basis for us to understand the cognition and behavior of blind users and characterize the nature of problems that they face in web interaction.

METHODOLOGY AND RESEARCH DESIGN

Our objective is to develop a holistic understanding of accessibility and usability problems blind users face during Web interaction. The context of our study was online assessments presented over learning management systems (LMS). In this section, we describe our methodology and research design. We employed verbal protocol analysis, which is a method of collecting and analyzing qualitative evidence of users' observations and experience during system interaction. In the first subsection, we describe this method in more detail and present reasons for our choice. We then provide demographic details about the 6 blind participants in our study. Jacob Nielsen recommends recruiting at least 5 participants for usability evaluation studies (Nielsen, 1994). We conducted the study with the cooperation of institutions of special education for the blind. Following that we give an account of the study sites. To create a context of Web interaction, we designed a representative online assessment over the Blackboard LMS. In the next subsection, we provide a detailed description of this task environment. Evidence for this study includes verbal protocols of blind participants. Next, we explain the process of collecting this evidence. The verbal protocols are transcribed and broken into single units of thought. We then describe the transcription and segmentation process. To categorize the segments, we developed a coding scheme adapted from Norman's Seven-Stage Action model. In the final subsection, we describe how we use coded segments to trace problems that were observed and experienced by our participants.

Research Method

Our method includes verbal protocol analysis (VPA), a kind of direct observation in which subjects think aloud while performing a task (Ericsson and Simon, 1984). Verbal protocol analysis offers an effective technique for studying the complete interaction process between a user and a system (Todd and Benbasat, 1987). We chose this method because it is considered ideal for tracing usability problems in Web applications (Cotton and Gresty, 2006).

Verbal protocol analysis involves both collection and analysis of evidence. The process begins with the collection of contextually-rich qualitative evidence in the form of audio-recordings of subjects' verbalizations. Before processing this evidence, a space of possible encodings representing task-relevant information is defined (Todd and Benbasat, 1987). The next step is to transcribe the audio-recordings and segment the verbalizations. The segments are then encoded by identifying the category that expresses the same information (Ericsson and Simon, 1984). We follow these norms of VPA using our adapted version of Norman's Action Model. Segments categorized as dissonance and failures helped us trace problems of blind subjects during the interaction process.

Participants

Participants in this study included six blind individuals with an average age of 23 years. Of these, four were college bound, one was a college freshman and one was a government employee. At the time of the study, all participants were enrolled in Institutions of Special Education for the Blind (ISEB). These institutions facilitated recruitment based on their availability and their qualifications as blind users. All participants had at least 5 years experience using computers and the Web through Jaws screen-reader, and none had ever interacted with computers using sight. According to the participants, the two most common reasons for using the Internet were e-mail and information search. No one reported having used an LMS (e.g. Blackboard, Moodle or WebCT).

Site

We conducted the study at two sites, namely the Texas School for the Blind and Visually Impaired (TSBVI) and the North Carolina Division of Services for the Blind (DSB) Rehabilitation Center. Both institutions offer residential programs to train blind students to use computers and the Internet, in addition to other vocational and educational training. These institutions provided us access to our participants as well as access to their computer labs for conducting the study. We conducted one-on-one study sessions that were scheduled after school hours.

Task Environment

We designed a representative assessment task using the Test Manager functionality within the Blackboard LMS. Blackboard, the most popular LMS, is used by more than 3,700 academic institutions across 60 countries (http://en.wikipedia.org/wiki/Blackboard_Inc). We chose Blackboard as the LMS for our study since it supports online assessment and is available to us through our university. The assessment task included questions in three commonly used formats: multiple-choice, multiple-answer, and short-answer. The task commenced with a user locating and activating the link "Web Accessibility Quiz" under the "Assignments" section of Blackboard. Figure 1 is a screenshot of the Blackboard page that instructs users to take the assessment. We created this page in the Assignments section of Blackboard that serves as our study material. It includes a link to the assessment named "Web Accessibility Quiz." This is shown below in Figure 1.

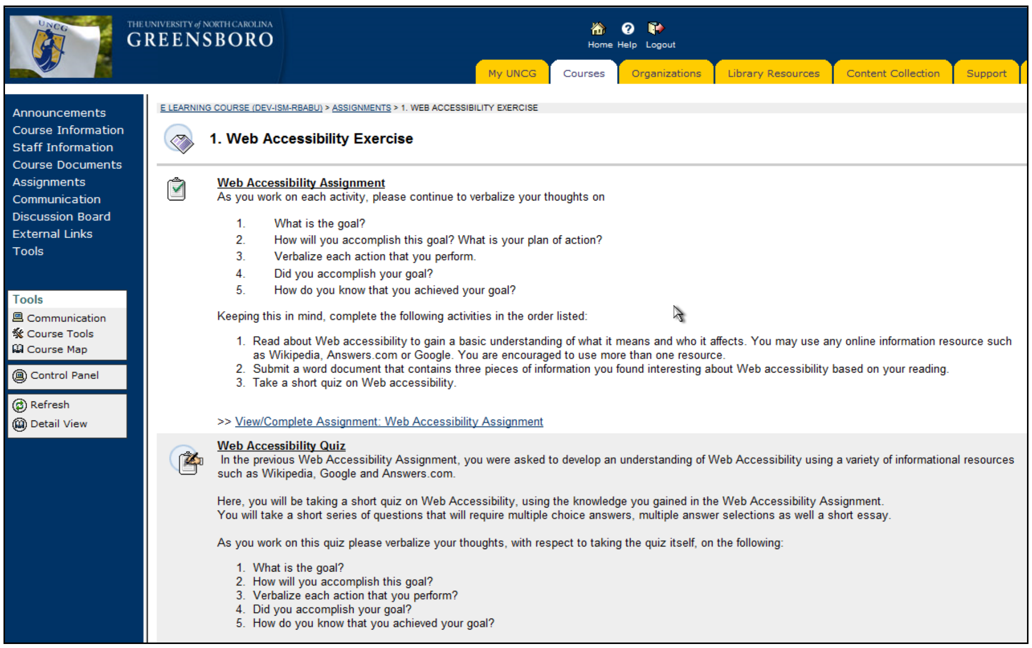

Figure 1: Step 1 - The user finds the Web Accessibility Quiz under the Assignments section of Blackboard

Activating the link "Web Accessibility Quiz" takes the user to a second page that displays the message "Click OK to begin the quiz".

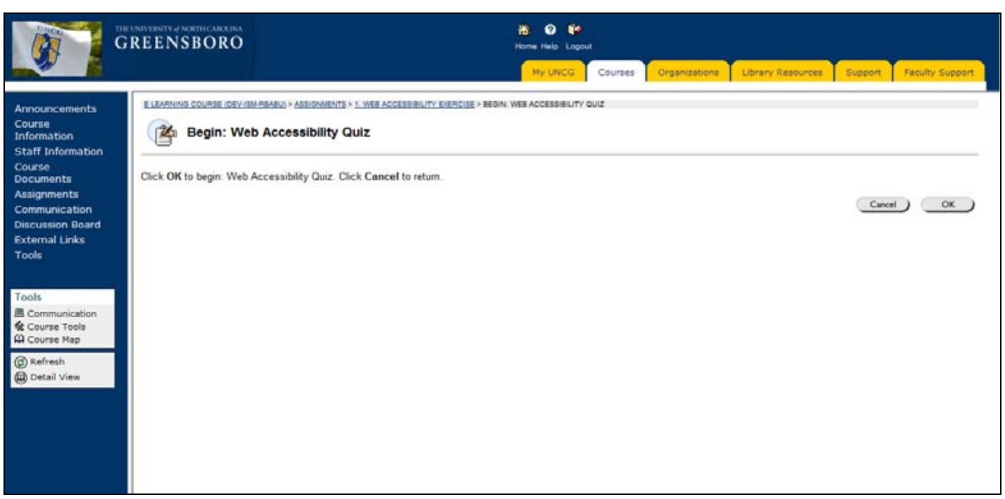

Figure 2: Step 2 - The user begins the quiz by activating the "OK" button

On activating the OK button, the user arrives on a third page that contains instructions on completing the assessment and the first question. This question is in multiple-choice format, including the question text and four options. To choose an option, the user must select an adjacent radio button. A navigation bar appearing near the bottom of the page presents buttons for moving to the previous or next question. On activating these buttons, a message appears asking the user to confirm question submission.

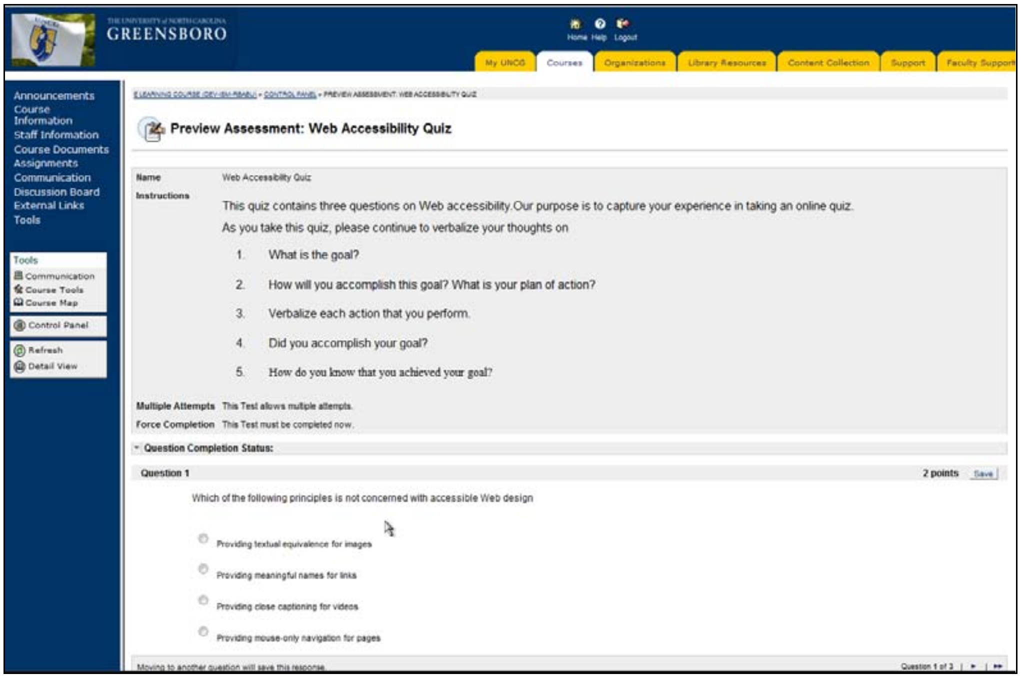

Figure 3: Step 3 - The user arrives on the page with the first question

After confirming question submission, the user moves to a fourth page displaying the second question. This is a multiple-answer question containing the question text and four options. The layout of this page is almost identical to the previous one. Here, the user is required to respond by checking multiple checkboxes, each corresponding to an option. The only difference is a security information dialogue box that pops up on confirming the question submission. It prompts the user to provide a response before moving on to the next question on a subsequent page.

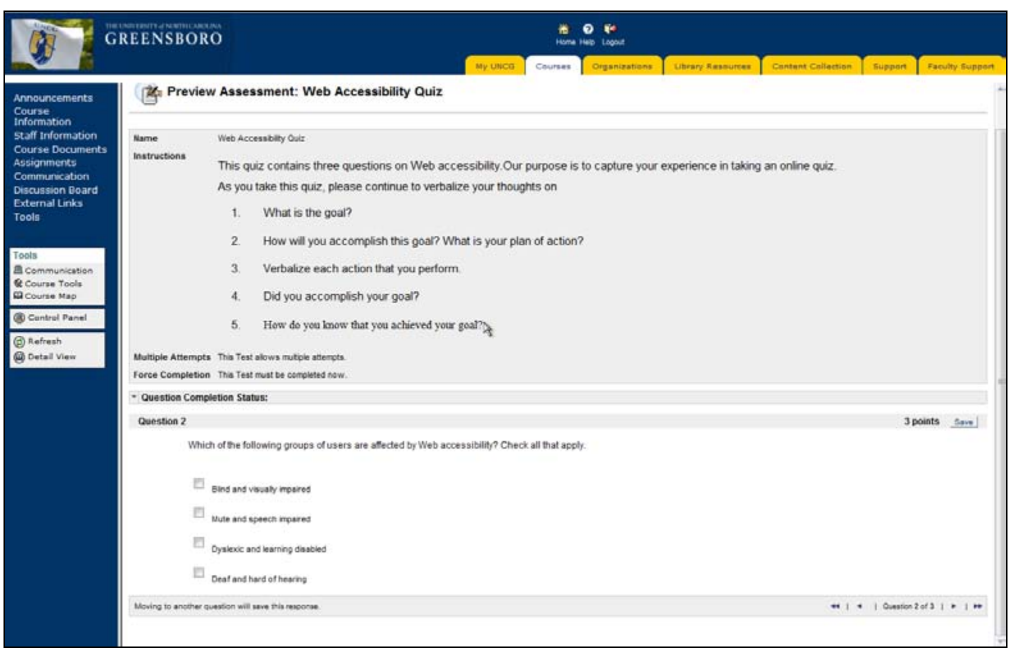

Figure 4: Step 4 - The user moves to question 2 after confirming response for question 1

The third question is in the short-answer format. It includes question text and an input field to provide a response. One important feature of this page is a set of formatting controls interspersed between the question text and the input area. Just like the other questions, navigational buttons are located towards the bottom of the page. Here, the user finds the "Save and Submit" button instead of the "Go to Next Question" button. This allows the user to submit the assessment. The subsequent page displays a message confirming assessment submission and grade information.

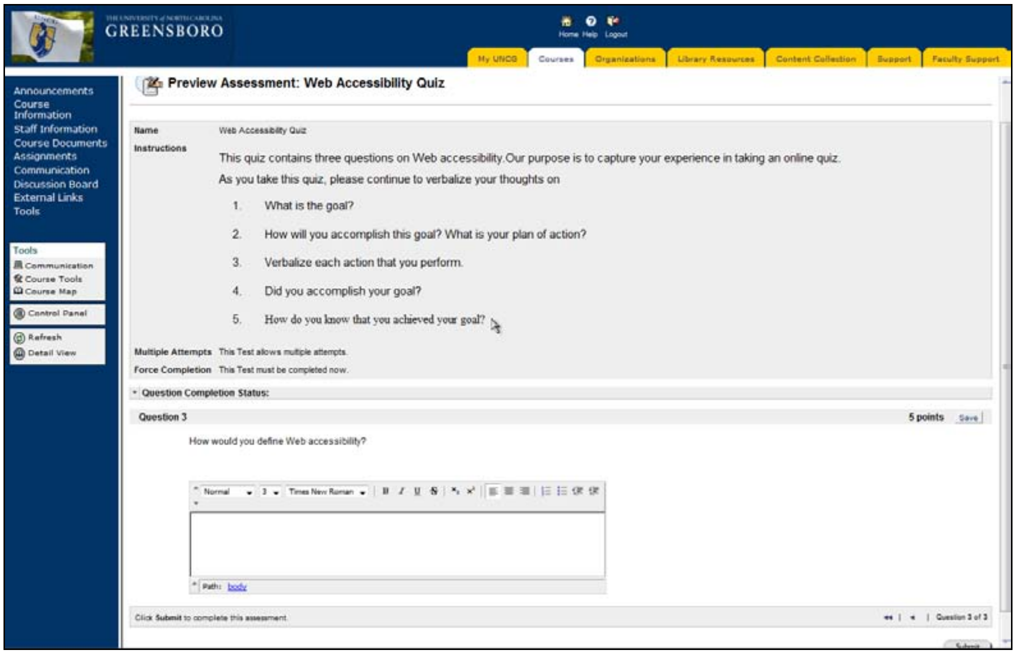

Figure 5: Step 5 - The user types in a short essay response and submits the entire quiz for assessment

Evidence Gathering

In each session, we instructed the participant to begin by reading a document saved on the desktop of the assigned computer. This document guided her in logging on to Blackboard and working on her task with concurrent verbalizations. If we observed that she paused for more than a minute, we urged her to continue verbalizing. These verbalizations reflect a participant's thoughts about the task being performed (Ericsson and Simon, 1984). Coupled with screen-reader's speech output, these verbalizations also revealed what actions she performed using the keyboard in the process. When she hit a roadblock and requested assistance, we intervened to move her along, without revealing the process. Our purpose was to understand her cognition and behavior in the instance of such a roadblock occurring again. Our audio-recordings captured participants' verbalizations as well as the screen-reader's speech.

Transcription and segmentation

We transcribed the audio-recordings into a rich set of qualitative evidence. The transcripts comprised three categories of evidence:

- Participant's verbalizations
- Screen-reader's speech output
- Conversation between participant and researcher

We separated participant verbalizations and decomposed them into single units of thought, or segments. We numbered these segments serially so that we could determine the context of an observation. We then categorized each segment according to our coding scheme.

Coding scheme

We developed a coding scheme, adapted from Norman's (1988) seven-staged action model, to characterize the cognition and behavior of blind users' Web interaction. It enabled us to map blind users' problems to a specific stage in the interaction process and study them in further detail. Our coding scheme has strong theoretical foundations, as discussed in section 2, and was validated using a pilot study with two blind participants. The various categories of our coding scheme include:

- **Problem formulation**: Segments representing a goal or an intention. We combined these individual stages in Norman's original model into one category, since both represent statements about instructions that we provide. This is consistent with Norman's (1988) observation about the flexible nature of his model, as well as Newell and Simon's (1972) problem solving theory.

- **Method**: Segments representing a plan of action. These include statements about an action (e.g. activate a link), or identifying a key command (e.g. hit enter on the link).

- **Expectation**: Segments representing expected consequences of an action. This is an addition to Norman's model; it is founded on the theory of mental models, according to which we form an expectation about the outcome of an action (Johnson-Laird, 1989). Our contention is that the user forms an expectation about a system's behavior in response to the method chosen.

- **Action**: Segments representing execution of a method by physically interacting with the system. This includes statements about individual keystrokes.

- **Perceiving system state**: Segments referring to specific screen-reader feedback corresponding to a change in system state.

- **Interpretation**: Segments revealing what sense the participant makes of the screen-reader feedback. We subcategorized this as consonance and dissonance. Dissonance can either be a total failure to interpret system response due to no feedback; or inconsistencies that result from incomplete feedback from the system. Each form of dissonance indicates gulf of evaluation (Norman, 1988).

- **Goal accomplishment**: Segments representing participant's judgment about the outcome. We separated segments characterized as failure from segments characterized as success. Failure to accomplish goal indicates gulf of execution (Norman, 1988).

Analysis

We examined coded verbalizations, along with the speech output of screen-reader, to understand where and why blind participants faced accessibility and usability problems while completing the online assessment task. Our primary focus was on examining segments suggestive of dissonance or failure. Segments in other categories provided contextual information, and helped us gain a holistic understanding of a problem. Speech output of the screen-reader provided valuable clues to what actions participants took that they did not verbalize. This technique proved useful in capturing the complete interaction process and tracing additional problems users experienced.

FINDINGS AND DISCUSSION

Our qualitative analysis reveals that blind users are likely to face four major accessibility and usability problems while completing online assessments. In this section, we discuss our findings about these problems as observed and experienced by blind participants. In addition, we identify the aspects of Web design responsible for these problems and characterize them in terms of good Web design principles. Below we provide a detailed discussion on individual problems our analysis identifies, followed by a summary of our results.

Susceptibility of skipping a question

Our analysis tells us that participants were vulnerable to being unaware of inadvertently skipping assessment questions. Committing such an error is something blind users cannot afford. Error avoidance principle (Nielsen, 1993) recommends that Web design should reduce user's susceptibility to committing error and facilitate quick recovery.

Table 3 presents evidence that demonstrates how participants were oblivious to committing errors. In such situations, the user lost all possibilities of recovery.

Table 2 includes evidence of an error committed by participant S1 and narrowly avoided by participant S4. It first presents S1's experience. This evidence begins with the screen-reader's announcement indicating S1 had successfully submitted a response to question 1. It indicates that S1 arrived on the question 2 page positioned near the "next question" button. It shows that S1 activated this button, completely unaware that he skipped question 2. It is noteworthy that this finding was based on analysis of the screen-reader's announcement in the absence of S1's verbalization. Evidence of this problem comprise the screen-reader's announcement (prefixed J), the screen-reader's typing echo (prefixed J*), and participant verbalizations (prefixed S1). Table 2 also presents evidence of S4's vulnerability to the error, which she avoided after being prompted to verify her location.

Table 2. Evidence on susceptibility of skipping question 2

J. 1: Microsoft Internet Explorer Dialogue: Confirm question submission. Okay button. To activate, press space bar. J*: Space. J. 2: two percent...one hundred percent. Frame 4. Course content frame. Updated. Go to first question button. Go to previous question. Question 2 of 3. Go to last question. Blank. Graphic links to assessment questions and answers. Same page link. Read question. Same page link. Course content frame. S1: Oh, sorry...just going up and down. J. 3: Go to next question button. J*. 2: Enter. J. 4: Microsoft Internet explorer dialogue. Question may be incomplete: 2. Continue? Okay button. To activate, press space bar. J*. 3: Space. J. 5: Microsoft Internet explorer dialogue. Confirm question submission. Okay button. To activate press spacebar. J*. 4: Space.
S4: I'm going to the next question. So Enter on Go to Next Question. Q: Which question are you on now? S4: One. So, I'm going to go to question 2. Q: How do you know that you are at question 1? S4: Because it says 'go to question two'. Go to the next question... Q: Where does it say that? J: Question two of three. S4: There we go! Right there. J: Go to next question button. S4: Alright. Q: So what are you going to do? S4: Go to question two. Q: How are you going to do it? S4: By "Go to next question." Q: Which question are we on? S4: Question one. Maybe go on that one. Q: What did it just say? S4: Question two of three. Q: What does that mean? S4: I'm on question two. Q: So why did you go to next question? S4: Oh! Well, I thought I was still on question one.

A primary reason blind users are susceptible to skipping a question is default cursor focus. When a new question page loads, the system brings the cursor focus to the navigation bar that has a "Go to Next Question" button (refer to J. 2 in Table 4). Incidentally, the user arrives here by activating the "Go to Next Question" button in the corresponding section of the previous page. The user is likely to misunderstand that the previous attempt of activating the button failed, and therefore makes another attempt to do so. As a result, she unintentionally skips the question (refer to J. 3 and J* 2 in Table 3). As evidence reveals, messages like "Question 2 of 3" and "This question may be incomplete" are ignored by participants (refer to J. 2 and J. 4 in Table 3). These messages are announced without the context, and therefore do not adequately capture participants' attention.

This represents both an accessibility and a usability problem. It is an accessibility problem because it violates perceivability and understandability principles. When a new page with a new question has loaded, users cannot perceive this. They do not understand the context and are disoriented. It is a usability problem because the system violates visibility and error avoidance principles. Users cannot "see" that a new question has appeared. Therefore, they are vulnerable to committing the error of skipping a question without answering it. According to Norman's (1988) Action Model, this indicates a gulf of evaluation because users cannot perceive or interpret the information that a new question is available.

One solution is to program the application so that the cursor focus moves to the question text when a new question page loads. This would make the new question "visible" to the user. Visibility means a user can perceive a change in state just by observing it (Norman, 1988). Visibility for a blind user is the ability to perceive data objects and available commands by listening to a screen-reader (Yoshikawa, 2003). Enhanced visibility can reduce blind users' susceptibility to skip questions.

Inability to comprehend the process of answering multiple-option questions

We find that blind users observe inconsistent system responses when answering questions with multiple options. This type of system behavior gives rise to a conflict between user's prior cognition and present observation, which results in cognitive dissonance (Festenger, 1957). This dissonance prompts the user to modify her cognition about answering multiple-option questions. However, repeated dissonance across multiple attempts will prevent her from understanding the process of answering questions in this format. She must relearn how the system works in every instance of use. This creates problems in the form of extra steps or increased cognitive load (Norman, 2001).

Generally, users can submit their response to multiple-option questions by activating the "Go to Next Question" button on the navigation bar. Users can also submit their response if they hit Enter twice on the radio button or the checkbox corresponding to an option. However, this second method of trying to submit the response does not always result in moving to the next question page. Users may sometimes go back to the previous question page instead of moving forward. To illustrate this inconsistency, we present evidence of S4's experience. S4 hit Enter on a radio button corresponding to an option with the goal of answering Question 1. She hit Enter again on the selected radio button, this time with the goal of moving to Question 2. The system changed, and brought up the subsequent question. She used this observation to develop her conceptualization of answering multiple-option questions. According to this, selecting options and submitting answers can be achieved by hitting Enter on an option. In Question 2, she hit Enter twice on an option with the goal of moving to Question 3. Instead, the system took her back to Question 1. She became confused, believing she must have committed an error. Table 3 presents evidence of S4's experience of dissonance in multiple-option questions. It includes her verbal reports (prefixed S4), the screen-reader's announcement (prefixed Jaws) and the investigator's questions (prefixed Q).

Table 3: Evidence of dissonance experienced by S4

Verbal reports for answering Question 1:
S4: So how do you select...? I'm going to say you Enter on the one that you want. I mean I don't know but I'm going to try it well. Jaws: Enter, content frame updated. S4: I got it, but now, I can't get to the next question. Maybe try…Enter? Jaws: Enter. Forms mode off. Enter. Out of table. S4: Whoa. Jaws: Confirm question submission. S4: Yes!
Verbal reports for answering Question 2:
S4: The answer to...two. I think it's that one. So I'm going to do Enter. Jaws: Enter. Checkbox checked... S4: Ah! So I checked that one. Alright. Then Enter again. Jaws: Enter. Question one of three. S4: Oh. Q: What question are you on? S4: Question one. I need to go to the next—go to question three. Wait. No. I Entered on something I shouldn't have. Go up Jaws: Question one of three S4: Well, I went to question one, and I'm trying to get to three.

The problem results from the lack of a one-on-one correspondence between the user action, which is needed to submit an answer, and the system's response. This represents a violation of the good mapping principle (Norman, 1988). The good mapping principle requires the system to help the user in mapping a single action to a single outcome. The lack of a one-on-one mapping implies that users relearn how to navigate out of multiple-option question in every attempt. This violates the memorability principle (Nielsen, 1993), which requires that users should not have to relearn system functionality and navigational items. This is also a violation of consistency principle (Shneiderman and Plaisant, 2004) that requires that the sequence of user actions remain consistent for similar task situations. According to the Action Model (Norman, 1988), the problem indicates a gulf of execution. The user believed she could move to the next question by hitting Enter on a checkbox, but the system did not lead her forward.

This problem can be avoided if Web applications are designed so that there is one-on-one correspondence between user action and system response. In addition, system functionality and navigational actions should result in the same outcome under similar task situations. Consistency in presentation of operations and results is important for all users. It is particularly important for blind users who have to memorize hundreds of key commands to carry out operations. Consistency in the action-outcome mapping allows blind users to focus on accomplishing the objective of the online task without worrying about system functionality and navigational issues.

Ambiguity about responding to short-answer questions

We observed that our participants had difficulty understanding how to respond to short-answer questions. It took some time and exploration for these participants to figure out that they needed to type in their input and not select an answer as in multiple-option questions. A set of formatting controls appearing between question text and input area significantly contributed to this ambiguity. Participants came across an object labeled "Graphic Question 3 Answers" just before these controls. This seemed to imply that what followed was a set of possible answers. However, they became frustrated when they did not find the possible answers or a place to type their own answer. This ambiguity is especially undesirable in a time-bound activity such as an assessment; users cannot afford to waste time and effort, both mental and physical, in secondary aspects of the task. We present evidence about this phenomenon in Table 4 through the experiences of participants S1 and S4. This includes participants' verbal reports (prefixed S1 and S4) and the screen-reader's announcements (prefixed Jaws). Here, both participants have read the question text and are in the process of navigating further down the Web page to find a place to provide their response. Instead, they come across several formatting controls which they perceive as possible answers to a multiple-option question.

Table 4: Ambiguity about responding to short-answer question

S1: it's kind of tough, it's not really telling me. I mean, it's far more easier to do like radio buttons when it came to like five out of four when it was like multiple choice that way. Otherwise, if it this way it's harder, it's much more tough. But I don't really know how to answer these. I don't understand how to really answer them.
Jaws: Graphic question three answers. S4: So, I'm going to hear the answers. Oh no I can't find the answers. I'm going to go up until it says something like answers...maybe you have to type it? I'm going to look and see if it says answers. Maybe, you do have to type it because I'm not seeing anything that says answers. Jaws: Graphic question three answers. S4: Oh! I found the answers. I'm going to go to where it says answers. Jaws: Graphic question three answers. S4: I'm going to Enter on that. Jaws: Enter. S4: Aww man! I can't find the answers. Maybe, I should look at the whole thing. I think I did find the answers. Maybe not.

Our analysis revealed that this problem occurred because the input field was not "visible" to the user. According to participants' verbal protocols and the screen-reader's announcements, the input area for responses to the short-answer questions remained obscure to blind users. Unlike sighted users, a blind user cannot use visual cues (i.e. a rectangular input field) to determine that the question requires a typed answer. She can recognize this input field only when the screen-reader announces "Edit." Locating an input field surrounded by numerous formatting elements by deciphering the screen-reader's announcements is like searching for a needle in a haystack.

This problem represents a lack of accessibility and usability of the system. Violation of visibility principle is perhaps the most significant contributor to this problem. Lack of visibility hampers the user's ability to recognize the input area. The user's productivity is adversely affected due to the time and effort spent identifying the input field. This violates the principles of efficiency and learnability (Nielsen, 1993). It also compromises the understandability factor, thereby violating WCAG's accessibility criteria. According to the Action Model (Norman, 1988), this indicates a gulf of evaluation since the user is unable to interpret the information that the system communicates.

A possible solution to this problem is to place the input field adjacent to the text of the short-answer question. In this condition, the user will hear "Edit" immediately after hearing the question text. This makes responding to the question much more intuitive. Our evidence also points out that blind users prefer input areas that use an edit field. This type of input field is most common in Web pages, and is easy to operate with a screen-reader.

Threat of losing the assessment

Our participants had problems using the input field assigned for a short-answer question for typical word-processing operations. Analysis reveals that when participants hit the backspace key to delete text in this input field, the system expelled them from the assessment. Use of backspace to delete typographical errors is a common operation in word processing. Input fields are meant to support word processing operations; users will typically use the backspace key to delete text. If the outcome of pressing backspace is to lose the assessment, blind users are at a huge disadvantage. In Table 5, we present evidence of this problem as experienced by participant S6. Evidence includes participant verbalizations (prefixed S6) and the screen-reader's announcement (prefixed Jaws). Here, participant S6 is responding to the essay-type question by typing an answer in the input field. He hits the Backspace key to delete a typographical error. However, he is confused by the screen-reader's unexpected announcements. Later, he realizes that the page had changed; he was expelled from the assessment and not allowed to retake it.

Table 5: Evidence of problem resulting from use of backspace

Jaws: Space, Frame 4. S6: What?! What... Jaws: Space. S6: What? This computer is being crazy. Jaws for some reason went forms mode off for some reason. And now I'm... Jaws: Frame 4, course content updated. S6: Oh wait! I'm not stuck. I don't know why it's doing that. It was supposed to type in. I hit backspace to delete mistakes I had made. It took me out of that. I do not know where I am right now. Jaws: Forms mode off. S6: I know where I was ok, never mind. Oh! Now I got to take the quiz again. Oh my gosh! I don't know what happened. Somehow it took me back to where I started from. . as the beginning to the assignment list. It says review assessment. It somehow jumped. S6: Okay so it won't let me take that again. It took me out, and did not allow me back to the quiz.

From the viewpoint of good Web design principles, this is an accessibility and a usability problem. It is an accessibility problem because the system violates both operability and robustness criteria. It is not operable since it does not support the common keyboard operation to delete text. It is not robust as it behaves in an unreliable manner while typing essay-type answers. It is a usability problem as the system violates Nielsen's (1993) satisfaction criteria. Participants were dissatisfied with its unreliable behavior, particularly since they could not complete their task. This problem points to a gulf of execution between the user and the system according to Norman's (1988) Action Model. This is because the user's conceptualization of using backspace in the input area is inconsistent with the actions the system allows.

Since the use of backspace is quite common in word processing, the only possible solution to the problem is to use input fields that support the use of this important key command.

Summary of results

In Table 6, we summarize our results and list each problem our participants faced, associated aspects of interface design, and the character of the problem. We determined the accessibility character of a problem [marked by (a)] based on our conceptualization of the principles of perceivability, operability, understandability and robustness. We determined the usability character of a problem [marked as (u)] using Nielsen's (1993), Norman's (1988) and Shneiderman-Plaisant's (2004) good design principles.

Table 6: Snapshot of findings

User's Problem	Problematic Aspect of System Design	Design Principle Violated
Susceptibility of skipping a question	Positioning of cursor focus on the navigation bar	Error Avoidance (u) Visibility (u) Perceivability (a) Understandability (a)
Inability to comprehend process of answering multiple-option questions	Inconsistency between user action for submitting an answer and its resultant effect	Consistency (u) Memorability (u) Good Mapping (u) Understandability (a)
Ambiguity about response method for short-answer questions	Lack of visibility of input field	Visibility (u) Learnability (u) Efficiency (u) Understandability (a)
Threat of losing the assessment	Lack of support for use of backspace in input field	Operability (a) Robustness (a) Satisfaction (u)

In an online assessment, blind users are likely to skip questions unintentionally. This happens when the cursor focus moves to the "Go to Next Question" button on a new question page. Consequently, users cannot perceive or interpret information about the availability of a new question. This points to a gulf of evaluation according to Norman's (1988) Action Model. This is a violation of both perceivability and visibility principles as users cannot tell if they have arrived on a new question page. They are unaware of the context and feel disoriented. This violates the understandability principle. In such situations, they activate the "Go to Next Question" button, mistakenly leaving the question unanswered. This violates the error avoidance principle. Susceptibility to skipping assessment questions is both an accessibility and a usability problem.

Blind users taking an online assessment may not be able to identify and apply the correct sequence of actions to submit their responses to multiple-option questions. This happens if the system changes the question page after the user hits enter twice on a radio button or a checkbox corresponding to an answer choice. This points to a gulf of execution. The user believes she can move to the next question by hitting enter on a checkbox, but the system does not move to the next question page. Blind users have to relearn the process of submitting the response in different attempts for multiple-option questions. This problem violates principles of good mapping, memorability and consistency for system usability. Therefore, this problem is primarily a usability issue.

In essay-type questions, blind users may not understand the nature of the response required. This happens when text formatting controls are available between the question text and input area. Users cannot determine the purpose of these controls in answering the question without "seeing" the input field at the same time. This points to a gulf of evaluation between the user and the system (Norman, 1988). It is a violation of the understandability principle. The labels on these formatting controls do not communicate their purpose effectively, so the user feels disoriented. The user's dilemma is confounded by the lack of visibility of the input area. As a result, the user spends much time exploring the page, and may even forego answering the question if she is unable to find the input area. This is a violation of the principles of learnability and efficiency. Ambiguity about response method for essay-type questions is both an accessibility and usability problem.

In the input area of a web page, a blind user faces the threat of losing the assessment while typing an answer for an essay-type question. This happens when the input area does not support the use of the Backspace key as a legitimate operation. This indicates a gulf of execution. There is a discrepancy between the user's conceptualization of operations needed to delete text in the input area, and the operation the system actually allows for this purpose. The user cannot execute a common text-editing operation like deleting text by using Backspace. This violates the operability principle. This unreliable behavior of the system violates the robustness principle. It expels the user from the assessment without allowing a retake. The user feels frustrated and dissatisfied. This violates the satisfaction principle for usability. Therefore, the threat of losing the assessment due to use of Backspace is both an accessibility and a usability problem.

CONCLUSION

In this research, we examined the question: *What is the nature of accessibility and usability problems blind users face while performing a Web-based task*? For this purpose, we adopted a task-oriented approach that helped us understand aspects of a Web-based task that are challenging for the blind. The context of our investigation was online assessment, which is a common Web-based task in an academic environment. Through a field study, we obtained the verbal protocols of 6 blind participants as they completed an assessment over the Blackboard LMS. Audio recordings of these verbal protocols, along with speech output from a screen-reader, helped us capture thoughts, perceptions, and actions of participants during the task. Analysis of this evidence revealed four aspects of Web design that presented challenges for our participants in completing the task. Viewing these problems through the lens of good Web design principles, we found that the online assessment environment violated several accessibility and/or usability criteria. We suggest possible remedies that can reduce or eliminate the accessibility and usability problems blind users face in online assessments. We believe these remedies are simple and straightforward if we have a good understanding of the problem from blind user's perspective.

One of our findings is that in current LMS, blind users are prone to missing questions without even noticing. The problem is that the system does not make a change of question obvious to a blind user. A lack of clear feedback, and the position of cursor focus on the navigation bar, leads the user to falsely believe that the system state remains unchanged. Looking at this problem from good design principles, we find that the system violates usability criteria of error avoidance and visibility. This also accounts for violation of an accessibility criterion that requires providing context and orientation information. A possible remedy could be to position the cursor focus at the question text on moving to the new question page.

A second finding reveals that blind users had difficulty comprehending a process for answering multiple-option questions. This is because they are likely to observe inconsistent system behavior in response to their action of submitting answers from one attempt to another. The particular user action has to do with hitting the enter key on a checkbox corresponding to an answer. This problem reflects a violation of usability criteria including consistency, memorability, and good Mapping. A solution would be to bring about a one-to-one correspondence between user action and system response.

Our third observation is that blind users are likely to get confused due to the page layout in essay-type questions. Our participants had difficulty understanding how to provide a response to the short-answer question. The page design did not make the input area apparent to a blind user. The users spent extra time and effort figuring out where to type in the response. In terms of usability principles, this represents violation of criteria such as visibility, learnability and efficiency. This also indicates a violation of understandability criteria of the Web accessibility principle. The remedy can be as simple as placing the input field right after the question text.

Our fourth finding suggests that a blind user faces the threat of losing the assessment altogether. We observed that when a participant used the backspace key to delete text in the input area of an essay-type question, the system expelled him completely out of the assessment, and did not allow a second attempt. This is a clear violation of operability criteria of Web accessibility principle that requires Web applications to support all keyboard operations that blind users typically use. A possible remedy is to use an edit field as the input area instead of a frame (as is the case presently).

The solutions we suggest may be evaluated in future research through an experiment. These findings have implications for design of Web systems used not just for assessments, but also for similar purposes including interactive forms and questionnaires. By including the three types of assessment question formats: multiple-choice, multiple-answer, and short-answer, we have covered the three most common methods for soliciting user responses through Web-based questionnaires and online interactive applications. These applications are used for common purposes, such as online shopping, blogging, and filing tax returns.

Our study explores what blind users observe and experience while interacting with online assessment environments. This understanding is necessary to create Web sites and Web applications that meet the accessibility and usability needs of blind users. The scant research on blind users' experience with the Web does not clearly explain where and why blind users are likely to find themselves in difficult situations. Our study examines the thoughts, perceptions, and actions of blind users as they perform Web-based tasks. This helps us understand how blind users think about and deal with problems. This kind of knowledge is needed to design more accessible and usable Web applications for online assessments, questionnaires and interactive forms.

Another contribution of our study is a very effective and feasible technique for subjective evaluation of Web accessibility and usability for the blind. It demonstrates how to trace accessibility and usability problems from blind user's perspective, and characterize these with the help of extant design principles. To date, a paucity of research has examined blind users' experiences on the web (e.g. Theofanos and Redish, 2003; Lazar et al., 2007). Researchers have previously relied on participants' accounts of accessibility and usability problems. While this is necessary to understand the problem from the user's perspective, some problems may go unreported. Most users report a positive online experience even when they fail to accomplish a goal (Nielsen, 2001). This is particularly true for blind users since they are accustomed to lack of Web accessibility (Gerber, 2002). Under such situations, users normally blame their lack of proficiency (Norman, 1988). Our method captures the thoughts, perceptions, and actions of participants as they interact with the Web environment. For this purpose, we make use of participants' verbal protocols and screen-reader's speech output. This helps us trace accessibility and usability problems that participants would not have reported. For instance, the fact that blind users are susceptible to missing assessment questions in an LMS was established based on screen-reader's speech. Therefore, we advocate including screen-reader's speech output along with participants' utterances when employing verbal protocol analysis involving blind users.

LIMITATIONS AND FUTURE RESEARCH

The findings of our study contribute knowledge about Web accessibility and usability problems for the blind. However, we recognize that there are limitations to our study. Our findings are based on verbal reports collected from six blind participants about their experiences in interacting with a popular LMS to complete a representative online assessment task. The small sample size, use of one Web application and a single task context limit the generalizability of our findings. We used qualitative methods to develop a deeper understanding of the nature of accessibility and usability problems that blind users face in trying to accomplish their objectives in common Web interaction tasks. This provides the basis for our continued work using different Web interaction tasks on different Web sites.

Our future research will further investigate the problems identified in this study to develop a more robust and in-depth understanding of the nature of blind users' Web accessibility and usability problems. Specifically, our ongoing and future research will create a more comprehensive understanding of these problems by replicating the study presented here with a larger set of participants with varying degrees of vision impairment. In addition, we will conduct future research using other common LMS tasks, such as completing online assignments and contributing to class discussions, to understand the nature of accessibility and usability problems with a wider range of LMS tasks. We will also investigate the kinds of problems that occur when blind users interact with Web applications in other genres, such as online stores and social networks. Findings from these ongoing and future studies will allow greater generalizability of our understanding of the nature of Web interaction problems that blind users face.

ACKNOWLEDGEMENTS

This article is based on our research funded by the National Science Foundation under Grant No. 204060 and Award No. BCS-0938539. Another aspect of this research was supported by the IT Funk program of the Research Council of Norway under Grant No. 202201.

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ISSN: 1944-3900

Transactions on Human-Computer Interaction