IMPACT OF UNIVERSAL DESIGN BALLOT INTERFACES ON VOTING PERFORMANCE AND SATISFACTION OF PEOPLE WITH AND WITHOUT VISION LOSS

A Dissertation
Presented to
The Academic Faculty

by

Seunghyun Lee

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy in Industrial Design in the
College of Architecture

Georgia Institute of Technology

May 2015

IMPACT OF UNIVERSAL DESIGN BALLOT INTERFACES ON VOTING PERFORMANCE AND SATISFACTION OF PEOPLE WITH AND WITHOUT VISION LOSS

Approved by:

Associate Professor Jon Sanford, Advisor
Director of CATEA
School of Industrial Design
Georgia Institute of Technology

Carrie Bruce, Ph.D.
Senior Research Scientist, CATEA
School of Interactive Computing
Georgia Institute of Technology

Professor Ellen Yi-Luen Do, Ph.D.
School of Industrial Design
School of Interactive Computing
Georgia Institute of Technology

Juan Gilbert, Ph.D.
Associate Chair of Research
Computer and Information Science and Engineering Department
University of Florida

Associate Professor Bruce Walker, Ph.D.
School of Psychology
School of Interactive Computing
Georgia Institute of Technology

Date Approved: January, 8th, 2015

To my family for their endless love and support within God’s grace

ACKNOWLEDGEMENTS

I would like to gratefully and sincerely thank my advisor and mentor, Jon Sanford. He was always willing to share his thoughts with me and encouraged me to be an independent design researcher and thinker. His class on "Universal Design" opened my eyes and changed my perspective on my responsibility as a designer and a researcher. I thank him for the enormous amount time he gave to me for advising me during my long Ph.D journey.

I would also like to thank all of my committee members. I am grateful to Ellen Yi-Luen Do for her willingness to support me academically and personally. She was my motivator since I was a master's student and encouraged me to start and finish my journey. I have to gratefully acknowledge Bruce Walker. I learned a lot from many of his classes, and I thank him for his willingness to share his advice on my dissertation work from brainstorming concept development to designing research studies as well as statistical advice. I also gratefully thank Carrie Bruce for her enthusiastic advice on my work. Her detailed and sharp comments were always helpful. I acknowledge my external committee member, Juan Gilbert who has given me thoughtful comments on my work from the experience of his voting research.

I thank all of my team members including those in the design and research team, Yiline Elaine Liu, Ljilja Kascak, and Xiao Xiong; and software development team, Samrat Ambadekar, Ramik Sadana, and Matthew Swarts. Working together was a challenging but necessary design experience. I am grateful that I could lead a team of designers and engineers that helped me to practice the agile research and development processes.

I also thank my motivators and friends, Vincent and Synge. I learned from them about various types of visual abilities and how design and technology can impact their lives. They were always willing to provide me their feedback as subject experts for any of my design projects for visually-impaired users.

I am grateful for all of my study participants supported by the Center for the Visually Impaired, Atlanta VA Rehabilitation R&D Center of Excellence, Center for Assistive Technology and Environmental Access (CATEA), All About Development Disabilities, Alternative Media Access Center, and Georgia Tech Research Institute.

I would like to acknowledge the generous funding for my dissertation research and support during my doctoral training. This study was funded, in part, by the Information Technology & Innovation Foundation as part of a grant from the U.S. Election Assistance Commission. I am grateful for my research assistantship during my Ph.D supported by the Atlanta VA Rehabilitation R&D Center of Excellence CATEA and. I am grateful for all of the researchers and staff members at CATEA for supporting me both financially and mentally.

Finally, I would like to especially thank my parents and parents-in-law, two brothers who are in Korea, without whose guidance and support I would not be here. Last, but not least, I truly appreciate my husband, Matt, for his encouragement, support, and love. Without him, I could not have completed my long journey. I also thank to my 2-year old daughter, Yena, who is the best gift in my life during my journey.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AD	Accessible Design
DRE	Direct-Recording Electronic
HAVA	Help America Vote Act
UD	Universal Design
UI	User Interface
VVSG	Voluntary Voting System Guidelines

SUMMARY

Since the Help America Vote Act (HAVA) in 2002 that addressed improvements to voting systems and voter access through the use of electronic technologies, electronic voting systems have improved in U.S. elections. However, voters with disabilities have been disappointed and frustrated, because they have not been able to vote privately and independently (Runyan, 2007). Voting accessibility for individuals with disabilities has generally been accomplished through specialized designs, providing the addition of alternative inputs (e.g., headphones with tactile keypad for audio output, sip-and-puff) and outputs (e.g., audio output) to existing hardware and/or software architecture. However, while the add-on features may technically be accessible, they are often complex and difficult for poll workers to set up and require more time for targeted voters with disabilities to use compared to the direct touch that enable voters without disabilities to select any candidate in a particular contest at any time.

To address the complexities and inequities with the accessible alternatives, a universal design (UD) approach was used to design two experimental ballot interfaces, namely EZ Ballot and QUICK Ballot, that seamlessly integrate accessible features (e.g., audio output) based on the goal of designing one voting system for all. EZ Ballot presents information linearly (i.e., one candidate's name at a time) and voters can choose Yes or No inputs that does not require search (i.e., finding a particular name). QUICK Ballot presents multiple names that allow users to choose a name using direct-touch or gesture-touch interactions (e.g., the drag and lift gesture). Despite the same goal of providing one type of voting system for all voters, each ballot has a unique selection and navigation process designed to facilitate access and participation in voting.

Thus, my proposed research plan was to examine the effectiveness of the two UD ballots primarily with respect to their different ballot structures in facilitating voting performance and satisfaction for people with a range of visual abilities including those with blindness or vision loss. The findings from this work show that voters with a range of visual abilities were able to use both ballots independently. However, as expected, the voter performance and preferences of each ballot interface differed by voters through the range of visual abilities. While non-sighted voters made fewer errors on the linear ballot (EZ Ballot), partially-sighted and sighted voters completed the random access ballot (QUICK Ballot) in less time. In addition, a higher percentage of non-sighted participants preferred the linear ballot, and a higher percentage of sighted participants preferred the random ballot.

The main contributions of this work are in: 1) utilizing UD principles to design ballot interfaces that can be differentially usable by voters with a range of abilities; 2) demonstrating the feasibility of two UD ballot interfaces by voters with a range of visual abilities; 3) providing an impact for people with a range of visual abilities on other applications. The study suggests that the two ballots, both designed according to UD principles but with different weighting of principles, can be differentially usable by individuals with a range of visual abilities. This approach clearly distinguishes this work from previous efforts, which have focused on developing one UD solution for everyone because UD does not dictate a single solution for everyone (e.g., a one-size-fits-all approach), but rather supports flexibility in use that provide a new perspective into human-computer interaction (Stephanidis, 2001).

CHAPTER 1

INTRODUCTION

Technological innovations in ballot design for U.S. elections have both helped and hindered voting, and as such can influence election outcomes (Bederson, Lee, Sherman, Herrnson, & Niemi, 2003; Wand, 2001). Following the infamous "butterfly ballot" in 2002 U.S. presidential election in Florida, U.S. Congress passed the Help America Vote Act (HAVA) in 2002 that addressed improvements to voting systems and voter access through the use of electronic technologies. Unlike older voting systems such as paper ballots, levers, or punch cards, newer direct recording electronic (DRE) voting systems, also known as touch-screen voting systems, provide a way to verify the votes before casting the ballot (Jastrzembski & Charness, 2007). More importantly, they offer accessible features for voters with disabilities through the use of a variety of multi-modal inputs and outputs as the HAVA requires that all polling places have at least one voting system "be accessible for individuals with disabilities, including nonvisual accessibility for the blind and visually impaired, in a manner that provides the same opportunity for access and participation (including privacy and independence) as for other voters" (HAVA Section 301 (a)(3)(A)) (United States. Election Assistance Commission, 2002).

Although voting accessibility has been improved with the DREs, voters with disabilities have been disappointed and frustrated, because they have not been able to vote privately and independently (Runyan, 2007). In fact, voters with disabilities, regardless of any physical barriers that might make getting to a polling place difficult, preferred to vote in person at the polls, as opposed to absentee ballot by mail (Sanford et al., 2013). However, according to the National Organization on Disability (NOD), they were not able to vote in person because of the lack of available accessible transportation (29%), inaccessible polling place (21%), not understandable voting machine (19%), unavailable accessible options (e.g., large print ballot) (12%), and no available help with the voting machine (8%) (Runyan, 2007). A recent report ("Experience of Voters with Disabilities in the 2012 Election Cycle," 2013) from the National Council on Disability (NCD) also revealed that voters with disabilities do not have equal access to voting systems because accessible voting machines had malfunctioned, were broken, were unavailable for use, or poll workers were unable to operate. In addition, researchers (Bederson et al., 2003; Burton & Uslan, 2002, 2004; Herrnson et al., 2007; Herrnson et al., 2008; Runyan, 2007; Runyan & Tobias, 2007) have examined the usability of commercially-available DREs (e.g., AccuVote-TS, Vote-Trakker, and eSlate) and found evidence of serious usability problems with DREs regarding setup process, audio-tactile interface, adjustability, clear instructions, and ballot layout interfaces.

Voting accessibility for individuals with disabilities has generally been accomplished through specialized designs, providing the addition of alternative inputs (e.g., headphones with tactile keypad for audio output, sip-and-puff) and outputs (e.g., audio output) to existing hardware and/or software architecture. However, while the add-on features may technically be accessible, they are often complex and difficult for poll workers to set up and require more time for targeted voters with disabilities to use compared to the direct touch that enable voters without disabilities to select any candidate in a particular contest at any time. Poll workers who were unfamiliar with the one accessible voting machine allocated to their polling places did not know how to activate the audio ballot, resulting in voters needing some assistance (Chen, Savage, Chourasia, Wiegmann, & Sesto, 2013; Runyan & Tobias, 2007; Vanderheiden, 2004). The complexity of audio voting led to frustration and long completion times to cast a ballot (e.g., 65minutes in November 2004 election) even for experienced technology users (Noel Runyan, 2007). The specialized accessible voting systems that are intended for voters with disabilities rather than for all voters have caused the problems above.

As opposed to designing for specialized voting systems for voters with disabilities at the end of or after the product development, researchers (Piner & Byrne, 2011b; Runyan, 2007) suggested that accessible options need to be integrated with all voting machines in the early design phase of the development so that the process is the same for everyone and does not require any special setup process. This design philosophy is known as “universal design” (UD), which reflects entire population comprised of individuals representing diverse characteristics and abilities by providing inclusive solution that is integrated accessible design features in a mainstream product (Connell & Sanford, 1999; Sanford, 2012; Vanderheiden, 1990b). Thus, UD integrates human factors and social equity approaches that provide opportunities to achieve both usability and inclusivity for people with all types and levels of abilities (Sanford, 2012).

To address the complexities and inequities with the accessible alternatives, a universal design (UD) approach was used to design two experimental ballot interfaces, namely EZ Ballot and QUICK Ballot, that seamlessly integrate accessible features (e.g., audio output) based on the goal of designing one voting system for all. The overall design research process of this work included two phases of the iterative process. The first phase was involved team design and testing with voters with a range of disabilities. The specific aims were to: 1) design and develop the EZ Ballot concept based on the UD criteria and implement a testable prototype; 2) identify the usability of the EZ Ballot by voters with a range of disabilities, and 3) revise the UD Ballot design criteria based on the formative study results. EZ Ballot was designed with a linear, binary yes/no input system for all selections that fundamentally re-conceptualizes ballot design to provide the same simple and intuitive voting experience for all voters, regardless of abilities (Lee, Xiong, Yilin, & Sanford, 2012). The formative study with 21 voters with vision, dexterity, and cognitive limitations demonstrated that people with different limitations could perform voting tasks on a single system. The study also suggested recommendations of the EZ Ballot refinement and an alternative ballot interface that provides random access selection that minimizes voting effort.

The second phase was involved independent design and testing with voters with a range of visual abilities. The specific aims were to: 4) design the QUICK Ballot along with the EZ Ballot refinements; 5) utilize experts to identify the potential impact of both ballots; and 6) examine the effectiveness of the two ballots with voters with a range of visual abilities. As one of the recommendation from the formative study, the second interface, QUICK Ballot was designed with a random access that focuses on fast information processing and provides rich touch interactions. While sighted voters can directly select candidates without scanning, non-sighted voters require scanning the visual contest by moving a finger on the screen and then releasing it to select a particular candidate.

Thesis Statement and Research Questions

The central question that motivates the research was the following question: *"How might we design a voting system that provides the same opportunities for people with disabilities to participate in voting as the rest of the general public?"* To provide one type of voting system for all voters rather than separate solutions for voters with disabilities, our team designed and developed the EZ Ballot and evaluated it by voters with a broad range of disabilities. Then, suggestions from the formative study indicated the need for a second interface, for which I designed the QUICK Ballot with the same goal, namely that of providing one type of voting system for all voters. Although both ballots have the same goal of providing one type of voting system for all voters, each ballot has a unique selection and navigation process (linear EZ Ballot and random QUICK Ballot) designed to facilitate access and participation in voting.

Thus, my proposed research plan was to examine the effectiveness of the two UD ballots primarily with respect to their different ballot structures in facilitating voting performance for people with a range of visual abilities including those with blindness or vision loss. According to the National Health Interview Survey (NHIS), 20.6 million adult Americans, a substantial portion of the voting population, have "trouble seeing" or are "unable to see" even when wearing glasses or contact lenses (CDC, 2014). These voters with vision loss have a substantial difficult experience with voting as voting takes significantly longer (31 vs. 5 minutes) compared to sighted voters (Piner & Byrne, 2011a) and navigating a ballot often leads to confusion (Burton & Uslan, 2004; Gilbert et al., 2010; Runyan & Tobias, 2007).

Thus, the dissertation addresses my central research questions by demonstrating the following thesis statement:

"Universally designed ballots that are intended for all users, to the greatest extent possible without the need for specialized design, will enhance voting performance and satisfaction for voters with a range of visual abilities."

This dissertation has two main research questions that are focused on evaluating two ballot systems by voters with a range of visual abilities. The research questions, hypotheses, and outcome measures are summarized in Table 1.

Research Questions and Hypotheses

In order to evaluate my thesis statement, the following research questions were addressed through this work. My overarching hypothesis is that both ballots, designed based on UD guidelines, are usable by individuals with a range of visual abilities without personal assistance. However, usability does not indicate that individuals with all ranges of visual abilities perform equally well on the two ballot designs. Thus, the purpose of this work was to examine the effectiveness of the two UD ballots with respect to their different ballot structures in facilitating voting performance of people with a range of visual abilities including those with blindness or vision loss. The following research questions are focused on the effect of the ballot structure measured by voter performance and satisfaction, and the changes in voting performance measured by voter performance across trials.

RQ1. What is the effect of the ballot structure (linear selection EZ Ballot vs. random selection QUICK Ballot) on completing voting tasks as measured by observed voter performance (e.g., time, number of errors) and user feedback (e.g., perceived usability, workload, user preference) from voters with a range of visual abilities?

Hypothesis 2.1. The performance on the voting tasks using the QUICK Ballot for navigating and selecting candidates will result in more erroneous selections compared to the performance on the voting tasks using the EZ Ballot.

Hypothesis 2.2. The performance on the voting tasks using the QUICK Ballot will be faster than the EZ Ballot for navigating and selecting candidates.

I hypothesize that voter performance on voting tasks using the QUICK Ballot will be faster than using the EZ Ballot because selection could be provided randomly using the QUICK Ballot rather than selection could be provided by linearly using the EZ Ballot. However, the random QUICK Ballot will result in more erroneous selection and more assists compared to the linear EZ Ballot because whereas EZ Ballot requires step-by-step using the "Yes" and "No" binary selection throughout the voting process, the QUICK Ballot requires rich gesture interaction (i.e., drag and lift finger) for the selection that may be unfamiliar for people with low vision.

Hypothesis 2.3. People with vision loss will report higher perceived usability scores with the EZ Ballot than the QUICK Ballot; whereas people without vision loss will report higher perceived usability scores with the QUICK Ballot than the EZ Ballot.

Hypothesis 2.4. People with vision loss will report lower workload scores with the EZ Ballot than the QUICK Ballot; whereas people without vision loss will report lower workload scores with the QUICK Ballot than the EZ Ballot.

Hypothesis 2.5. People with vision loss will prefer to use the EZ Ballot, whereas people without vision loss will prefer to use the QUICK Ballot.

I hypothesize that there will be differences of subjective ratings between voters with without low vision because whereas EZ Ballot is designed for linear structure that is suitable for auditory presentation, QUICK Ballot is designed for random structure that is more suitable for visual presentation. Thus, people with vision loss will prefer to use the linear EZ Ballot, whereas people without vision loss will prefer to use the random QUICK Ballot.

RQ2. Is there a change in voting performance on the EZ Ballot or the QUICK Ballot as measured by observed voter performance (e.g., number of errors, ballot completion time) across trials of voters with a range of visual abilities?

Hypothesis 3.1. The number of errors (voting errors and usability issues) will decrease over time using the EZ Ballot and the QUICK Ballot for voters with a range of visual abilities.

Hypothesis 3.2. The ballot completion time will decrease over time using the EZ Ballot and the QUICK Ballot for voters with a range of visual abilities.

I hypothesize that voter performance will improve over time when using both EZ and QUICK Ballots. Voters with a range of visual abilities will perform more accurately and faster as they get more practice and gain familiarity with the system.

Table 1. Research Plan Summary

Research Questions	Hypotheses	Outcome measures
RQ1. What is the effect of the ballot structure (linear selection EZ Ballot vs. random selection QUICK Ballot) on completing voting tasks as measured by observed voter performance (e.g., number of errors, time) and user feedback (e.g., perceived workload, user preference) from voters with a range of visual abilities?	**H1.1.** The performance on the voting tasks using the QUICK Ballot for navigating and selecting candidates will result in **more erroneous selections** compared to the performance on the voting tasks using the EZ Ballot.	• Number of errors • Number of assists
	H1.2. The performance on the voting tasks using the QUICK will be **faster** than the EZ Ballot for navigating and selecting candidates.	• Ballot completion time
	H1.3. People with vision loss will report **higher perceived usability scores** with the EZ Ballot than the QUICK Ballot; whereas people without vision loss will report **higher perceived usability scores** with the QUICK Ballot than the EZ Ballot.	• System Usability Scale (SUS) • Usability ratings for voting-specific tasks
	H1.4. People with vision loss will report **lower workload scores** with the EZ Ballot than the QUICK Ballot; whereas people without vision loss will report **lower workload scores** with the QUICK Ballot than the EZ Ballot.	• NASA Task Load Index (NASA-TLX)
	H1.5. People with vision loss will **prefer** to use the EZ Ballot, whereas people without vision loss will **prefer** to use the QUICK Ballot.	• Preference
RQ2. Is there a change in voting performance on the EZ Ballot or the QUICK Ballot as measured by observed voter performance (e.g., number of errors, ballot completion time) across trials of voters with a range of visual abilities?	**H2.1.** The **number of errors** (voting errors and non-voting errors) will **decrease** over time using the EZ Ballot and the QUICK Ballot for voters with a range of visual abilities.	• Number of errors over time
	H2.2. The **ballot completion time** will **decrease** over time using the EZ Ballot and the QUICK Ballot for voters with a range of visual abilities.	• Ballot completion time over time

Contributions

The contribution of this study includes the design of UD ballot interfaces and the examination of these interfaces by experts and voters with and without vision loss. The iterative design processes and evaluation activities include investigation of the existing DRE voting systems, design and development of universal ballot interfaces based on UD and VVSG guidelines, refinement of the interfaces by experts and voters with a range of disabilities, and evaluation of the effectiveness of two UD ballot interfaces that no prior research has examined. More importantly, this work demonstrates the potential impact of a UD voting system in facilitating voting activity and promoting participation of all individuals in the voting process.

The main contributions of this work are in: 1) utilizing UD principles to design ballot interfaces that can be differentially usable by voters with a range of abilities; 2) demonstrating the feasibility of two UD ballot interfaces by voters with a range of visual abilities; 3) providing an impact for people with a range of visual abilities on other applications.

Document Overview

This introduction provided a brief overview of the motivation for this work and the thesis statement, the research questions with hypotheses, and the contributions of the research. Chapter 2 reviews the problems with existing DRE voting systems, the studies of ballot interfaces, and the universal design approach. Chapter 3 introduces the design criteria of universal ballot interfaces, and then presents the overall design research process of this work. Chapter 4 presents the team design and testing on the EZ Ballot with people with a range of disabilities. Chapter 5 presents the independent design and testing with experts. Chapter 6 presents an empirical study of the summative evaluation to examine the effectiveness of different ballot interfaces. Finally, Chapter 7 concludes this dissertation by describing successful contributions that resulted in the utilization of UD principles to design ballot interfaces, the demonstration of the feasibility of two UD ballot interfaces, and the provision of impact on people with a range of visual abilities on other applications.

CHAPTER 2

BACKGROUND AND RELATED WORK

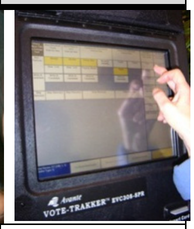
This chapter reviews the lack of equal access to electronic voting systems. First, I review the problems with existing electronic voting systems regarding the setup process, audio-tactile interface, adjustability, clear instructions, and ballot layout interfaces. Further, I summarize other ballot interfaces under development that provide full ballot single screen and one contest single screen along with the findings of the ballot layout evaluation. Finally, I review the potential design approaches (i.e., accessible design and universal design) for designing universal ballot interfaces.

Problems with Existing Electronic Voting Systems

Unlike various other types of voting equipment (e.g., paper ballot, optical scan paper ballot, and punch card), electronic voting systems allow accessibility features (e.g., audio voting) for voters with disabilities. They have been more favorable than paper ballots and have given voters more confidence about their voting outcomes (Jong, Hoof, & Gosselt, 2008; Sarah et al., 2008; Scott et al., 2005). Electronic voting systems consist of direct recording electronic (DRE) voting systems that voters record their votes directly into a computer, and ballot marking devices (BMD) that require manually scanning a ballot after marking the paper ballot through the accessible features. Since the HAVA required that every polling place provide accessible voting systems for voters with disabilities, all states have been adopted such DRE voting systems. The main advantages of the electronic voting systems are being able to review the votes before casting the ballot including the detection of overvoting (i.e., when a voter makes more than the allowed number of selections) or undervoting (i.e., when a voter does not make a voting selection which may or may not be a voter's intention) and accessibility features that minimize the number of voters with disabilities who are unable to use the voting system. However, voters with disabilities have reported that they still face barriers to voting privately and independently ("Experience of Voters with Disabilities in the 2012 Election Cycle," 2013; Runyan, 2007). In addition, human-factor studies (Bederson et al., 2003; Everett, 2007; Herrnson et al., 2007; Herrnson et al., 2008; Roth; Runyan, 2007; Runyan & Tobias, 2007) stated that existing DRE systems have many significant usability flaws associated with the need for help for voters with and without disabilities.

Most DRE voting systems use touch screens that allow voters to directly touch the screen to navigate through the ballot. They include Accuvote TS from the Diebold, AVC Edge from the Sequoia, and Vote-Trakker from the Avante International Technology. One DRE, eSlate from the Hart Intercivic, uses a dial and buttons to move through the ballot and vote. A hybrid ballot marking device, AutoMARK from the Election Systems and Software, consists of a scanner, printer, touch screen display, and input device. Table 2 shows photos and other specifications of the five DRE voting systems. To understand such usability and accessibility issues, various researchers (Bederson et al., 2003; Burton & Uslan, 2002, 2004; Cook & Harniss, 2012; Gilbert et al., 2010; Herrnson et al., 2007; Herrnson et al., 2008; Runyan, 2007) have evaluated DRE voting systems. These studies have identified problems with the setup process, audio-tactile interface, adjustability, clear instructions, and ballot layout interfaces.

Table 2. Existing DRE Voting Systems

Name	AccuVote TS	AVC Edge	AutoMARK	eSlate	Vote-Trakker
					
Touch screen	Yes	Yes	Yes	No	Yes
Display size (in inches)	9x12	9x12		7.75x10	11 x 8.5
Tactile keypad	Tethered Telephone keypad (tethered)	Tethered 4 control buttons (tethered)	Built-in 9 control buttons (fixed)	A wheel and 5 control buttons (fixed)	keyboard
Simultaneous video and audio voting		No	Yes	Yes	No
Adjustable font size	No	No	Yes	No	No
Adjustable contrast	No	No	Yes	Yes	No
Adjustable audio speed	No	No	Yes	No	Yes

Setup Process

Studies (Cook & Harniss, 2012; Runyan, 2007; Runyan & Tobias, 2007) have reported that accessible DRE voting systems are complicated to set up for the average poll worker, resulting in voters with disabilities not being able to vote independently. According to a survey by National Federation of the Blind (NFB) (Cohan & McBride, 2008), more than one-third (37%) of legally blind voters did not have an accessible voting machine available to them. About one in five voters said poll workers had trouble setting up, activating, or operating an accessible machine. As a result, voters had to wait 15-16 minutes for an accessible machine prior to their arrival or, in the worst case, required assistance from a family member, a friend, or a poll worker.

Runyan (2007, p.10), who is blind, reported his frustrated voting experience about the complicated audio voting setup process with accessible voting system (i.e., Sequioia Edge II) in real-word elections:

> *In my first attempt to vote on a DRE in a real election, the poll workers were never able to get any of the machines at our polling place to boot with the audio assist feature working. After 45 minutes of struggling with the systems, the poll workers gave up and I had to have someone do my voting for me* (March 2004 Election).
>
> *The poll workers were unable to get the Sequoia machine booted up in the audio mode. After my wife borrowed the poll workers' operator's manual and figured out the correct audio boot process, she finally managed to get the machine properly rebooted and talking* (November 2005 Election).

I had a similar experience when I accompanied a friend who is blind to vote in the 2012 presidential election when the poll worker was unable to set up the accessible voting machine. As a result, he had to vote on an inaccessible machine where I had to read aloud all of the names on the screen, and he had to tell me all of his selections to input. This problem presented that people with disabilities still have not had equal access to voting systems, resulting unequal participation in elections. This setup problem with one accessible voting systems could be removed if accessible features are integrated into all the voting systems rather than designing specialized accessible voting systems (Piner & Byrne, 2011b).

Audio-tactile Interface

Individuals with visual limitations such as people with blindness or low vision, and those with limited literacy, or who desire audio outputs to vote, use an audio-tactile interface that requires voters use a physical keypad to scroll through the ballot and choose candidates via audio (speech) output through a headset (see Figure 1).

Figure 1. A Visually-Impaired Voter Using DRE Machine with Audio-Tactile Interface

Unfortunately, the audio-tactile interface for DRE voting systems takes a significant amount of time to use and is also difficult to learn, particularly for voters who have had little or no screen reader experience. For example, Runyan's voting experience in November 2004 election took a total of about 65 minutes to mark and record his ballot: rebooting the machine for audio voting (8min), making his choices (30min), reviewing and verifying his votes (23min), and making a correction and recording his vote (4min). In November 2006 election, the audio vote casting took him a total of one hour and 17 minutes. Moreover, for voters who had no technology background, audio-tactile interface was difficult to learn: the training of the audio voting took 4.29 minutes on average, but 5 out of 41 participants never became independent even after extensive training (Golden, 2013). The audio-tactile interface on the DRE voting systems have not been designed for the general population of voters with disabilities (Runyan, 2007).

One possible reason for the complex use of the audio-tactile interface is how the audio interface is designed. Several DREs (e.g., iVotronic, AccuVote TSX, AVC Edge) provide the hierarchical structure with contest and candidate levels (Burton & Uslan, 2002; Runyan & Tobias, 2007). For example, hierarchical structure is designed with contest and candidate levels. Initially, the voter is in the top level, contest level. Using Up and Down arrows, the voter navigate contests then presses Select key to enter a race. In a race, the voter navigates candidates using Up and Down arrows. If the voter moves past the last candidate in a race, the system takes up a level which is the contest level positioned with the next race. In order to go back to the previous race, the voter needs to navigate contests again to enter the particular race. In fact, all 13 visually impaired users needed some assistance when scrolling through this hierarchical ballot structure (Burton & Uslan, 2004). Instead of the hierarchical structure, those users felt easier with the straight linear ballot (e.g., eSlate) that allows scrolling the last candidate, the title of the next race, and the first candidate for that race linearly (Burton & Uslan, 2002, 2004). Runyan (2007) suggested that each race should be displayed on a separate screen in a simple linear format without multiple columns (Runyan, 2007).

Another reason pertains to inconsistent tactile input devices. All four DRE voting systems (iVotronic, eSlate, AccuVote TS, and AVC Edge) consist of very different tactile controls. The controls on iVotronic contain two yellow *Up* and *Down* triangular buttons, a green diamond-shaped *Select* button, and a black oval *Vote* button. The eSlate's control contains red *Cast Ballot* button, white two triangular buttons, oval *Help* button, an *Enter* button, and a round *Select* wheel that the voter rotates to scroll through the ballot. The AVC Edge has a separate hand-held control box with a square blue *Help* button, a triangular yellow *Back* button, a triangular green *Next* button, and a red round *Select* button. Thus, visually-impaired voters find it challenging to complete the voting process by scrolling using a keypad control (Gilbert et al., 2010; Runyan & Tobias, 2007). Some suggest that a more consistent design of input devices on voting machines could foster familiarity and comfort (Piner & Byrne, 2011a).

Adjustability

To accommodate the wide range of abilities, providing a wide range of choices of visual and audio features and settings is essential to meet individual voter needs (Cook & Harniss, 2012; Runyan, 2007). Adjustable visual settings include providing choices of font size and color contrast and adjustable audio settings include providing choices of audio speed and volume. The simultaneous audio and visual outputs also can help voters with low vision, low literacy, or other cognitive limitations who are not familiar with audio-tactile interface only. Researchers (Cook & Harniss, 2012; Runyan & Tobias, 2007) suggest that incorporating any adjustable settings within the voting application from the beginning of the design for voting systems rather than adding those later or being dependent upon the browser or operating systems. In addition, the voter should be able to adjust any visual or audio settings throughout the voting session while maintaining their voting process (Cook & Harniss, 2012).

Adjustable Visual Settings

The ability to adjust font size, high contrast, or inverse colors can help voters with low vision, cognitive disabilities, or older adults (Cook & Harniss, 2012; Theofanos & Redish, 2005). However, existing DREs either do not provide adjustability or have a limited choice of font size. For example, several DREs (i.e., AVC Edge, eSlate) do not allow the voter to control the font size (Burton & Uslan, 2002, 2004). Several (i.e., AccuVote-TSX and AutoMART) offer the adjustability of font size, but they are not big enough (i.e., 8.5-point and 17-point font size in AutoMARK, normal and twice the normal size). In fact, low-vision participants asked for greater magnification such as 24-point or even 34-point font size (four times the normal size) (Runyan, 2007).

Adjustable Audio Settings

The ability to adjust various audio settings such as audio volume and speed are highly desirable aspects (83.9% and 79.4%, respectively) to increasing the understandability of the voting process (Cook & Harniss, 2012; Piner & Byrne, 2011a). The survey among 180 legally blind users (Piner & Byrne, 2011b) also found that a common complaint was the lack of appropriate audio controls on the DRE (e.g., eSlate). One participant commented: “The most cumbersome was not being able to adjust the rate of the synthetic speech.” In fact, experienced screen readers typically listen at a very fast speed (e.g., 300 words per minutes). Voting systems should provide flexible audio speed options so that experienced and non-experienced audio interface users can adjust the settings to their preferred speed to be able to vote at their own pace.

Simultaneous Audio and Visual Outputs

Several DREs (i.e., iVotronic, AVC Edge, and Sequoia Edge II) provide either a visual or auditory interface, but not both. When audio voting begins, the screens go black. As a result, Runyan (2007) reported that voters with low-vision had to ask their blind friends to vote for them using the Sequoia audio access because they were not comfortable with audio-only interface. Thus, many low-vision users who were not able to see the visual screen complained about the lack of such a feature (Burton & Uslan, 2002; Pierce, 2005; Runyan, 2007; Runyan & Tobias, 2007). Depending on their visual functional limitations, those users might not need audio access technology (e.g., screen reading software) or have not used it before. Likewise, older adults, who comprise a substantial portion of visually-impaired individuals are unfamiliar with audio only access option because they have had their vision most of their lives (Runyan, 2007). Thus, in order to increase understandability of the content, this simultaneous audio and visual outputs should be helpful for not only people with visually impaired but also older adults who often have both low vision and moderate hearing loss (Cook & Harniss, 2012).

Clear Instructions

Voting machines should provide clear instructions so that all voters including those with disabilities to cast their ballots independently. Unfortunately, studies (Burton & Uslan, 2004; Cohan & McBride, 2008; Herrnson et al., 2008) indicate that both voters with and without disabilities needed assistance. According to the NFB survey (Cohan & McBride, 2008), about half of 560 legally blind voters relied on the assistance from their family, friend, or poll workers in 2008 election. In a study of the usability of accessible voting machines (Burton & Uslan, 2004), all 13 legally blind users needed some assistance with each of the voting machines (e.g., VoteTrakker (n=11), eSlate (n=8), AVC Edge (n=10), and AccuVote TS (n=8). The most assistance was required in tasks associated with scrolling through the ballot when they use the audio voting. In addition, the task of changing a vote was the most difficult task without assistance. One study found that almost all participants (n=45) had problems of remembering to deselect (Redish, Chisnell, Newby, Laskowski, & Lowry, 2009), and this changing votes and correcting mistakes led to many of the requests for help on the voting systems (Herrnson et al., 2008).

Another study (Herrnson et al., 2008) indicated that substantial numbers of voters (18 to 36% of 1540 respondents) without disabilities felt the need for assistance on most of the voting systems (e.g., AccuVote TS, Vote-Trakker, and eSlate) at rates of 18, 29, and 36 % respectively. Requests for help were related to navigating backward and forward, using review screens, deselection before reselection, and typing in names. Among those, they found that voters with little computer experience, senior citizens, and non-English speaker had a greater need to ask for help on most of the systems.

The need of help may be reduced if the system provides clear instruction about how to use the ballot. In contrast, confusing wording and inadequate help message create misunderstanding how to use the ballot (Selker, 2007). For example, the user can interpret the message “You are finished voting” to mean that you are done voting and can walk away (Runyan & Tobias, 2007). Long instructions can be also difficult for most voters to remember. Thus, a ballot with instructions that use plain language can significantly reduce voter accuracy (Redish et al., 2009). No voting system provide any practice mode that users can first practice how to mark, review, and change their choice on a simplified example ballot (Runyan, 2007).

Ballot Layout Interfaces

The ballot layout interface can have a large impact on the voting experience depending on an individual's visual and cognitive capabilities (Jastrzembski & Charness, 2007; Kimball & Kropf, 2005; Norden, Kimball, Quesenbery, & Chen, 2008). The incorporation of more cognitive supports into the ballot is a necessity for voters with visual impairments, who require much more demanding cognitive effort, can be confused and overwhelmed by the amount of information and visual complexity of a standard ballot (Ott, Heindel, & Papandonatos, 2003). While the full ballot structure provides an overall orientation without individual guidance, the page-by-page ballot structure provides guidance for individual contests without an overall orientation to all of the contests. However, several DRE voting systems (e.g., Accuvote TS, iVotronic TS, AVC Edge) present an inconsistent ballot layouts (See Figures 2, 3, and 4) that provide multiple races in multiple columns on one single page, which may increase confusion visually and through audio for screen reader users (Gilbert et al., 2010). Norden and other researchers (2008) suggested that placing candidates for one contest per page can reduce any confusion as people are more likely to miss questions if they are asked to answer more than one at a time.

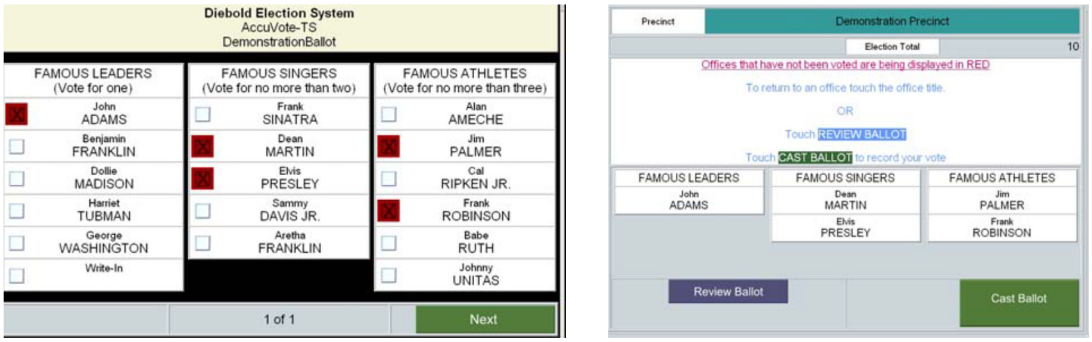


Figure 2. Accuvote TS Ballot Contest (Left) and Review (Right) Page

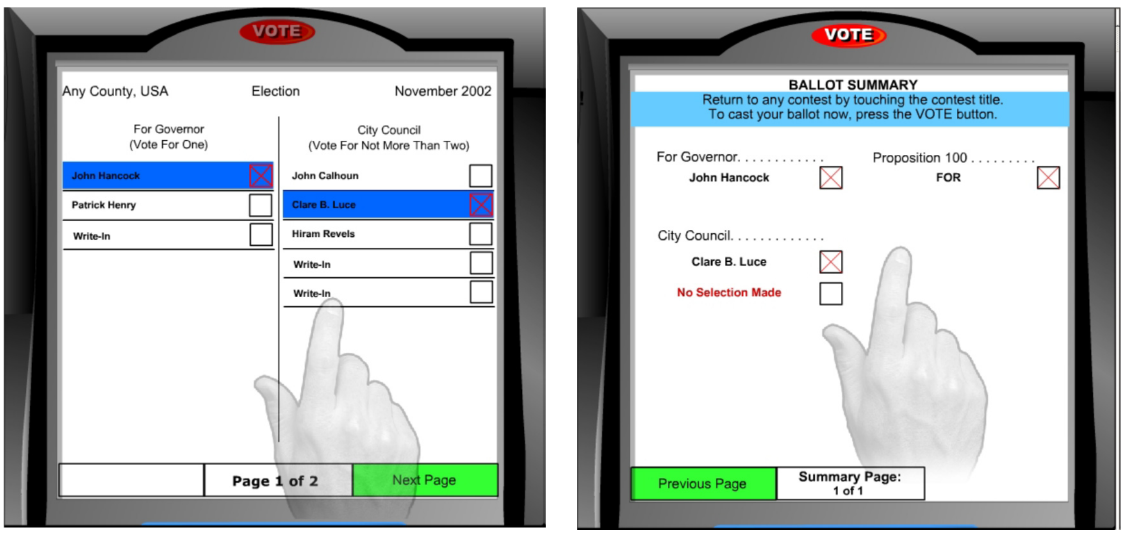


Figure 3. iVotronic TS Ballot Contest (Left) and Review (Right) Pages

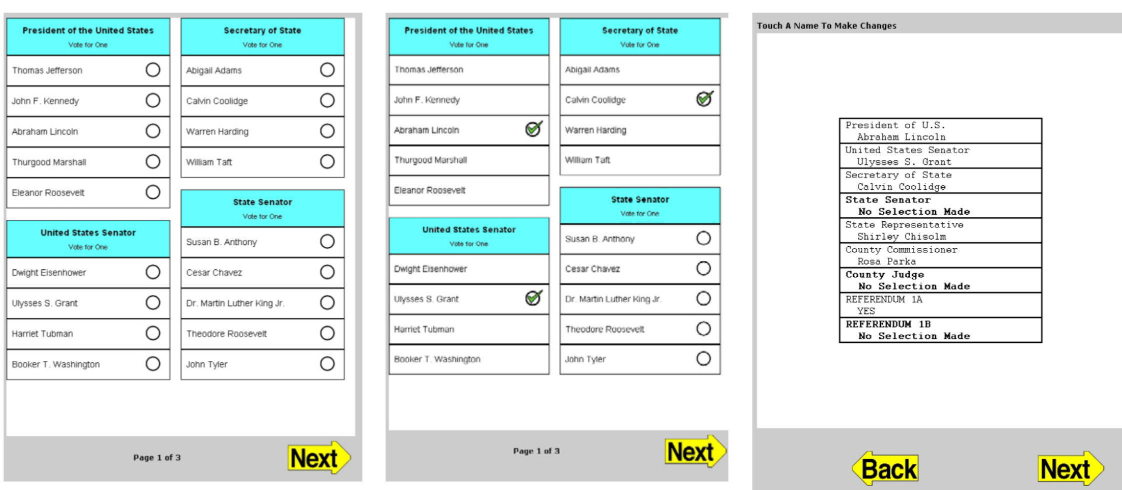


Figure 4. AVC Edge Ballot Contest Page Before (Left) and After the Selections (Middle) and Review Page (Right).

Studies of Ballot Interfaces

To improve the usability of existing DRE voting systems, several groups (Cohen, 2005; Gilbert, 2005; Herrnson et al., 2007; Selker, Hockenberry, Goler, & Sullivan, 2005; Summers, Chisnell, Davies, Alton, & Mckeever, 2014; Vanderheiden, 2004) have developed ballot interfaces focusing on a full ballot structure, mixed ballot structure, and a page-by-page ballot structure that provide different advantages and limitations. Other studies (Campbell, 2013; Harley et al., 2013; Jastrzembski & Charness, 2007) have examined the effectiveness of the ballot layout with electronic voting systems.

Full Ballot Structure

A full ballot structure provides a visual overview of the whole ballot and allows one to navigate freely between an overview of the entire ballot and the details of a specific race. The Zoomable prototype (Herrnson et al., 2007), developed at the University of Maryland, allows voters to navigate freely between an overview of their ballots and the detailed zoomed view of the contents of each specific race (see Figure 5). For example, if the voter touches the box of the screen titled "President and Vice-President of the United States," the list of the candidates for President and Vice-President of the United States will "zoom" into view. Then, if the voter reselects the overview, the screen shrinks back showing the entire ballot. This Zoomable interface as a metaphor of personal photo browsing, was designed for inexperienced users to understand the ballot process (Bederson, 2001). Although this Zoomable interface was rated highly in terms of ease of use, voters commented that the zooming feature was distracting or confusing, and older voters were less satisfied with this interface than younger voters because of confusing features (Herrnson et al., 2008).

However, this full ballot structure could create visual complexity particularly when increasing the number of races, resulting in confusion and more time (Herrnson et al., 2008; Selker et al., 2005). Too much information on one page can result in poor legibility due to the size of the text, decreasing usability for older adults who have limited vision.

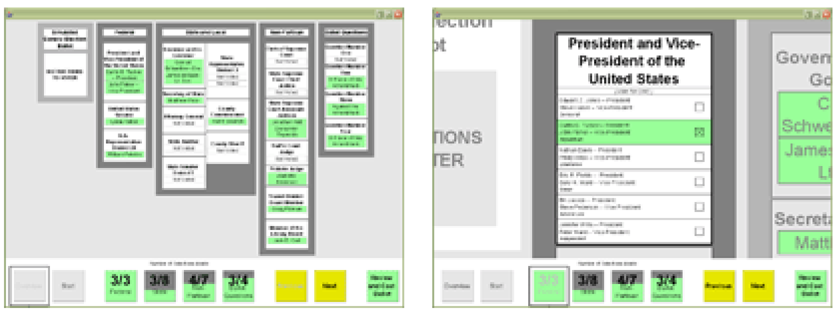


Figure 5. Zoomable Interface Overview Page (Left) and Zoomed Page (Right)

Mixed Ballot Structure

While the full ballot structure provides an overview of the whole ballot on one screen, the mixed ballot structure provides lists of both the contests and candidates by using tabs, and the page-by-page ballot structure has just one contest per page. Voting system prototypes that provide a mixed ballot structure include LEVI (Lower Error Voting Interface) and Prime III.

LEVI prototype was designed and tested through the CalTech MIT voting technology project. Using this interface, voters can see all races on the side navigation tab of the screen and color-coded information whether the voter has voted or not (Cohen, 2005; Selker et al., 2005). On the list of races on the left menu, green color tab indicates the voter has made selections, the grey tab indicates the voter has not yet made a selection (see Figure 6). For the contest requiring two selections, once the voter has made one selection, the tab will be half green and half grey. The evaluation of the LEVI interface showed that while voters made significantly less number of errors using the LEVI than using commercial DREs (i.e., Sequoia and Diebold), they took significantly more time using the LEVI than using other DREs.

Figure 6. LEVI Contest Page (Left) and Review Page (Right)

Prime III, created at Auburn University in 2003, is a multimodal electronic voting system (Gilbert, 2005) that enables voters to cast their ballots using touch and/or voice and dual switch. Similar to the LEVI, the visual layout of Prime III (see Figure 7) displays all races on the side navigation tab, but the list of candidate names as one contest per page.

The advantage of this system is that voters can choose any of the desired input methods interchangeably. Particularly, the speech input is used for voters with vision and dexterity limitations. Voters receive audio output that plays the displayed ballot options on the screen through the headset. For example, if the choices are Democrat, Republican, and Green Party; the ballot will prompt the voter “Say four to vote for the Democratic Party <beep> say three to vote for the Republican Party <beep> say two to vote for the Green Party <beep>” After the <beep> sound, the voter has 2 seconds to respond the number associated with the candidate. To keep voters' privacy, the speaking number is not associated with the order of the candidates. Although, this speech input has potential as an input method for visually-impaired voters and for those who are unable to use the touch screen, this method may confuse voters who may forget the number associated with a candidate and voters who need more time than 2 seconds to answer.

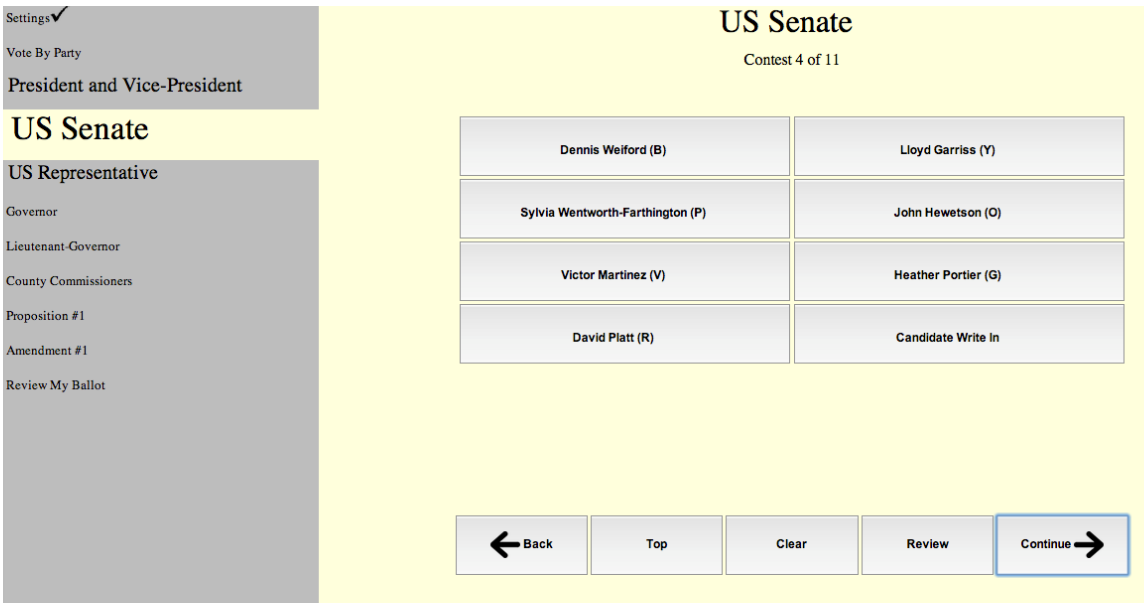


Figure 7. Prime III User Interface

Page-by-page Ballot Structure

Not presenting a list of contests, the page-by-page ballot structure provides a linear navigation with a one contest per page, which could reduce voter confusion (Chisnell, Davies, & Summers, 2013; Gilbert, 2005; Jastrzembski & Charness, 2007; Runyan, 2007). One study (Jastrzembski & Charness, 2007) examined ballot layouts (i.e., Full ballot structure vs. page-by-page ballot structure) by older (n=30) and younger (n=30) participants. The study found that page-by-page ballot layout (i.e., a single contest in one screen) on the touchscreen resulted in the lowest error rates. The multiple page ballot structure that provided verification for each office may have helped with lower error rates compared to the single verification from the entire office with the full ballot design.

Voting system prototypes that provide a page-by-page ballot structure with one contest per page include Enhanced and Extended Usability (EEU), and Anywhere Ballot. EEU (see Figure 8), developed by the Trace Center at the University of Wisconsin-Madison (Vanderheiden, 2004), consists of a touch screen interface integrated with physical tactile buttons using large arrow shaped buttons to move back and forth through

Figure 8. EEU with EZ Access keypad.

the races. In addition, it provides visual and audio enhancements such as zoom capability, “voice confirm”, and “touch to hear” features that accommodate voters who are blind, who have low vision, as well as who have any reading problems. The “voice confirm” feature allows the voter to get voice confirmation when marking or unmarking the candidate. The “touch to hear” feature allows the voter to touch any of the text on the screen and be read to them. When the voter finds the name they desire, they can touch the checkbox next to the name. However, voters who are blind or have severe vision loss may get confused in performing these multiple actions (i.e., find the name using the "touch to hear" feature and move the finger to the left and touch the check box). The EEU provides a separate EZ Access keypad that allows full control of the voting process to be flexibly placed in several positions for voters who are unable to use the touch screen. However, this physical keypad, which uses indirect control, provides more cognitive demand than the direct control (e.g., touch screen) that could add to more confusion for voters who use this the first time (McLaughlin, Rogers, & Fisk, 2009; Rogers, Fisk, McLaughlin, & Pak, 2005).

A recent online ballot prototype (see Figure 9) that also used page-by-page ballot structure with one contest per page is Anywhere Ballot (Chisnell et al., 2013; Summers et al., 2014). This ballot was focused on designing "plain interaction" with "plain language" for voters who have low literacy skills or mild, age-related cognitive impairments.

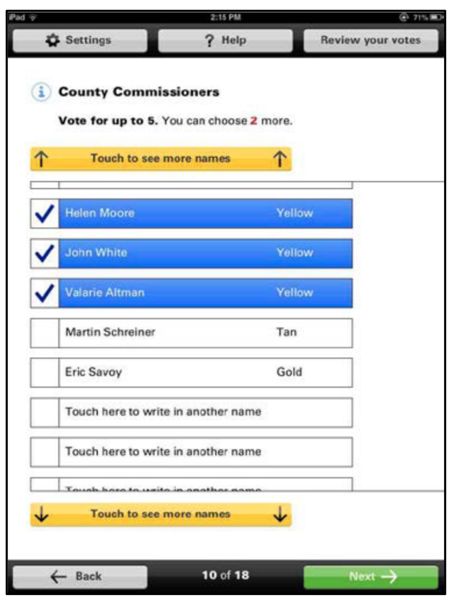


Figure 9. Anywhere Ballot.

Following user studies with various reading levels of participants, this ballot has been through several iterations. Since the ballot has been successful in making voting easier for low-literacy voters, the "plain language" can be adopted for developing our ballot design development. However, “plain interaction” can be different depending on the types of limitations, particularly for visual limitations.

Anywhere Ballot provides multiple methods for navigating long ballot contests by dragging the scrollbar, swiping with figure gestures, and touching on-screen buttons with the label “Touch to see more names.” Although providing multiple methods for voters who are familiar and comfortable with gestural and touch interface, visually-impaired voters who use screen readers may experience problems navigating names using any of the method because the ballot was not designed to integrate audio outputs. k

When the ballot contents get long (e.g., many names of candidate), one contest per page cannot fit onto one screen. To display long ballot content, ballot designers should decide form one of three ballot layouts: multiple columns, scrollable page, or multiple pages. One recent study (Harley et al., 2013) evaluated the three ballot layouts (i.e., multiple columns, paginated content, and scrollable pages) with three controls (i.e., 2-button, 5-button, mouse) by 18 participants (26±13 years) without any disability. The study did not find any significant difference between the three ballot layouts and three controls for the ballot duration, mean click time, number of undervotes, or number of times that the Help button was selected. However, participants preferred the multiple column ballot layout and the use of the mouse. On the contrary, another study (Campbell, 2013) found that displaying long ballot content as a single scrollable screen led to more voting errors, which may lead to the negative effect of electronic voting systems. Paginated long ballot content was better in terms of producing less errors for both candidate page and review page than scrollable contest.

Although these studies have a slightly different focus and target populations, one contest single screen structure has been found to be better than the full ballot single screen structure. When the contest page gets long (long ballot content with many number of candidates), paginated long ballot was found to be a better choice than the scrollable ballot.

Although Prime III and EEU have the similar design goal, one type of voting system for all voters, no studies have investigated the effectiveness of ballot layout measured by voting performance for voters with a range of visual abilities including blindness and individuals with vision loss.

Universal Design Approach

Designing voting systems is particularly challenging because such systems should accommodate all citizens including voters with all types and levels of abilities. To design a voting system, two very different design approaches, *reactive approach* and *proactive approach*, can be applied.

Like many other products, many DRE voting systems have been designed and developed for "normal" users who are not classified as individuals with disabilities. Then, for those with specific types and levels of disabilities, specific accessible inputs (e.g., audio voting) are added to existing electronic hardware and/or software architecture at the end of or after the design process. This *reactive approach*, is known as accessible design (AD) that distinguishes between two populations, a normal population and a disabled population, which results in segregation and stigmatization (Sanford, 2012).

AD is linked to compliance with legal mandates, guidelines, or code requirements associated with the Americans with Disabilities Act of 1990 (ADA), and Section 508 of the Rehabilitation Act requires the federal government to show preference when purchasing electronic and information technologies accessible to people with disabilities (Vanderheiden, 2000). Because AD is a disability-specific approach that applies a separate design for different types of functional limitations, it can only be useful to individuals with specific types of functional limitations (Sanford, 2012).

Instead of adding accessibility to an existing system, many researchers recommended that voting systems should be integrated with necessary accessible features so that process is same, not requiring the complex use of specialized system (Gilbert et al., 2010; Piner & Byrne, 2011b; Runyan, 2007). This *proactive approach* is also known as universal design (UD) which is "the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design" (Connell et al., 1997). UD does not view disability as a static point but rather a continuum of ability, so it reflects only one population comprised of individuals representing diverse characteristics and abilities (Connell & Sanford, 1999; Iwarsson & Stahl, 2003; Sanford, 2012). Thus, UD integrates human factors and social equity approaches that provide opportunities to achieve both usability and inclusivity for people with all types and levels of abilities (Sanford, 2012).

While AD is for individuals with specific types and levels of disabilities through specialized design, UD is for all types and levels of abilities through better design overall. Whereas the approach of AD is reactive, which indicates that is added to after or late in the design process, that of UD is proactive, which is accounted for from the early design phases of new products and services (Emiliani & Stephanidis, 2005; Sanford, 2012; Stephanidis, 2001). In addition, UD, which provides one type of design process for accommodating a wide range of individual preferences and abilities, is a more economical solution than AD, which provides design for each specific type and level of disability (Sanford, 2012; Vanderheiden, 1990b). Table 3 summarizes the differences between AD and UD.

Table 3. Differences between AD and UD (Sanford, 2009)

	Objective	Approach	Design Strategy	Result
AD	For individuals with specific types and levels of disability through specialized design	Reactive. (Band-Aid)	Prescriptive	Designs where usability is added in after or late in the design process
UD	For all types and levels of ability through better design overall	Proactive (problem solving)	Performance	Usability is the design goal

In contrast to specialized AD accommodations that are added into the product, UD is everyday design of products, technologies, interfaces, and hardware that in integrated into the system (Sanford, 2012). Many UD examples came from the built-in environment such as ramp, curb-cut, and automatic door, usable for not only people with wheelchair but also people with stroller, bike, or roller skates. This UD approach can also be applied to digital interfaces. Tobias (2003) stated that if a design offers more choices, it will provide more flexibility. For example, if there is a way to use speech recognition for data entry in addition to the regular keyboard, it would be useful for people with and without disabilities just as a ramp can be useful for many people who do not use wheelchairs. A well-known example of UD is the closed-caption feature, which was originally intended for people with hearing impairments. However, this feature can be useful for children learning to read, people learning English is a second language, or people in a noisy environment (e.g., airport) to enable people be able to hear important announcements.

Another UD example for digital interfaces is in Apple's accessibility features on Apple devices (e.g., iPhone, iPad) that have successfully been integrated into mainstream products. Accessibility features include VoiceOver, Speak Screen, Zoom, Font adjustment, Invert Color, and Siri. VoiceOver, the first gesture-based screen reader, makes it possible for people with visual disabilities to use the touch screen interface. Speak selection is to read highlighted text aloud for people with low vision who do not use VoiceOver. Zoom is a built-in magnifier that can magnify up to 1,500 percent for people with los vision. Font adjustment allows to increase the text size in applications such as Mail, Contacts, and Messages. Invert colors lets users invert the colors that can make it easier to read what is on the screen. Siri, an intelligent personal assistance, allows users speak to send messages, place phone calls, schedule meetings, and search anything they like. It also provides other languages such as French, German, Japanese, and Spanish. Many of these accessible features can be used not only for people with disabilities but also people with temporary impairments caused by injuries or illness and different situations (Vanderheiden, 2001). For example, Siri can be a useful feature for people with visual disabilities and people whose eyes are busy when driving a car. Table 4 shows the parallel between disability needs and situations everyone experiences. Thus, researchers argue that the inclusion of the accessibility design feature in a mainstream product can be a substantial benefit to society as a whole (Clarkson, 2009; Sanford, 2012; Vanderheiden, 1990a).

Table 4. Parallel Between Disability Needs and Situations Everyone Experiences (Vanderheiden, 2001)

Disability-related need	Situation-related need
People who are blind	People whose eyes are busy (e.g., driving a car or phone browsing) or who are in darkness
People with visual impairment	People using a small display or in a high glare, dimly lit environment
People who are deaf	People in very loud environments or whose ears are busy or are in forced silence (e.g., in a library or meeting)
People who are hard of hearing	People in noisy environments
People with a physical disability	People in a space suit of chemical suit or who are in a bouncing vehicle
People who use a wheelchair or have limited reach	People who are out of position or have multiple devices to operate
People with a cognitive disability	People who are distracted, panicked, or under the influence of alcohol
People with a cognitive language, or learning disability	People who just have not learned to read this language, people who are visitors, people who left their reading glasses behind

Principles of Universal Design

A group of experts, architects, product designers, engineers, and environmental design researchers, developed the seven principles of UD to provide a guidance for designers to better integrate features that meet the needs of as many users as possible (Connell et al., 1997; Joines, 2009; Sanford, 2012). Table 5 describes the seven principles of UD. The principles include both participation (principle 1) and activity (principle 2-7) outcomes (Sanford, 2012). The participation through social inclusivity is the first principle of equitable use. The activity through usability includes other six principles, flexibility in use, simple and intuitive use, perceptible information, tolerance for error, low physical effort, and size and space for approach and use. Sanford (2012) states that UD is the only design approach that emphasizes both the usability and the social inclusivity aspects of design. Even though the principles of UD have not been empirically validated, this seven principles of UD aim to support the evaluation of existing designs, guide the design process, and educate both designers and consumers about the characteristics of more usable products and environments (Björk, 2009; Bühler, 2001).

Table 5. Principles of Universal Design (Connell et al., 1997)

PRINCIPLE ONE: Equitable Use
The design is useful and marketable to people with diverse abilities.

PRINCIPLE TWO: Flexibility in Use
The design accommodates a wide range of individual preferences and abilities.

PRINCIPLE THREE: Simple and Intuitive Use
Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.

PRINCIPLE FOUR: Perceptible Information
The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.

PRINCIPLE FIVE: Tolerance for Error
The design minimizes hazards and the adverse consequences of accidental or unintended actions.

PRINCIPLE SIX: Low Physical Effort
The design can be used efficiently and comfortably and with a minimum of fatigue.

PRINCIPLE SEVEN: Size and Space for Approach and Use
Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.

CHAPTER 3

DESIGN CRITERIA

In this chapter, I begin to describe design criteria of the UD voting system, and then I describe the overall design research process of this project.

Design Criteria of Universal Voting System

Design criteria for the UD voting system are organized according to the principles of UD (see Table 5). The system is based on the seven UD principles and the Voluntary Voting System Guidelines (VVSG Draft 1.1), relevant standards and guidelines (e.g., Section 508 of the Rehabilitation act of 1973 as amended), and other relevant research findings.

UD PRINCIPLE 1. Equitable Use
Guidelines:

1a. Provide the same means of use for all users: identical whenever possible; equivalent when not.
1b. Avoid segregating or stigmatizing any users.
1c. Provisions for privacy, security, and safety should be equally available to all users.
1d. Make the design appealing to all users.

The design goal is one type of voting system for all rather than accessible design for people with disabilities. As a universally designed system, the ballot design avoids segregating or stigmatizing users by providing the same means of use for all users. One type of voting system for all can benefit not only voters who need accessible voting machines but also eliminating the need for specialized designs so that poll workers do not need to set up a specialized accessible voting machine. In addition, if all voting systems are accessible, voters who need an accessible voting system do not need to wait in a long line to use the only specially equipped voting statin in a polling place. Thus, equitable use also promotes social inclusion by providing opportunities for all voters to participate in person voting at the polls.

The voting system should also support voter's privacy during the voting session by providing appropriate shielding of the voting station (VVSG 3.2.3.1 b). In addition, the audio interface of the voting system should be presented only to the voter by providing headsets (VVSG 3.2.3.1 c).

UD PRINCIPLE 2. Flexibility in Use
Guidelines:

2a. Provide choice in methods of use.
2b. Accommodate right- or left-handed access and use.
2c. Facilitate the user's accuracy and precision.
2d. Provide adaptability to the user's pace.

The voting system should be designed to accommodate a wide range of individual preferences and abilities including the cognitive, visual, and manipulative abilities that are most likely to be adversely affected by ballot design; providing multimodal inputs with either hand that enable voters to choose the methods of use; facilitating and adapting to the voter's levels of precision, accuracy, and pace. Multimodal inputs could include physical tactile input, touch screen input, and gestural inputs, and speech input (VVSG 3.3.9) that could particularly increase accessibility for individuals who have limited or no hand dexterity (Cook & Harniss, 2012). The ballot should be designed with multimodal outputs that use visual, speech, and tactile feedback about voters' actions (e.g., candidate selection). To ensure that all users have access to all inputs and outputs, the default mode is to have all modalities turned on rather than forcing voters to select those that they need and then limiting the types of modalities.

Voters should be able to operate the voting system with one hand (right or left-handed access) (VVSG 3.3.4 d) without excessive force. In addition, an audio-tactile interface should support the full functionality of the visual ballot interface (VVSG 3.3.3 b). For example, blind or visually-impaired voters who use the audio-tactile interface should be able to skip to the next contest or return to previous contest and skip over the reading of a referendum if desired.

UD PRINCIPLE 3. Simple and Intuitive Use
Guidelines:

3a. Eliminate unnecessary complexity.
3b. Be consistent with user expectations and intuition.
3c. Accommodate a wide range of literacy and language skills.
3d. Arrange information consistent with its importance.
3e. Provide effective prompting and feedback during and after task completion.

Regardless of the voter's experience, knowledge, language skills, or level of concentration, voting systems, particularly since they are not used often, should be easily understood, natural, simple and intuitive to use. To accomplish this, complexity should be eliminated, and ballot information should be presented as consistent with voter expectations and intuition. To avoid the complexity, the voting system should visually present a single contest in one screen rather than presenting a single contest spread over two pages or two columns (VVSG 3.2.4 e). However, this guideline is not feasible when a contest has a large number of candidates. In this case, the ballot design should avoid page scrolling (VVSG 3.2.6 a) by voters since studies (Indrani et al., 2011)found that scrolling is not an intuitive operation for those unfamiliar with computers. Even those experienced with computers often do not notice a scroll bar and miss information at the bottom of the page. Thus, pagination (i.e., moving to the next or previous page) may be required for the contest that has a large number of candidates rather than the scrolling (Campbell, 2013).

To be consistent with voter expectations, the ballot design should provide familiar and common words and symbols rather than technical or specialized words or symbols that voters are not likely understand (Redish, Chisnell, Laskowski, & Lowry, 2010). To accommodate a wide range of literacy and language skills, the voting system should also provide plan language for any instructions or warning messages (VVSG 3.2.4 c) and alternative language access (VVSG 3.2.7). In a case, if a voter initially choose an English version of the ballot, but wish to switch to another language to read a referendum question, the voting system should allow the voter to select any available language throughout the voting session while keeping the current votes (VVSG 3.2.7).

The instructions using the plain language should be provided for all voters to get help from the system anytime during the voting session (VVSG 3.2.4 a; 3.2.4 b). Guidelines recommend that all instructions not be presented at the beginning of the ballot (Norden et al., 2008), and they should first provide the context of the action and then the action. For example, a recommended instruction was "In order to change your vote, do X", rather than "Do X, in order to change your vote (VVSG 3.2.4 c)." Moreover, voters should be able to move to the instructions and from the instructions to the ballot at any time without having to listen to all the details. For the first-time voters, a practice mode before beginning the voting process can be also helped (Runyan & Tobias, 2007).

Future, the voting system should provide clear feedback regarding voter's selection (e.g., visual and audio feedback such as checkmark displays when the voter selects a candidate) throughout voting process.

UD PRINCIPLE 4. Perceptible Information
Guidelines:

4a. Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information.
4b. Provide adequate contrast between essential information and its surroundings.
4c. Maximize "legibility" of essential information.
4d. Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions).
4e. Provide compatibility with a variety of techniques or devices used by people with sensory limitations.

To effectively communicate essential information to voters who have a variety of abilities, multimodal sensory outputs such as visual, audio, and tactile information should convey the information using different ways (e.g., pictorial, text, sound, speech). In addition, legibility of information should be maximized by providing adequate contrast between the information and its surroundings, and differentiate elements.

Researchers recommended that the voting system should integrate simultaneous visual and audio outputs as desired by visually-impaired voters (Burton & Uslan, 2002; Pierce, 2005; Runyan, 2007). The redundant cues can facilitate sensory feedback for people with low vision, older adults, and also who have difficulty reading the text on the screen. For example, buttons and controls on-screen should be distinguishable by both shape and color (VVSG 3.3.2 c).

To maximize legibility of essential information on the display, ease to read font and adequate contrast is required. All text intended for the voter should be presented in a sans serif font (VVSG 3.2.5 f) because sans serif fonts are easier to read even for the reduced size and people with low vision and sighted users all preferred san serif to serif font on-screen (Theofanos & Redish, 2005). The electronic display screen should present all information in high contrast by default. High contrast is a figure-to-ground ambient contrast ratio for text and information graphics of at least 50:1 (VVSG 3.2.5 i).

Voting systems should also provide visual (e.g., font size, color, contrast) and audio adjustability (e.g., audio volume, rate of speech) anytime by voters while keeping the current votes (VVSG 3.2.5 b, 3.2.5 c). Unlike blind users who typically use screen reading software, low-vision users who use screen magnifier software often customize visual characteristics widely based on their visual abilities and preferences (Theofanos & Redish, 2005). Although no simple solution exists for low vision users in terms of what type size to use, what colors to use, and what screen layout to use (Theofanos & Redish, 2005), existing guidelines suggest specific recommendations regarding visual and audio characteristics. Specifically, voting systems must be capable of displaying information in at least two font sizes: 3.0-4.0 mm (the height of an upper case letter in the smaller text size) and 6.3-9.0 mm (the height of an upper case letter in the larger text size) (VVSG 3.2.5 d). In addition, depending on their level of experience with screen-reading software, the screen-reading users prefer either very fast speed or slow speed when listening to the audio. The range of speech speed should support 75% to 200% of the nominal rate but not affecting the pitch of the voice (VVSG 3.3.3 c). This adjustability guideline can be also followed by UD principle 2, providing choices in visual and audio characteristics.

UD PRINCIPLE 5. Tolerance for Error
Guidelines:

5a. Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded.
5b. Provide warnings of hazards and errors.
5c. Provide fail safe features.
5d. Discourage unconscious action in tasks that require vigilance.

Voting system should enable voters to cast their ballots as intended, which is a critical outcome for voter performance (Cook & Harniss, 2012; Jastrzembski & Charness, 2007). To minimize hazards and unintended actions that could have adverse voting outcomes, voting system should provide warnings of errors and fail-safe features about voters' actions, including selecting a candidate, deselecting a candidate, and reviewing their votes to help them to achieve their goal of casting their ballot as desired. Warnings of errors include feedback about voter's actions regarding their selections. For example, the voting system should provide feedback to a voter that identifies specific contests or ballot issues for which the voter has made no selection or fewer than the allowable number of selections (i.e., undervotes) before final casting of the ballot (VVSG 3.2.2.1 b). In addition, the system should prevent voters from selecting more than the allowable number of choices (i.e., overvotes) for each contest (VVSG 3.2.2.1 a).

Fail-safe features include an un-do function that allows the voter to change a vote within a contest when the voter made an unintentional action or changed their mind (VVSG 3.2.2.1d). In addition, warnings and alerts issued by the voting system should clearly state the nature of the problem and the set of responses available to the voter. The warnings should clearly state whether the voter has performed or attempted an invalid operation or whether the voting equipment itself has malfunctioned in some way.

UD PRINCIPLE 6. Low Physical Effort
Guidelines:

6a. Allow user to maintain a neutral body position.
6b. Use reasonable operating forces.
6c. Minimize repetitive actions.
6d. Minimize sustained physical effort.

The voting system should be designed to require low physical effort. Examples how this principle will be implemented regarding touch interaction and button location. Regarding the touch interaction, voting systems should use the capacitive touchscreen rather than resistive touch screen that requires more physical force (Lee & Zhai, 2009), and use simple touch interaction (e.g., single tap) rather than requiring multiple actions (e.g., double tap, split-tap) or sustained force (e.g., holding a button to complete a task).

The main touch input buttons (e.g., “Okay,” “Cancel,” “Back,” or “Next”) should be located in natural body position. The same button locations can also minimize physical effort, particularly for voters who have limited vision. Studies (Leporini, Buzzi, & Buzzi, 2012b; Oliveira, Guerreiro, Nicolau, Jorge, & Gonçalves, 2011; Park, Han, Park, & Cho, 2008) have shown that blind or visually-impaired users can easily find buttons if they are in fixed reference points such as the corners or the edges of the screen. Thus, simple touch interaction and the same button locations as those in natural positions such as corners or the edges of the screen is recommended.

UD PRINCIPLE 7. Size and Space for Approach and Use
Guidelines:

7a. Provide a clear line of sight to important elements for any seated or standing user.
7b. Make reach to all components comfortable for any seated or standing user.
7c. Accommodate variations in hand and grip size.
7d. Provide adequate space for the use of assistive devices or personal assistance.

This principle can be applied to the hardware (e.g., tablet) and software (e.g., button size) design in voting system. The tablet-based voting systems with adjustable and tilted stand can easily accommodate for any seated voters who use wheelchairs and standing voters. This portable tablet-based system can minimize the problems of existing voting systems that are placed in a fixed position that lacks flexibility in the placement of displays and input devices (Cook & Harniss, 2012).

In addition, the voting system should provide large size buttons regardless of various finger sizes. Existing standards provide guidelines for optimal touch screen buttons and gap sizes. The ANSI/HFES (2007) recommends that touch areas be at least 9.5 mm square and the gap between sizes greater than 3.2 mm. However, ISO9241-9 suggests that the size of a touch sensitive area should be at least equal to the breadth of the index finger of a male in the 95th percentile of finger size, which is 2.28cm. In addition, studies (Chen et al., 2013; Jin, Plocher, & Kiff, 2007a; Sesto, Irwin, Chen, Chourasia, & Wiegmann, 2012; Sun, Plocher, & Qu, 2007) have found that button size, but not spacing, improves user performance (i.e., the completion of a four-digit entry task).

One study (Jin et al., 2007a) of older adults with poor manual dexterity has suggested that a larger button size of 19.05mm square is the most accurate, but a button size of 16.51 mm square is acceptable on only a limited screen space. Another study (Chen et al., 2013) of individuals with and without motor control disabilities has shown that as button size increases (10mm to 30 mm), the number of errors and misses as well as time to complete tasks, particularly for disabled groups, decreases. Runyan and Tobias (Runyan & Tobias, 2007) suggested an optimal design for a touch screen controls on a voting system consists of square or circular targets with large, evident dead spaces between them. Since button size suggestions depend on the size of the display, considering the limited mobile display size, the touch button size should be at least 20mm wide.

Design Research Process

The overall design research process of this project included two phases of the iterative process. The first phase was involved team design and testing with voters with a range of disabilities. The specific aims were to: 1) design and develop the EZ Ballot concept based on the UD criteria and implement a testable prototype; 2) identify the usability of the EZ Ballot by voters with a range of disabilities, and 3) revise the UD Ballot design criteria based on the formative study results.

The second phase was involved independent design and testing with voters with a range of visual abilities. The specific aims were to: 4) design the QUICK Ballot along with the EZ Ballot refinements; 5) utilize experts to identify the potential impact of both ballots; and 6) examine the effectiveness of the two ballots with voters with a range of visual abilities. Figure 10 shows the iterative steps of overall design research process.

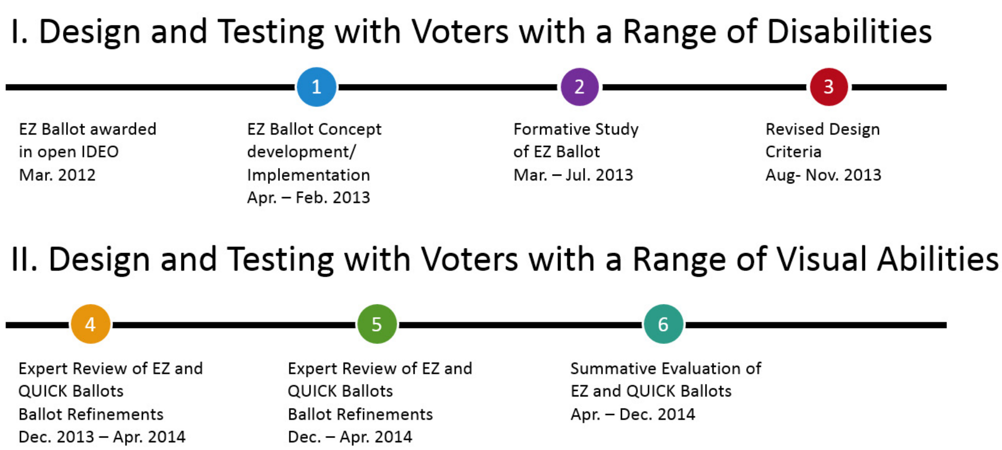


Figure 10. Overall Design Research Process.

CHAPTER 4

PHASE I: TEAM DESIGN AND TESTING

This chapter presents the first phase of the design research process, team design and formative usability study of the EZ Ballot with people with a range of disabilities.

Design of EZ Ballot (Specific Aim 1)

To meet the criteria outlined above, Lee et al., (2012) developed a tablet-based voting interface, EZ Ballot (see Figure 11). The concept of the EZ Ballot was one of the concepts awarded in Open IDEO, which asked “How might we design an accessible election experience for everyone?”(Lee, Liu, Xiong, & Sanford, 2012). The ballot integrates a binary structure of navigation and selection that requires responses of only “Yes” and “No” by following a particular sequence of steps. The information architecture of EZ Ballot (see Figure 12) employs a form of strictly linear and guided navigation between contests and candidate pages, which enables users to accomplish each required voting task.

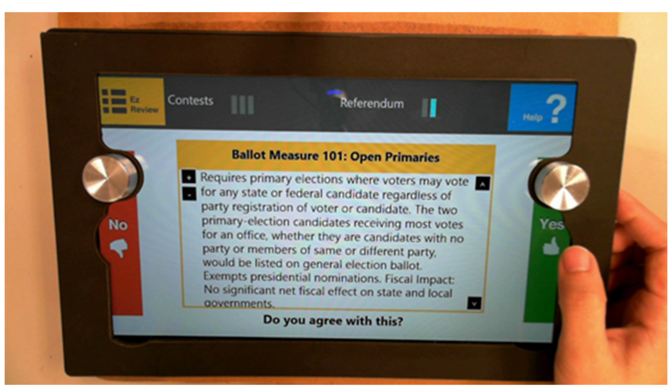


Figure 11. Multimodal Inputs of EZ Ballot Prototype

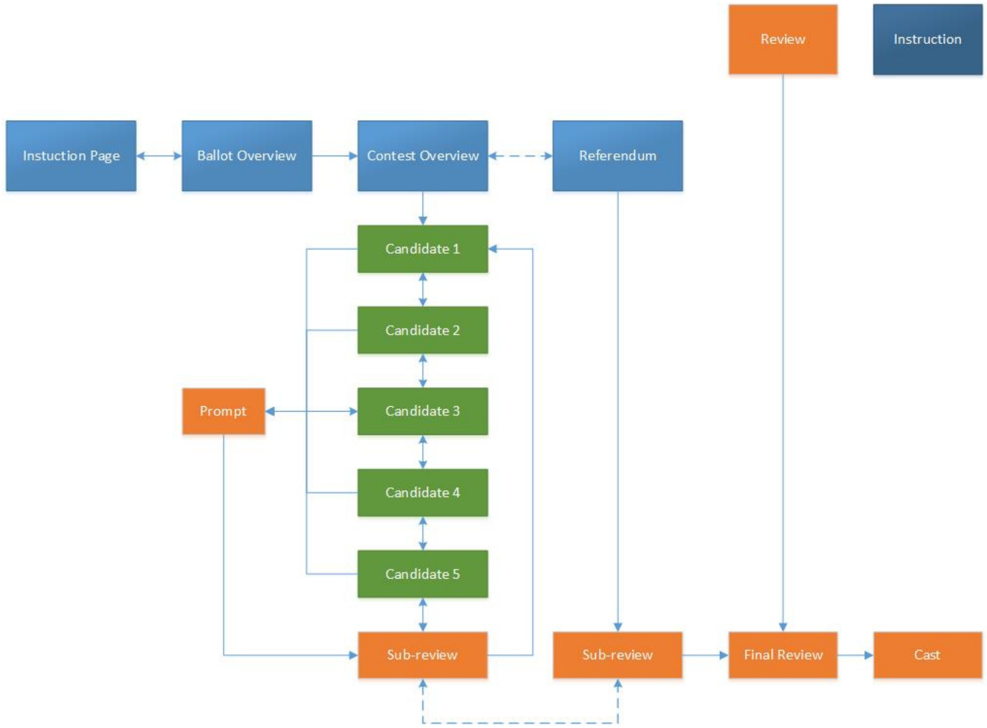


Figure 12. Information Architecture of EZ Ballot ver1.0

EZ Ballot provides a step-by-step and strictly linear, guided ballot structure to accomplish specific tasks by responding “Yes” or “No.” In this ballot structure, the ballot sequentially presents pages both across and within contests (i.e., candidate pages). In contest pages, users start with the first contest page and then move consecutively through the pages by responding with “Yes” or “No” binary choices. Alternatively, users can navigate back and forth between contest pages using swiping gestures. For example, on the “Contest 1” page, users are asked the question of whether they want to vote for the particular contest. If they select “No,” they skip the first contest and move to the next contest. If they select “Yes,” they see the first candidate of the first contest. Figure 13 shows the information architecture for the navigation across contests.

To avoid any confusion about where they will go after they press the “Yes” and “No” buttons, users receive instructions. For example, the overview of the President and

Vice-President Contest page includes the question "Do you want to vote for President and Vice-President?" followed by the instructions "Press Yes to vote in this contest. Press No to skip this contest" (see Figure 14).

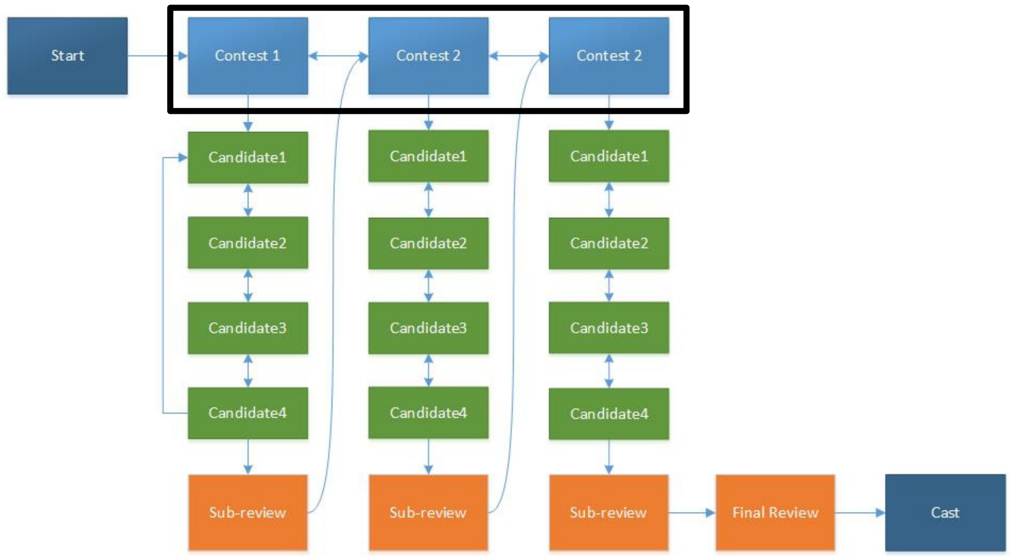


Figure 13. Navigation across Contests

Figure 14. A screenshot of the Overview of the First Contest

After selecting a contest in which they wish to vote, users enter the candidate page, start with the first candidate page, and move consecutively through the candidate pages using the Yes or No binary choice (see Figure 15). They can navigate back and forth between contest pages alternatively by using swiping gestures. For example, on the first candidate page, users are asked the question of whether they want to vote for the particular candidate (see Figure 16). If they select "No." they move to the next candidate. If they select "Yes," they receive a prompt message (see Figure 17). For example, if they want to select the fourth candidate in a list of candidates, they must traverse the first four candidate pages to get to it by "No" button or using the gesture.

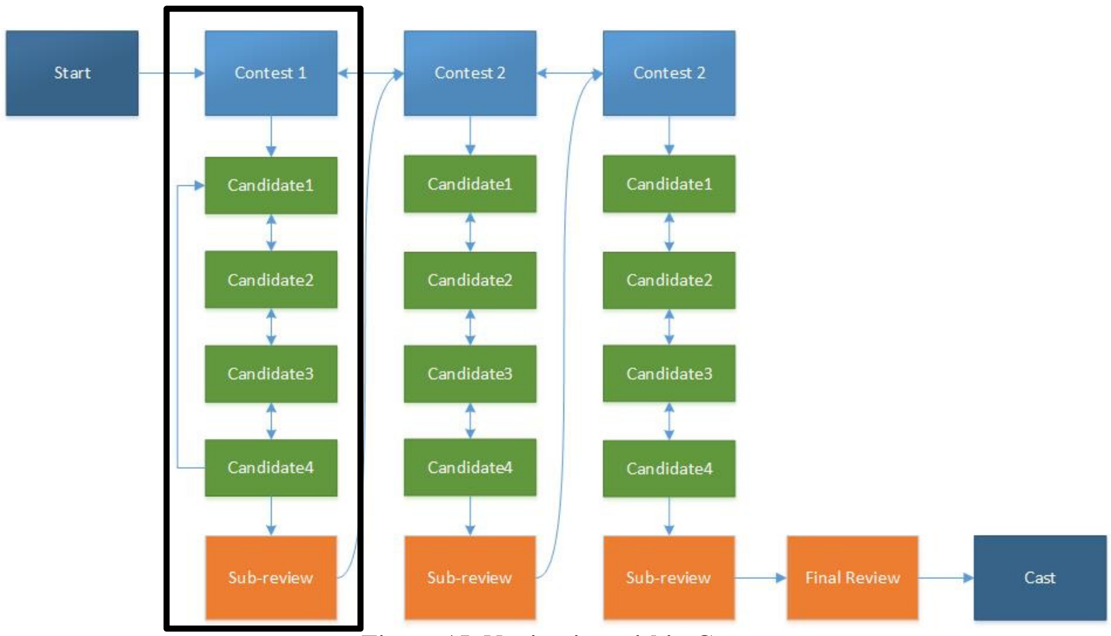


Figure 15. Navigation within Contests

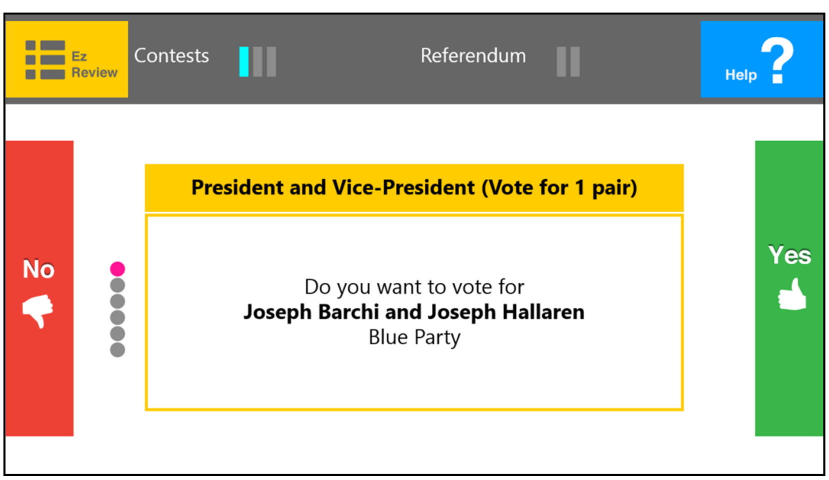


Figure 16. A Screenshot of a Candidate Page

The following design features and characteristics of the EZ Ballot are categorized by UD principles.

Principle 1. Equitable Use

Following the first principle, EZ Ballot provides the same means of voting for people with and without disabilities. Rather than specialized accessible interface, all voters can use the same type of voting system (i.e., EZ Ballot) because accessible features (e.g., speech output) are integrated in a ballot as a default.

Principle 2. Flexibility in Use

EZ Ballot input and output features were specifically designed to accommodate a range of abilities including the cognitive, visual, and manipulative abilities that are most likely to be adversely affected by ballot design. Multimodal inputs include physical tactile input, touch screen input, and gestural inputs. The prototype of the physical tactile buttons (see Figure 11) are two conductive rubber buttons covered with aluminum metal. Touch screen buttons are placed on each side of the screen where the tablet is typically held. Speech inputs for EZ Ballot allow voters to answer either “Yes” or “No” verbally. This also ensures privacy as others do not know the specific candidate that is being selected (i.e., any audio output is provided through headphones). Gesture inputs allow users to browse pages without making a decision on each page. Navigation between contests requires left and right swiping gestures, and navigation between candidates requires top and bottom swiping gestures. For example, the swiping bottom to top takes the user forward one candidate, and the swiping top to bottom moves the user back to the previous candidate.

The ballots were also designed with multimodal outputs that use visual, speech, and tactile feedback to provide orientation to the structure of the ballot (i.e., a progress bar to identify where the voter is in the voting process) and voters' actions (e.g., candidate selection) have been recorded. To ensure that all voters have access to all inputs and outputs, the default mode is to have all modalities turned on.

EZ Ballot can be used with one hand without excessive force. In addition, by pressing "No" for the question "Do you want to vote for X", voters can skip any contest or referendum if desired.

Principle 3. Simple and Intuitive Use

While many users are familiar with random access direct selection on touchscreen interfaces, for those who are not familiar with these types of interfaces or are unable to see the touchscreen, EZ Ballot has a simple and linear structure that provides two main advantages: directed guide and matched audio interface. Directed guide allows users to follow a particular sequence of steps so that users can easily manage to stay focused. For low-literacy or novice users, studies (Chaudry, Connelly, Siek, & Welch, 2012; Parikh, Ghosh, & Chavan, 2003) have suggested the use of a linear structure rather than a hierarchical structure, because users lose focus during navigation. The linear structure is a much simpler pattern for screen-reader users as well (Tao, Prathik, Robert, & Davide, 2013). Moreover, the nature of the linear structure resembles that of the linear audio interface, which can benefit users who are visually impaired or reading disabled.

EZ Ballot also provides familiar conversational interfaces that ask questions (e.g., "Do you want to vote for X?") and confirm the voter's actions (e.g., "You voted X. Do you want to go to next contest?") on each screen throughout the voting process. This conversational interface allows for a wide range of people to easily interact with the system (Huyck, 2011).

Principle 4. Perceptible Information

EZ Ballot integrates simultaneous visual and audio output interfaces, rather than using separate outputs that are found on most current systems. For example, "Do you want to vote for Joseph Barchi and Joseph Hallaren from the Blue Party?" is displayed visually and through audio (see Figure 16). In addition, all touch screen buttons provide redundant visual cues through colors, icons, and text and audio cue though speech (e.g., speech sound "Yes" for the Yes button when an action has occurred). Internationally recognizable green and red represent "Yes" and "No" buttons are also differentiated by text and common icons. The tactile cover that sits above a touchscreen helps users with limited or no visual abilities who have difficulties to locate the virtual buttons on the screen. The initial tactile cover indicated the location of virtual control buttons by adding indentations to the inner edge of the frame. In addition, EZ Ballot uses the san serif font and high contrast by default (e.g., black text in white background). In addition, EZ Ballot provides visual and audio adjustability.

Principle 5. Tolerance for Error

EZ Ballot provides two levels of verifying selections, a prompt message and a sub-review message, during voting process, and one final review page before casting a ballot. As shown in Figure 17, a prompt after each yes or no response (e.g., "Are you sure you want to vote for Joseph Barchi and Joseph Hallaren from the Blue Party?") reverts back to the previous selection question when users press "No". As shown in Figure 18, a sub-review message (e.g., "You voted for Joseph Barchi and Joseph Hallaren from the

Blue Party. Press Yes to go to next contest, Press No to change your vote") reverts back to the first candidate page when users press "No. The final review page shows all of the selections that voters made. Voters can easily recognize any errors (e.g., undervote, wrong vote) so that they can change their votes before casting a ballot.

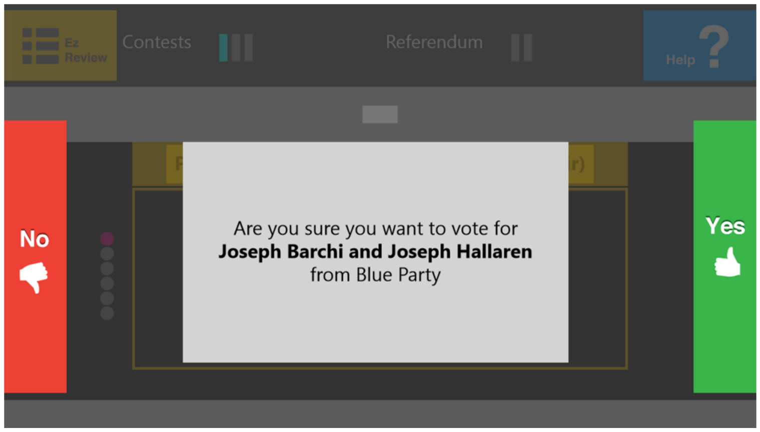


Figure 17. A Screenshot of the Prompt Message For Verifying Selections

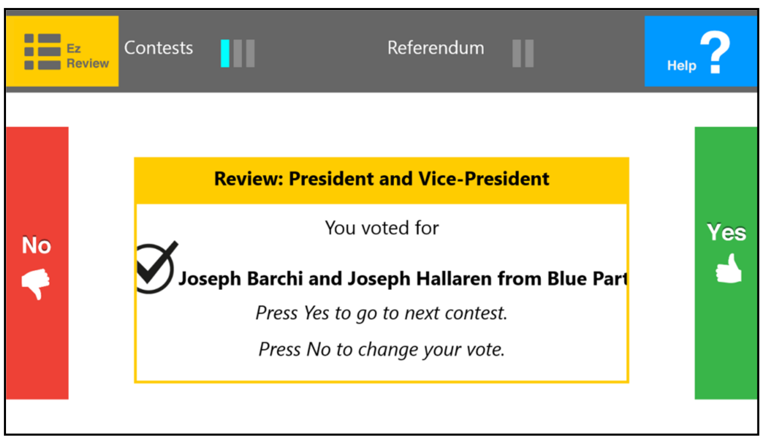


Figure 18. A Screenshot of the Sub-Review Message for Verifying Selections

Principle 6. Low Physical Effort

EZ Ballot has a capacitive touch screen with simple touch interactions (i.e., single tap) to avoid the confusion of multiple sequential actions such as double tap. In addition, all the touch buttons are located in the corners or on the edges of the screen so that blind or visually-impaired users can easily locate them (Leporini et al., 2012b; Oliveira et al., 2011; Park et al., 2008). For the voters' main inputs, "Yes" and "No" buttons are placed on the right and left side of the screen of the tablet, which allow users to hold the device. In the top left-hand corner of the screen, a yellow square button with a menu icon, labeled "EZ Review," provides a review page on which users can change their votes. In the top right-hand corner of the screen, a blue square button with a question icon, labeled "Help," provides an instruction page that explains how to use EZ Ballot. Users can click the EZ Review and Help buttons whenever they wish to review their choices or get instruction.

Principle 7. Size and Space for Approach & Use

EZ Ballot is designed as tablet-based voting system that can be easily accommodated for both seated or standing voters. In addition, all soft buttons provide large enough target size (i.e. minimum width measure of 20 mm) for users with a range of dexterity. All the buttons are placed in the corners or the edges of the screen allowing easier navigation for blind or visually-impaired users (Leporini, Buzzi, & Buzzi, 2012a; Oliveira et al., 2011).

Formative Usability Study of EZ Ballot (Specific Aim 2)

The purpose of the formative study (March – July, 2013) was to test the usability of EZ Ballot and refine the ballot based on feedback from people with a range of disabilities. Specific aims were to demonstrate that people with a range of disabilities could successfully perform voting tasks using EZ Ballot and to identify design factors (both positive and negative) that affect usability of the ballot. The study used direct observation of users' interaction with the EZ Ballot prototype application and semi-structured interviews for gathering post-trial qualitative data.

Methods

Participants

Twenty one adults (11 female; 10 male) who were eligible to vote participated in the study. These include visual disabilities (6 blind, 6 low vision), dexterity disabilities (2 no arm function, 2 hand dexterity limitations, 1 wheelchair user), and 4 mild cognitive disabilities. All participants were native English speakers. The age range was 21-64 years, with a mean age of 45.4 ± 11.74 years. Seventeen out of twenty one participants had used DRE voting systems in elections. Among those, eight of them had experience of audio voting using a keypad, two used large size text and high contrast, and one used large size text. Participants' mean level of self-reported touch screen devices was 6.00± 3.2, where 1 = novice and 10 = expert. Twelve out of twenty one participants were smartphone owners. Table 6 summarizes participants' demographics.

Test Prototype

A prototype of EZ Ballot prototype was developed for the Windows Surface tablet using the C# (sharp) programming language and .NET libraries for the WinRT (Windows Runtime) architecture. The dimension (width x height x depth) of the Windows Surface is 10.81" x 6.79" x 0.35" and the resolution of the screen is 1366 x 768. Gesture interactions such as swipe and pinch were available, but speech input was not implemented. For the speech output, candidate names were provided verbally with a human female voice. Before beginning to vote, one page short instruction was provided to help users how to use the ballot. A standard sample ballot developed by National Institute of Standards and Technology (NIST) with fictional candidates' names was used to avoid asking people to vote in a contest where they might have their own opinion (Quesenbery & Chisnell, 2009).

Table 6. Summary of Demographics

No.	Age	Gender	Types of Disability	Education	Touch.Exp 1-10	Use of DRE	Use of Smartphone
1	48	Male	Blind	Master's degree or higher	9	Yes	Yes
2	52	Female	Dexterity	Some college or Associate's degree	8	Yes	Yes
3	53	Female	Dexterity	Some college or Associate's degree	5	Yes	No
4	56	Female	Low Vision	Bachelor's degree or higher	3	Yes	No
5	64	Male	Low Vision	Master's degree or higher	2	No	No
6	58	Female	Low Vision	Bachelor's degree or higher	7	Yes	No
7	51	Male	Low Vision	Bachelor's degree or higher	10	Yes	Yes
8	37	Male	Blind	Master's degree or higher	10	Yes	Yes
9	41	Female	Cognitive	10th grade	1	No	No
10	38	Female	Cognitive	G.E.D.	1	No	No
11	47	Female	Cognitive	11th grade	1	Yes	No
12	24	Male	Low Vision	Some college or Associate's degree	6	Yes	Yes
13	60	Female	Blind	Master's degree or higher	8	Yes	Yes
14	26	Male	Dexterity	Some college or Associate's degree	5	No	Yes
15	61	Male	Blind	Master's degree or higher	8	Yes	Yes
16	53	Male	Dexterity	Master's degree or higher	9	Yes	Yes
17	37	Male	Blind	Bachelor's degree or higher	6	Yes	No
18	51	Male	Dexterity	Master's degree or higher	7	Yes	Yes
19	49	Male	Blind	G.E.D	2	Yes	No
20	45	Female	Low Vision	Some college or Associate's degree	8	Yes	Yes
21	21	Male	Cognitive	Some high school	10	Yes	Yes

Procedures

After signing an informed consent form approved by Georgia Tech IRB, we conducted pre-trial interviews consisting of demographic information including age, types of disabilities, previous touch screen experiences, and use of smartphone. Participants then simulated voting tasks as directed (e.g., voting for one candidate, voting for two candidates, reviewing the vote, and changing the vote) using EZ Ballot. During the trials, researchers observed the participants' interaction and recorded usability issues. Following each test trial, participants completed a post-trial interview to elicit user feedback including their perceived ease of use, qualitative feedback about the usability of each design feature, and preferred input methods. Each session lasted 90 minutes.

Results

The study identified observed usability issues, and user feedback including perceived ease of use, positive and negative design factors, and preferred input methods.

Observed Usability Issues

Three types of usability issues were observed with EZ Ballot (see Table 7). These problems related to instructions (Issues 1 and 2), navigation and selection in contest and candidate pages (Issues 3, 4, and 5), and gesture interactions (Issue 6). Participants' numbers are noted in parentheses.

1. Locating Yes and No buttons (n=7). Seven participants (33.3%), four totally blind and two low-vision participants, were confused about the placement of the physical and touch yes and no buttons and needed help from researchers: "Where is Yes?," "I am trying to find the Yes button" (13, 15, 18, and 20). Participants commented that the audio

instructions were not clear regarding the placement of buttons (i.e., the Yes button is on the right side of the tablet in the middle), so several participants literally touched the middle of the screen to find the Yes button. In addition, they touched an inactive area because they were not sure about the size of the touch area on the Yes and No buttons. Because they could see the Yes and No buttons, sighted participants did not have this issue.

2. Starting (n=2). Two participants (9.5%) who were not familiar with technology (e.g., the touch screen) were confused about how to start: "I don't know what to do" (10). However, after reading the instructions again, they started by pressing the "yes" button.

3. Changing a vote (n=6). Six participants (33.3%) were confused about how to change their votes: One (2) tried to directly select a candidate's name on the verification overview page, two (4, 7) were confused about the Yes and No instructions when adding multiple votes to a contest, two (6, 10) participants did not understand how to change their votes, and one (21) pressed the Yes text, not the button, on the verification overview page to change her vote.

4. Going back (n=5). Five participants (23.8%), one dexterity (16) and two low-vision (6, 7), participants were confused about how to go back to the previous page when accidently selecting the wrong candidates: "How do I go back?" One (7) was also confused, believing that the No button was a back button and the Yes button was the next button, which resulted in their skipping the contest by pressing no. Two totally blind (17, 18) participants tried to use a swiping gesture to go back to the previous page when they inadvertently skipped the contest.

5. Selecting a candidate (n=4). Four participants (19.1%) were confused about how to select a candidate. Two dexterity (3, 14) and one low-vision (5) participants first tried to directly select the name of a candidate on the contest overview page and then figured out that they had to press the Yes to select it. One low-vision (5) user and one cognitive (10) participant pressed the round dots on the candidate page (see Figure 16) to choose other candidates.

6. Incorrect gestures (n=5). Among the participants who used gestures, five (23.8%) participants, three totally blind (1, 8, and 13) and one low vision (20), used incorrect gestures. One (1) used horizontal swiping to move between candidates and vertical swiping to move between contests, opposite of the setup. Two (8, 13) swiped from the top of the tablet screen to the bottom to navigate the following candidates instead of from the bottom to the top. In addition, visually-impaired participants often could not place their fingers in the right place on the screen when using gestures.

Table 7. Observed Frequency of Unique Usability Issues by Disability Type

Usability Issues	Disability Type	Freq.	PCT (%)
Instructions			
1. Locating Yes and No buttons	Blind (n=5) Low Vision (n=2)	7	33.3%
2. Starting	Cognitive (n=1) Blind (n=1)	2	9.5%
Navigation and Selection in Contest and Candidate Pages			
3. Changing a vote	Dexterity (n=1) Low Vision (n=3) Cognitive (n=2)	6	28.6%
4. Going back	Low Vision (n=2) Dexterity (n=1) Blind (n=2)	5	23.8%
5. Selecting a candidate	Dexterity (n=2) Low Vision (n=1) Cognitive (n=1)	4	19.0%
Gesture Interactions			
6. Incorrect gestures	Blind (n=4) Low Vision (n=1)	5	23.8%

User Feedback

Participants self-reported their perceived ease of use on voting with just "Yes" and "No" as a range from 2-5 with a mean of 4.28 (*SD*=1.0), where 1= very difficult and 5 = very easy. Participants who responded that Yes and No voting was very easy commented that the Yes and No voting is simple and intuitive enough to vote independently: *"I think it simplifies it. It makes it easier and you don't have to think about it."* Participants who responded that "Yes" and "No" voting was difficult commented they had some difficulty with touch screen itself. Significantly, smartphone users' reported statistically greater perceived ease of use of EZ Ballot than non-smartphone users; t (19) = 2.182, p = .042 (see Figure 19).

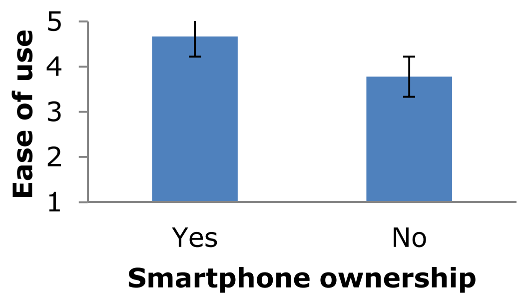


Figure 19. Mean Perceived Ease of Use Based on the Smartphone Ownership.

The qualitative user feedback was categorized into five positive and seven negative design factors (see Table 8). Participants' numbers are noted in parentheses.

Positive Design Factors

1. Simple and intuitive linear process. Fourteen (66.7%) participants commented that Yes and No voting was easy, simple, and straightforward. They commented that the Yes and No voting is simple and intuitive enough to vote independently: "I think it

simplifies it. It makes it easier and you don't have to think about it", "Yes and No was extremely simple and it made sense", "I like the yes and no because you didn't require me to have a list up there."

2. Redundant confirmation messages. Ten (47.6%) participants liked and preferred redundant confirmation messages. They commented that both forms of verification were necessary and many other people might need double-checking, particularly in the voting context. For example, "I very much liked the confirmations even though they required an extra step. I might not need two of them, but many people might need both" (5, low vision), "need to consider for lowest denominator like cognitive impaired people" (16, dexterity).

3. Free navigation between contest and candidates. Seven (33.3%) participants who used gestures to navigate candidates or contest pages liked that they could navigate freely between contests and candidates using gestures: "It was easy to go back if I wanted to change a vote. I could move faster to the person that I wanted to vote for using the gestures. It was quicker. You can't do that in regular voting" (20, low vision).

4. Helpful audio guidance. Audio speech was particularly favored by low- vision and cognitive participants. Five (23.8%) participants commented that audio guidance was helpful: "It's a wonderful guide to go from one selection to next. That was kind of a positive experience to voting assistance. It's very helpful" (4, low vision), "It (talking) made me more independent not relying on others. I was capable of voting by myself (17, blind). "I liked it because it read questions and gave directions on what to do" (21, cognitive).

5. Perceptible tactile information. Five visually-impaired participants (23.8%) commented that physical cut-out cover indentation helped indicate where the touch screen buttons were. One participant (7, low vision) suggested making the cover thicker so that he could feel better, and another participant (8, blind) suggested having a hole shape rather than the indentation of cut-out cover.

Table 8. Positive and Negative Design Factors

Positive design factors	**Disability type**	**Freq.**	**PCT (%)**
1. Simple and intuitive linear process	Blind (n=2) Low Vision (n=3) Cognitive (n=2) Dexterity (n=2)	14	66.7%
2. Redundant confirmation messages	Blind (n=1) Low Vision (n=3) Cognitive (n=3) Dexterity (n=3)	10	47.6%
3. Free navigation between contest and candidates	Blind (n=3) Low Vision (n=3) Dexterity (n=1)	7	33.3%
4. Helpful audio guidance	Blind (n=2) Low Vision (n=1) Cognitive (n=2)	5	23.8%
5. Perceptible tactile information	Blind (n=3) Low Vision (n=2)	5	23.8%
Negative design factors	**Disability type**	**Freq.**	**PCT (%)**
1. Too many confirmation messages	Blind (n=5) Low Vision (n=2) Dexterity (n=2)	9	38.1%
2. Ambiguous progress bar	Low Vision (n=4) Cognitive (n=1) Dexterity (n=2)	7	33.3%
3. Lack of control of audio characteristics	Blind (n=2) Low Vision (n=4) Cognitive (n=1)	7	33.3%
4. Lack of control of visual characteristics	Low Vision (n=6)	6	28.6%
5. Unexpected gesture directions	Blind (n=5)	5	23.8%
6. Too much information in the instructions	Blind (n=2) Low Vision (n=2)	4	19.0%
7. Lack of indication of gestures	Low Vision (n=1) Dexterity (n=2)	3	14.3%

Negative Design Factors

1. Too many confirmation messages. Nine (38.1%) participants, seven of whom were audio voting users, did not like redundant confirmation messages because the voting process became tedious and time consuming. Seven commented that they needed only one confirmation, not two: "I think second confirmation asking 'are you sure' is redundant" (2, dexterity) and "The sub-review page was not helpful to me" (20, low vision). Two blind (1, 13) participants commented that they preferred to have the review page only at the end of the voting process: "Having to listen to all of it again drives me crazy, and I forget stuff" (1, blind).

2. Ambiguous progress bar. Seven sighted participants (33.3%) commented that the progress bar was ambiguous. Four (2, 5, 12, and 16) did not notice the indicator showing the progress on the top of the screen: "I didn't realize it. It (progress bar) doesn't seem like it's a part of the screen" (2, dexterity), "I didn't notice it (progress bar) maybe because of the contrast. It should be more noticeable" (12, low vision). Three did not understand the meaning of the bars: "I didn't quite understand what that was about. I think there is a line of some sort, but I don't know what it means" (4, low vision), and "Maybe it should be labeled with numbers. For me, numbers work" (6, low vision).

3. Lack of control of audio characteristics. Seven (33.3%) participants' preferences of characteristics of the speech output were varied. While experienced screen-reader participants (8, 13, and 20) commented that they would speed up the audio as they normally do, non-experienced screen-reader participants (4, 16, and 21) commented that the speed was somewhat fast when the page had a large amount of information (e.g., the instruction page). One low-vision participant (7) was particularly

annoyed that the interface did not talk when he touched the screen: "When you touch the screen, it doesn't talk!"

4. Lack of control of visual characteristics (i.e., size, color). All six (28.6%) low-vision participants commented about several issues pertaining to visual output such as size and color. Four (4, 5, 7, 12) commented that the overall text size was too small. Two (4, 6) users complained that the background was too white and suggested a change to a darker background. Two (7, 12) wished to magnify everything, including the buttons on the screen. Two (7, 20) commented that the color was not useful because they are color blind.

5. Unexpected gesture directions. Five (23.8%) blind participants among those who used gesture interaction were confused about the direction of the gesture interaction while navigating contests and candidate pages. Their comments included "In my mind, I wanted to move right or left among the candidates and the various referendums, I prefer to gesture up and down for a referendum" (1), "If you want to go forward on the contest, you have to swipe to the left. The yes button is on the right side. What if going forward is right instead of left?" (8), "You should be swiping down to see the next candidate, not up. If you want to go forward, you'll swipe to the right and if you want to go backward you'll swipe to the left" (11).

6. Too much information in the instructions. Four (19.0%) participants who relied on speech output commented that the instructions contained too much information to listen and remember: "Too much talking" (1, 13), "I will be bored; especially when I have to listen to it in public" (13, blind). One participant (7, low vision) suggested that

the instructions provide an option for skipping: "If you already know how to use it, skip this one."

7. Lack of indication of gestures. Three participants (14.3%), one low-vision (6) and two dexterity (14, 16) participants, commented that they did not know they could use the gestural interactions even though they had experienced using gestures. The gestures were not indicated on the contest page.

Preferred Input Methods

Participants' preferences of input method were varied (see Table 9). Participants (50.0%) preferred to use touch screen input.

Table 9. Preferred Input Method by Disability Type

Input Method	All	Disability type
Touch input	10 (50%)	Blind (n=3) Low Vision (n = 3) Cognitive (n = 2) Dexterity (n = 2)
Physical push button	4 (20%)	Blind (n=3) Dexterity (n = 1)
Stylus	3 (15%)	Low Vision (n=1) Cognitive (n=1) Dexterity (n = 1)
Speech input	3 (15%)	Low Vision (n=2) Dexterity (n = 1)

Four (three blind, one dexterity) (20.0%) preferred to use physical push buttons. Three participants (15.0%) preferred to use the stylus: one low vision participant (4) used her stylus to help reading text (see Figure 20), one cognitive participant (21) commented that stylus is comfortable because she is used to use the pen, and one dexterity participant used his mouth stick since he had no arm functions. Three (two low vision, one dexterity) (15.0%) preferred to use speech input: "I can just say 'yes' and it will repeat back who I voted. That would be the best I think" (5). One dexterity (19) participant commented that he would choose the speech input over his mouth stick if it responds well.

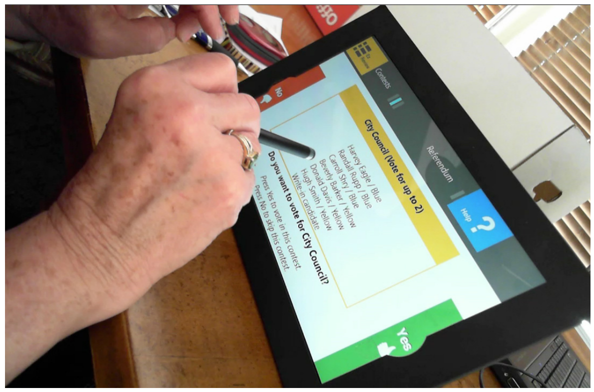


Figure 20. A Low Vision Participant Performing Tasks Using Stylus

Discussion

The study demonstrated that individuals with various types of disabilities could perform voting tasks on a single voting interface, EZ Ballot, using their preferred inputs. In general, participants with various types of disabilities perceived that voting with "Yes" and "No" was easy and simple and intuitive enough to vote independently. Interestingly, smartphone users perceived the EZ Ballot significantly easier than non-smartphone users. This finding also supports a recent study (Campbell, Tossell, Byrne, & Kortum, 2011) that found that smartphone users made significant fewer errors than non-smartphone users. In this study, smartphone users with visual or dexterity disabilities appreciated that they could use gestures to navigate pages or zoom the text size during the voting process. Interestingly, while one smartphone user participant with cognitive disability did not have any fear of using the touch screen, non-smartphone participants with cognitive disabilities had a fear of technology in general even though they commented that voting with "Yes and No" was easy for them: "That (yes and no) was easy. You just asked me to answer yes and no, but the computer is hard" (10). As expected, non-smartphone user participants were not familiar with some words related to gesture interactions (e.g., swiping up and down). Despite their confusion about the gesture interactions, they were still able to use the "Yes and No" inputs to navigate pages because gesture interactions on the EZ Ballot were optional.

Despite their high rating of perceived ease of use, this formative study identified several specific usability issues regarding instructions, navigation and selection in contest and candidate pages, and gestural interactions. The study also categorized participants' positive and negative design factors from post-trial interviews. From the observed frequency of usability issues and user feedback, the study finally developed five design criteria below.

Participants' preferred method of input also varied. Seven out of ten participants who preferred to use touch screen input, were also smartphone owners, which means they have daily touch screen experience. Interestingly, only three out of twelve participants with visual disabilities preferred to use the physical push buttons. It may be that most participants with a visual disability have experience with using their own touch screen devices, or they did not like the experience of the push buttons in terms of size, shape, or material. While half of participants preferred the touch input, other participants preferred the physical push buttons, stylus, or speech input. Some responded that they did not prefer to use speech input, because it may not be accurate and private in the context of voting; however, one participant, who does not have arm function, commented that the speech input made him feel that he could vote freely and independently.

Revised Design Criteria (Specific Aim 3)

Design Criteria 1: Refine the instructions for the first-time users.

Two observed usability issues (i.e., problem of finding buttons and starting) were strictly related to the instructions. Particularly, the problem of locating “Yes” and “No” buttons (33.3%) was critical issue since “Yes” and No buttons were main inputs for EZ Ballot. Audio instructions should provide clearer explanation about where all the visual elements are. As four participants commented that the instructions contained too much information to listen and remember, the refined instructions should be broken down into small chucks of information so that voters do not overwhelmed by too much information.

Interestingly, eight out of twelve visually-impaired participants (66.7%) were experienced smartphone users, and were familiar with gesture integrations. However, five of them were confused about the direction of touch gesturing on EZ Ballot (e.g., swiping up to see the following candidates), which was just the opposite of the way they usually interact with the voice-over accessibility feature on the iPhone. When turning on voice over on the iPhone, gesture interactions differ from those of sighted users. For example, blind users need to swipe left-to-right to navigate the next icon, swipe bottom-to-top to navigate to the next page, and double tap to open the app on the iPhone home screen. The study needs to further investigate how one single interface modality can enhance the experience of both sighted and non-sighted users with gestural interactions.

This issue about incorrect gestures could also be related to not sufficient instructions about gestural interactions for the first-time users of EZ Ballot. As expected, participants, non-smartphone user, were not familiar with some words associated to the gesture interactions (e.g., swiping up and down). Thus, instruction should avoid the technical word such as "swipe" and use simple and plain word so that even novice users will clearly understand how to use the gestures. In addition, as participants suggested, offering a practice mode for people who can touch the tablet to find where visual elements (e.g., "Yes" and no buttons, space, delete key) are and become familiar with new gesture interaction before starting the voting process could improve the overall voting experience.

Design Criteria 2: Refine the indicators of EZ Ballot.

Study suggested that the visual indicators for ballot progress and gestural interactions should be improved. Several participants did not notice the ballot progress bar that indicated the steps of the voting process. As they recommended, the indicator representation should be more prominent with a higher contrast and a better way of representing their progress. Eight participants commented that they preferred to see or hear numbers (e.g., 1 of 5, 2 of 6…); that is, the numbers would be accompanied by audio speech (e.g., "You are now on one of five, the 'president and vice president section'"). Thus, the indicator for the ballot progress will be refined as simple numbers instead of the progress bars. In addition, the lack of gesture indication resulted in not being able to know that gestures are available for navigating the contest pages. Thus, whenever gesture interactions are available, the screen should provide clear visual and audio indication so that users know that they can use gestural input.

Design Criteria 3: Refine the tactile cover design.

The study showed that visually-impaired participants expressed the benefit from the perceptible tactile cover that indicated where the touch screen buttons were. Interestingly, while only three visually-impaired participants preferred to use the physical push buttons, six of them preferred to use the touch input. It may be that most participants with a visual disability have experience with using their own touch screen devices, or they did not like the experience of the push buttons in terms of size, shape, or material. In addition, providing physical buttons on the existing touch screen hardware may limit the possibility to integrate all features into one system. Thus, we focused on refining the tactile cover design to provide not only tactile feedback but also to integrate with the touch inputs. The study should investigate various form factors of the cover to indicate the locations of the touch buttons of the ballot interface.

Design Criteria 4: Provide a way of controlling audio and visual characteristics.

The user feedback showed that participants needed different audio speed and text size, and they preferred different combination of the color contrast. In order to accommodate voters with a range of visual abilities, the interface should provide a way to controlling audio and visual characteristics. For controlling the audio, the voters should be able to adjust the speed and volume since adjustable audio speed and volume are important issues for all low-vision participants (Piner & Byrne, 2011a; Piner & Byrne, 2011b). For controlling the visual, the voters should be able to adjust the text size and color contrast. Low-vision participants varied in their levels of range of vision: while four participants who relied on the visual interface needed adjustable text size and color contrast, two severe low-vision participants relied on speech output and did not need the visual settings. Thus, the ballot design should provide a way of controlling audio and visual characteristics anytime while voting.

Design Criteria 5: Provide an alternative navigation and selection method.

Regarding navigation and selection in contest and candidate pages, participants were confused about going back, changing a vote, and selecting candidates. More than half of participants (66.7%) who were highly experienced with touch screen could be more familiar with direct touch selections and going back to the previous pages. Although only three participants (14.3%) commended on dissatisfaction with linear ballot structure and preferred to directly touch the candidate they want, the linear ballot could potentially impact on the voter performance such as going back, changing a vote, an selecting candidates. In addition, even though the linear ballot structure may be more accessible than the typical digital ballot interface that provides all options in one page, the former may result in taking longer time than the latter, particularly for sighted voters who are familiar with touch screen experiences. Furthermore, taking long time of using each ballot interface can effect in longer waiting lines at the polling place, which can potentially result in decreasing voter participation. In order to accommodate both sighted and non-sighted voters, the study needed to explore random access ballot structure that provides direct selection of candidates.

Regarding redundant confirmation messages, some provided positive feedback (i.e., they were helpful), but some provided negative feedback (i.e., there were too many). Nine (38.1%) participants were not satisfied with redundant confirmation messages because they can slow down overall voting process. If the UI provided a way to adjust the audio speed, these complain may have been be reduced. Since three visually-impaired and two cognitive impaired participants commented that redundant confirmation messages were helpful, the study needs to further investigate the impact of the redundant verification on voting performance (time and accuracy) and voter satisfaction.

In sum, the study needs to refine EZ Ballot regarding instructions, indicators for ballot progress and gesture interactions, and custom setting adjustment. Beyond the structure of EZ Ballot, the study will investigate an alternative ballot structure that provides direct selection of candidate for both sighted and non-sighted users that could also meet UD principles.

CHAPTER 5

PHASE II: INDEPENDENT DESIGN AND TESTING

Based on design criteria from the formative usability study, this chapter provides the second phase of the design research process, independent design including design of the QUICK Ballot and testing with both EZ and QUICK Ballots by experts.

Refinements of Ballot Design (Specific Aim 4)

Refinement 1: Enhancement of EZ Ballot

The formative usability study suggested refining the design of instructions, custom setting adjustments, indicators and visual design characteristics, and the tactile cut-out cover of EZ Ballot. The information architecture of EZ Ballot ver2.0 (see Figure 21) does not much differ about the information architecture of EZ Ballot ver1.0 except for providing custom setting features and optional page for the referendum. However, EZ Ballot ver 2.0 provides enhanced features regarding instructions, custom setting adjustment, visual design characteristics, and tactile cover design. Appendix A shows the whole flow chart of EZ Ballot ver2.0.

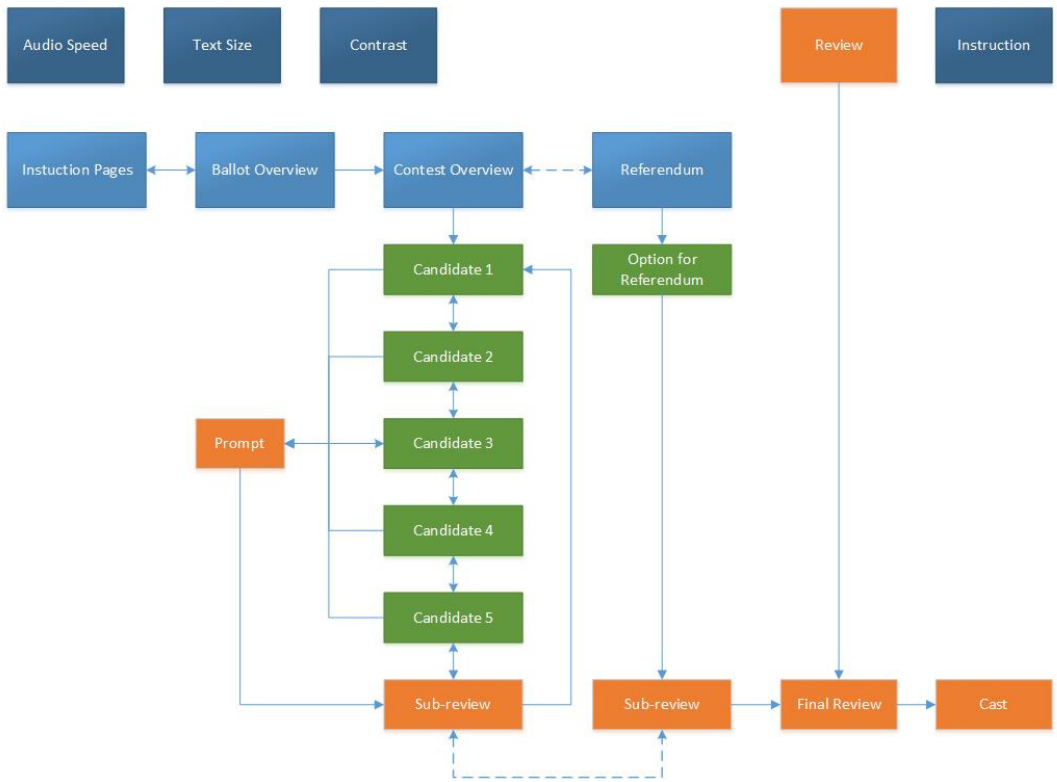


Figure 21. Information Architecture of EZ Ballot ver2.0

Refined Instructions (Design Criteria 1)

Refined instructions provide detailed information in a five screen section at the beginning of the voting process. Each instruction page has constant audio instructions that can be turned on and off depending on the user's need and preference. Default setting of EZ Ballot has audio turned on. Audio instructions are more detailed in terms of providing the location of the buttons than visual ones, but consistent with visual instructions.

- The first instruction page (see Figure 22) provides the option to skip the rest of the instructions and begin voting, or to navigate further. To keep the "Yes" and "No" binary linear structure, each instruction page provides "Yes" touch button to go to next page and “No” touch button to skip the instructions. It also explains how to select and navigate the ballot using “Yes” and “No” buttons.

- The second one (see Figure 23) describes about the location of the physical volume switch that is the part of tablet, and touch buttons that can be found using the raised tactile indicators. Each tactile indicator directly points to one of the buttons, allowing blind and visually-impaired users to easily find the touch buttons. It instructs the users on increasing and decreasing the audio volume, adjusting the settings regarding the Audio speed, Text size, and Contrast buttons, accessing the instructions using the Instruction button, and changing and reviewing the votes using the Review button.
- The third page provides an option if the user needs to change any settings.
- The fourth page (see Figure 24) explains the swiping gesture used to navigate between contests and candidates. Swiping is visualized using horizontal and vertical navigation dots.
- The fifth instruction page (see Figure 25) talks about the use of the scroll buttons.

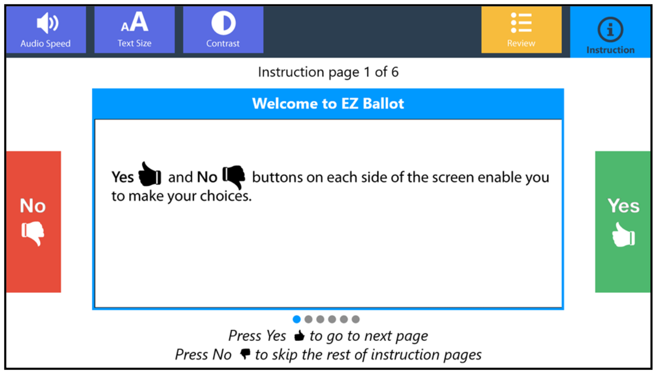


Figure 22. A Screenshot of the Instruction Page 1

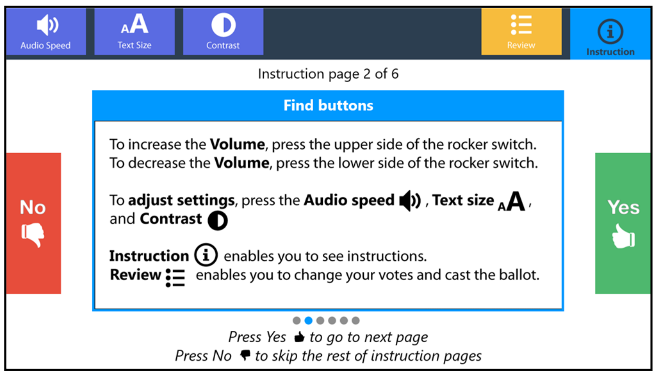


Figure 23. A Screenshot of the Instruction Page 2

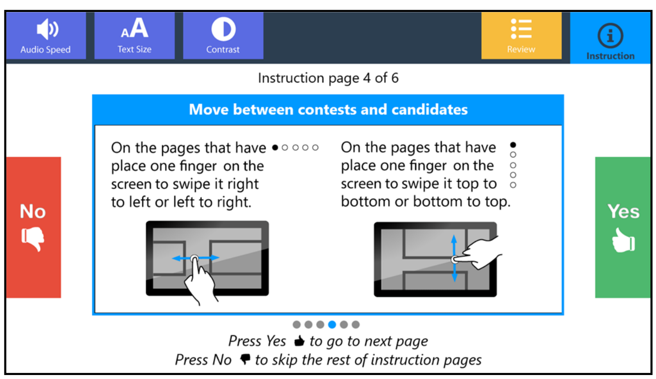


Figure 24. A Screenshot of the Instruction Page 4

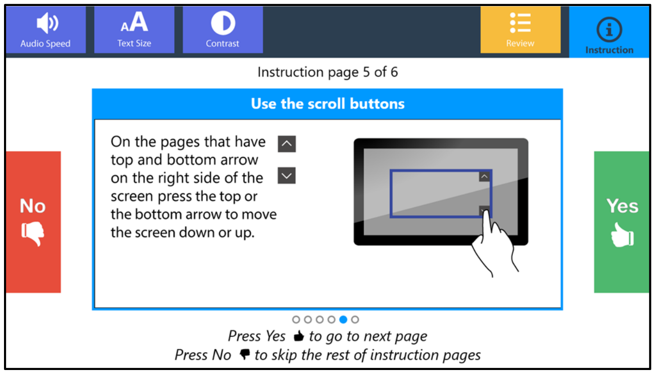


Figure 25. A Screenshot of the Instruction Page 5

Revised Indicators and Visual Design Characteristics (Design Criteria 2)

Refined visual indicators of EZ Ballot include simpler progress indicators and indicators for gesture interactions in contest page. As participants preferred to see the simpler form of the progress indicator, refined progress indicator illustrate the numbers (e.g., Contest 1 of 3) instead of the bar shapes (see Figure 26). In addition, circle indicators for using the gesture interactions were added not only candidate pages but also contest pages (see Figure 26). Furthermore, instead of the yellow and white color scheme or grey bar color, refined color scheme provide higher contrast of dark blue and white color for the ballot overall color scheme (see Figure 26). The observation from the previous study, participants tended to press the "Yes" and No buttons where text or labels was. Thus, we decreased overall height of the "Yes" and No buttons.

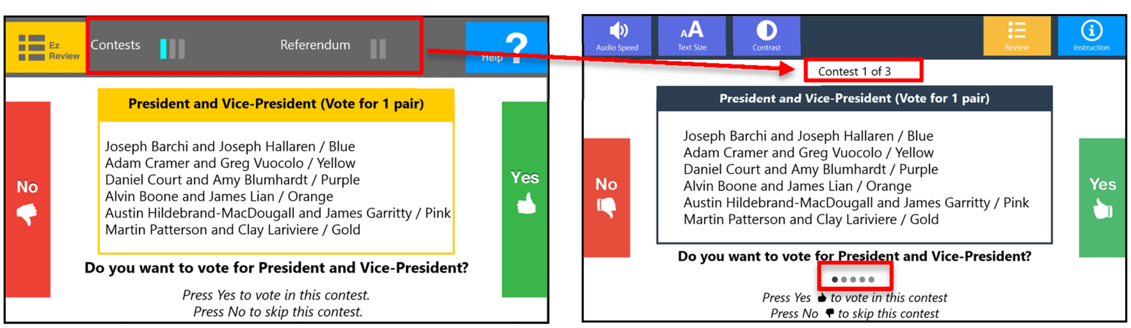


Figure 26. EZ Ballot Ver2.0 Refined Visual Design (Right)

Refined Tactile Cover Design (Design Criteria 3)

The tactile cover that sits above a touchscreen helped users with limited or no visual abilities to locate the virtual buttons on the screen. The initial tactile cover indicated the location of virtual control buttons by adding indentations to the inner edge of the frame. Among various shapes of tactile indicator ideas, a blind user helped us to choose the simplified with raised tactile indicators (see Figure 27), which allows users with limited or no visual abilities to use the edges of the screen as orienting cues without triggering the touchscreen next to it while locating the on-screen control buttons.

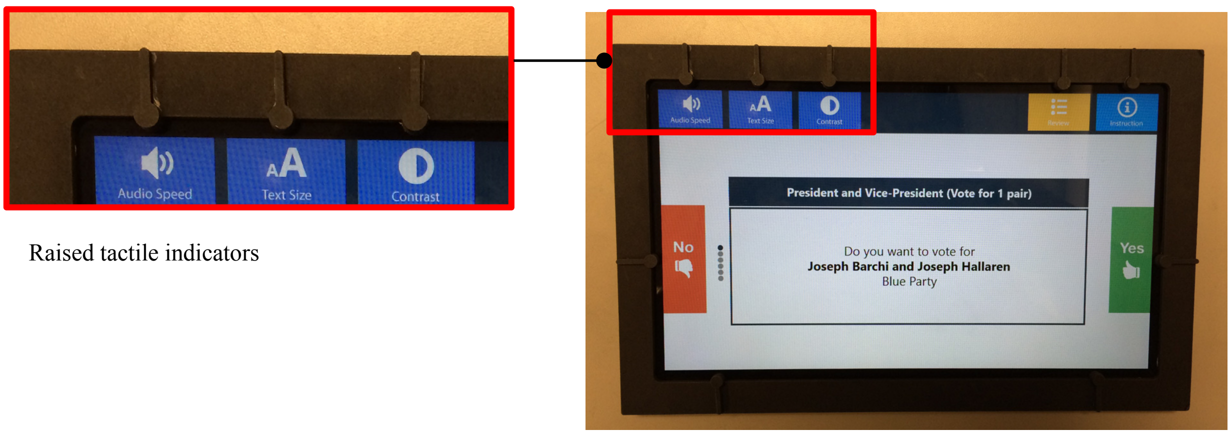


Figure 27. Refined Tactile Cover Design with Raised Tactile Indicators

Custom Setting Adjustments (Design Criteria 4)

The custom setting adjustments are designed with three separate menus (i.e., audio speed, text size, and contrast) by simple accessing the buttons on the main control panel. To match “Yes” and “No” linear structure, each setting page provides the options of “Yes” for the selection (i.e., confirmation of the choice) and “No” for the navigation (i.e., presenting other options. For example, when accessing the audio speed page, the user can hear the default audio speed; then the user can hear faster audio speed; Press Yes if this is your preferred audio speed" is presented visually and verbally on the screen. If that is the preferred audio speed it can be selected by touching "Yes." The user can hear faster audio speed by selecting "No." Touching "No" will lead the user through all the audio speed options. The audio speed adjustment page provides five levels: very slow, slow, normal, fast, and very fast. The text size adjustment page provides five levels: extra small, small, medium, large, and extra-large. The contrast adjustment page (see Figures 28 and 29) provides four different options: black on white, white on black, black on yellow, and yellow on black as representative choices of many electronic low vision magnifiers. All pages provide a visual and/or audio preview of the audio speed, text size, and contrast options before confirming the selection.

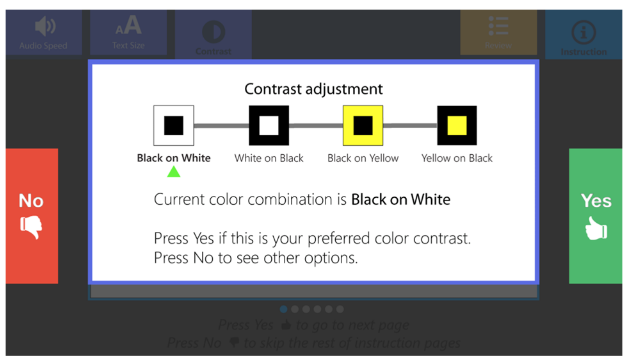


Figure 28. A Screenshot of the Contrast Adjustment Page (Black On White)

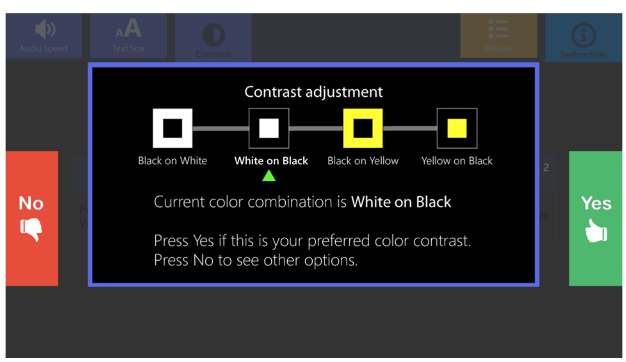


Figure 29. A Screenshot of the Contrast Adjustment Page (White On Black)

Refinement 2: Development of Alternative Ballot Structure

An alternative ballot structure, QUICK Ballot, was a design response to the Design Criteria 5: Provide an alternative navigation and selection methods that resulted from the formative usability study of EZ Ballot. As opposed to providing the linear access of EZ Ballot, QUICK Ballot provides random access that users can directly select candidate's name on the screen. However, QUICK Ballot was also developed to meet the design criteria followed by UD principles.

The information architecture of the QUICK Ballot employs a simple linear navigation between contests pages, which includes names of candidates that can be directly selected from the contest pages (see Figure 30). The QUICK Ballot provides randomly access navigation and selection methods that require users to directly select a candidate by touching the name of candidate or navigation buttons (i.e., next, back) on the screen (see Figure 31).

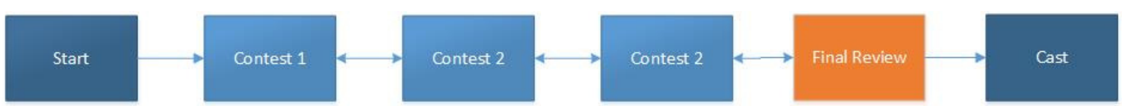


Figure 30. Information Architecture of QUICK Ballot

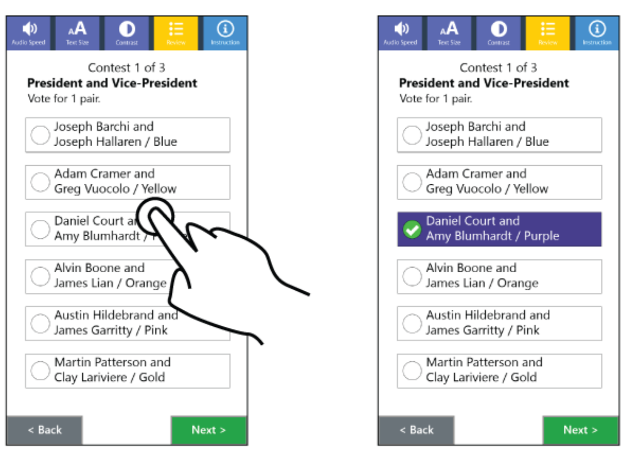


Figure 31. A Screenshot of Unselected (Left) and Selected Candidate Using Single Tap (Right)

The following design features and characteristics of the QUICK Ballot are categorized by UD principles.

UD Principle 1. Equitable Use

Like the EZ Ballot, QUICK Ballot provides the same means of voting for people with and without disabilities. Rather than specialized accessible interface, all voters can use the same type of voting system (i.e., QUICK Ballot) because accessible features (e.g., speech output) are integrated in a ballot as a default.

UD Principle 2. Flexibility in Use

The use of the two ballot interfaces (EZ and QUICK Ballots), in itself, provides flexibility in use. To accommodate a range of visual abilities, QUICK Ballot provides multimodal outputs that use visual, speech, and tactile feedback. While sighted voters can scan the information visually and directly select the candidate's name by the single tap, voters, who desire audio output, can browse the visual content (e.g., the name of the candidates) by dragging their finger on the screen and then releasing (i.e., drag-lift interaction) it to select a particular candidate (see Figure 32). For example, in a case in which a blind voter wants to select the third candidate "Daniel Court and Amy Blumhardt / Purple", the voter begins by sliding their finger from the top to the bottom of the screen. While moving one of their fingers over each candidate name, the voter can hear the following speech output: "Joseph Barchi and Joseph Hallaren Blue party," "Adam Cramer and Greg Vuocolo Yellow party," and "Daniel Court and Amy Blumhardt / Purple." After locating the third candidate, the voter can simply lift their finger to select one. Immediately after releasing their finger, the voter receives the audio feedback "selected Joseph Barchi and Joseph Hallaren Blue party."

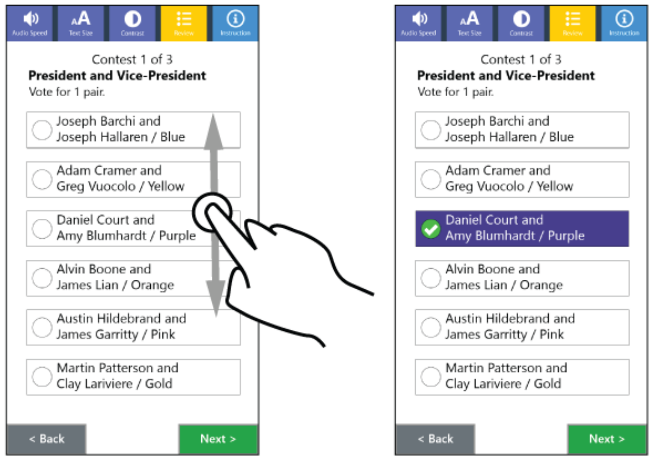


Figure 32. A Screenshot of Unselected (Left) and Selected Candidate Using Drag-Lift (Right)

QUICK Ballot also provides audio and visual adjustability such as choices of audio speed, text size, and color contrast. In addition, it can be used with one hand without excessive force for both direct single tap and drag-lift interaction. Voters can skip any contest or referendum by pressing the Next button.

UD Principle 3. Simple and Intuitive Use

QUICK Ballot is a familiar and intuitive interface for users who are familiar with linear navigation and random access direct selection on touch screen interfaces. The linear navigation allows users to navigate from the first contest page to the final review page back and forth using the familiar navigation buttons, 'Next' and 'Back'.

As opposed to the EZ Ballot, QUICK Ballot provides a random access within a contest page that allows voters to directly select the name of a candidate rather than going through each candidate. QUICK Ballot presents a single contest in one screen, and pagination for a contest that has a large number of candidates.

UD Principle 4. Perceptible Information

QUICK Ballot has integrated visual and audio output interfaces throughout the ballot. For example, QUICK Ballot provides simultaneous audio and visual mode when selecting and deselecting a candidate. When the user touches the box of the candidate's name, the box changes to the highlighted dark background and white text with a check mark icon that visually emphasizes the selection of the candidate (see Figure 33).

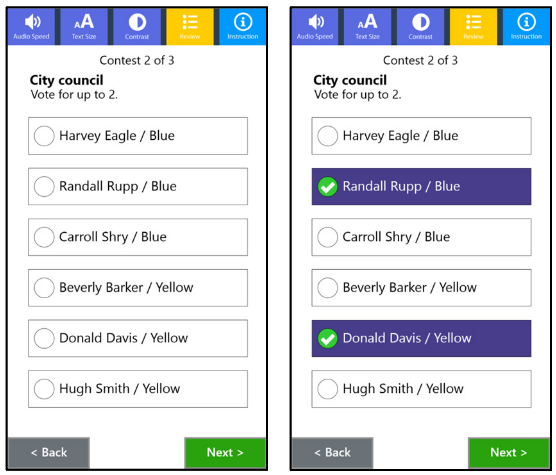


Figure 33. A Screenshot of Unselected (Left) and Selected Candidates (Right)

At the same time, audio feedback also plays "selected Randall Rupp Blue party." Like the EZ Ballot, QUICK Ballot prototype includes the tactile cover that sits above a touchscreen for users with limited or no visual abilities who have difficulties to locate the virtual buttons on the screen. In addition, QUICK Ballot also uses the san serif font and high contrast by default (e.g., black text in white background).

UD Principle 5. Tolerance for Error

Quick Ballot provides instant prompt message for users to prevent overvoting. For example, when the user is trying to select more than the number of allowable votes, the prompt message appears visually and through audio (see Figure 34). The message presents “You have already voted for 1 candidate. If you want to choose another candidate, touch the checked box you don’t want. Then, touch another candidate you wish to choose. To close this message, press the close button in the top left corner of the screen.” QUICK Ballot also provides a final review page that shows all the selections that voters made. Voters can easily recognize any errors (e.g., undervote, wrong vote) so that they can change their votes before casting a ballot.

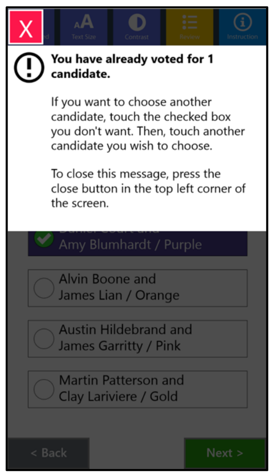


Figure 34. Prompt Message

UD Principle 6. Low Physical Effort

The random access system of the QUICK Ballot is designed to reduce the time and effort of using a linear selection system, the EZ Ballot. However, drag-lift interaction for voters who have limited visual abilities may require more physical effort than using Yes and No inputs on the EZ Ballot. In addition, all the touch buttons are located in the corners or on the edges of the screen so that blind or visually-impaired users can easily locate them (Leporini et al., 2012b; Oliveira et al., 2011; Park et al., 2008). For navigating pages, “Next” and “Back” buttons are placed on the right and left bottom corner of the screen of the tablet. All five control buttons (three custom setting buttons, review button, help button) are placed on the top of the screen.

UD Principle 7. Size and Space for Approach & Use

All soft buttons provide large enough target size (i.e. minimum width measure of 20 mm) (Jin, Plocher, & Kiff, 2007b) for users with a range of dexterity. All the buttons are placed in the corners or the edges of the screen allowing easier navigation for blind or visually-impaired users (Leporini et al., 2012a; Oliveira et al., 2011).

Differences in Design Characteristics between EZ Ballot and QUICK Ballot

Both ballots use the same ballot contents with the same size of text, the same size of touch buttons, the same means of tactile cover with indicators, and the same quality of voice. More importantly, both ballots aim to provide equal access to voters with a range of abilities, skills, and experiences. However, whereas EZ ballot provides a step-by-step directed guide that allows users to follow a particular sequence of steps, QUICK Ballot provides a familiar typical ballot format that allows users to directly choose a certain candidate on the touch screen.

Both EZ and QUICK Ballots provide the linear navigation methods across contests, but differently. They allow starting from the first contest and moving through to the last contest linearly by touching "No" button or swipe gesture (EZ Ballot) and "Back" and "Next" buttons (QUICK Ballot).

The main difference between EZ Ballot and QUICK Ballot is linear selection versus random selection method within contests. Within contests, EZ Ballot provides a **linear selection method** that allows starting from the first candidate and moving through to the last candidate by touching "No" and selecting the candidate by touching "Yes" button. In contrast, QUICK Ballot provides a **random selection method** that allows one to directly select the candidate by touching the name of the candidate. For visually-impaired users, QUICK Ballot provides one-finger scan and lift finger interaction for directly selecting a candidate. Table 10 summarizes main differences between EZ Ballot and QUICK Ballot across and within contests. Given these differences the final study will examine the effectiveness of the different selection methods using EZ Ballot and QUICK Ballot for voters with a range of visual abilities.

Table 10. Differences between EZ Ballot and QUICK Ballot

	EZ Ballot	QUICK Ballot
Across Contests	Linear selection • Yes or No • Swipe gesture	Linear selection • Back or Next
Within Contests	Linear selection • Yes or No • Swipe gesture	Random selection • Direct touch for sighted • One-finger scan and lift for non-sighted

Expert Review (Specific Aim 5)

The purpose of this expert review study was to evaluate and refine the ballot interfaces based on experts' review prior to testing the ballots with voters a range of visual abilities. Expert participants identified the potential impact of the EZ Ballot and the QUICK Ballot by rating the severity of usability problems using Nielsen's severity rating (Nielsen, 1992). The findings of the study informed the refinement of the design characteristics of the EZ Ballot and the QUICK Ballot.

Methods

<u>Participants</u>

Fifteen participants with expertise on human factors (HF), human-computer interaction (HCI), industrial design (ID), accessibility (A), universal design (UD), voting, and others, including assistive technology (AT), psychology (Psych), and gerontology (Geront), participated in the study. The criteria for inclusion in the study were that experts be at least 18 years of age and have more than two years of experience in the above areas of expertise. Participants had multiple expertise including accessibility (n=15), usability (n=14), human factors (n=13), universal design (n=12), human-computer interaction (n=10), voting (n=4), and industrial design (n=3). Participants who marked voting as their expertise are actively working on designing voting systems, testing usability and accessibility with current voting systems, and/ or creating training courses for poll workers. The mean years of their work experience was 16 years. Experts rated their familiarity with UI design for people with vision loss (VL) ranging from 0 = not familiar, 1= somewhat familiar, to 2 = very familiar. Experts were somewhat familiar (n=3) to very familiar (n=12) with UI design for people with vision loss (VL). Table 11 summarizes the participants' expertise.

<u>Test Prototype</u>

The test prototypes consisted of the linear EZ Ballot and the random QUICK Ballot described above in the formative study of EZ Ballot section. Since the QUICK Ballot was developed after the EZ Ballot, their implementation environments differ. While both ballots were high-fidelity prototypes that provide a true representation of the user interface, the initial QUICK Ballot prototype was not programmed with the function to keep track of votes. However, interaction regarding the navigation, selection and change of vote for sighted and non-sighted users was functional for the purpose of getting feedback from experts.

Table 11. Participants Expertise

	HF (n=13)	**HCI** (n=10)	**ID** (n=3)	**A** (n=15)	**U** (n=14)	**UD** (n=12)	**Voting** (n=4)	**Others**	**Years (Mean=16)**	**VL**
P01	O			O	O			AT	20+	2
P02	O	O		O	O	O		Psych	20	1
P03	O	O	O	O	O	O			10+	2
P04	O	O	O	O	O	O			7	2
P05	O	O		O	O			Psych	8	2
P06	O			O	O	O			28	1
P07	O			O		O	O		20	2
P08	O	O		O	O	O		AT	30	1
P09		O		O	O	O			3	2
P10	O	O		O	O	O		Geront	21	2
P11	O	O		O	O	O	O	AT	25	2
P12				O	O	O			7	2
P13	O	O		O	O	O	O		21	2
P14	O		O	O	O		O		3	2
P15	O	O		O	O	O			20	2

<u>Procedures</u>

After signing the informed consent form approved by the Georgia Tech Institutional Review Board (IRB), the experts completed a survey about areas in which they have expertise and the number of years they have worked in the field. Experts then performed directed voting tasks using the EZ Ballot first and then the QUICK Ballot without any training or assistance. They received a simple ballot script that included voting for one candidate, voting for two candidates, voting for a referendum, and casting the ballot. During the trials, experts provided qualitative comments through a "think aloud" method that involved participants thinking aloud as they are performing a set of voting tasks. Experts then completed a post-trial interview to provide in-depth feedback about both ballots. In this interview, they rated the severity of usability problems using Nielsen's severity rating (see Table 12). Experts' verbal comments were recorded using an audio recorder. Each session lasted about 90 minutes.

Table 12. Nielsen's Severity Rating (Nielsen, 1992).

0 = I don't agree that this is a usability problem at all
1 = Cosmetic problem only: need not be fixed unless extra time is available on project
2 = Minor usability problem: fixing this should be given low priority
3 = Major usability problem: important to fix, so should be given high priority
4 = Usability catastrophe: imperative to fix this before product can be released

Data Analysis

The data from experts' verbal comments from the "think aloud" protocol was aggregated and categorized using content analysis of the notes from three different note takers. Given the limited number of experts, we used manual content analysis with Microsoft Excel to compile frequencies of usability keywords. The number of experts that commented on the same issues was summed, and the severity ratings of these issues were averaged. Initial issues for the entire project at large were categorized into instructions, custom settings, navigation and selection, review and vote changing, write-in interface, and visual, auditory, and tactile characteristics. The following results focused on navigation and selection, and review and vote changing for both the EZ and QUICK Ballots that are relevant to the next summative evaluation. However, design refinements include changes on visual, auditory, and tactile characteristics based on the experts. Expert P04's data were excluded because the expert provided only the severity rating of each content category and not the descriptive usability issues.

Results

Tables 13 and 14 show the main usability issues of the EZ and QUICK Ballots that were identified by at least three expert reviewers.

EZ Ballot

Experts provided positive and negative comments regarding navigation and selection using the binary choice of the Yes or No button and using the alternative swiping gesture. The comments included the following: "skipping using the No button was an excellent way for visually impaired users to cycle through the list one at a time" (P01), "Yes and No and alternative swiping interactions are straightforward" (P02, P13) and "You allow people with visual impairments to navigate the way that makes the most sense to them without violating the convention of the primary navigation method" (P13). However, two experts (P02, P14) were concerned about memory issues when displaying one candidate at a time: "To me, it's kind of annoying to have to go through this as a sighted user. There may be issues for individuals who have memory issues resulting from candidates displayed one at a time (P14).

They also provided positive feedback about two confirmation processes when selecting a candidate, supported by the following quote: "Both confirmations are useful; you will have to listen to them more than once" (P13). In addition, they indicated the useful prompt "Are you sure you want to cast your ballot" when casting a ballot at the end of the review page.

Five issues were identified by at least three experts regarding navigating and selecting candidates, and reviewing and changing votes (see Table 13).

1. Unclear visual indicators (circles) for using swiping gestures (n=8). Unclear visual indicators, small circles, for indicating the use of gestures were the most frequently noted issue for navigating pages, eight experts having identified this issue. The mean severity rating was 2.63, which fell between minor and major usability issues. The issues included the small size of circles, low contrast between highlighted circles and non-highlighted circles, and lack of understanding of the meanings of the circles. The comments included the following: "I don't benefit from these illustrations (circles). I do not know what they mean" (P10), "I didn't even know I could swipe through the contests because it was so sequential" (P03), "they (the circles) actually struck me as a break line" (P07). Experts recommended larger circles that contrasted more strongly with the background or that took on a visual form that viewers could more easily distinguish.

2. Lack of indication of selected votes (n=4). Four experts identified that when they changed their votes, the EZ Ballot did not indicate their selected votes (mean severity rating = 2.5). This issue led experts to believe that they needed to start over again when changing their votes. They recommended that the interface clearly indicate the selected votes. P02 recommended that the question be revised to "Do you still want to vote for xxx?"

3. Lack of a going back function (n=3). Three experts identified that the lack of a function that allows the voter to return to a previous contest or to skip a contest and return to it later on could be a major issue (mean severity rating = 3). They wanted to have more freedom while navigating the contests. Their comments included the following: "I have to vote for someone in order to move on. There is no way for me to jump out of this contest and vote in it later" (P05), "I want to go back and look at what I just did "(P10), "It would be nice to go back to the overview ballot and pick one that I want to vote for (P12)."

4. Lack of direct touch when changing votes (n=3). Three experts stated that when they needed to change their votes, they wanted to directly select the votes by touching the name of the candidate or the box in the verification overview page instead of going through the options (mean severity rating = 2.33). They understood the value of the sequential review process in order to match the binary structure of "Yes" and "No." They recommended that the ballot contain an option of direct touch selection, which would add more flexibility for voters who can see.

5. Unexpected sequential review pages when voters press the "Review" button (n=3). Three experts did not expect to see the sequential review pages when pressing the "review" control button on the top menu (mean severity rating = 2.33). They recommended that the entire list of the candidates be displayed after voters press the "review" control button.

Two issues that two experts (n=2) stated that the "No" choice was not appropriate for changing votes. Experts commented that the input "No" for changing a vote or adding a vote was illogical. P10 recommended changing the statement to a question so that the "Yes" input could be used for changing votes. A recommended comment was "You have not voted for this contest. Do you want to vote for this contest?" From this question, a user could select "Yes" to vote.

Table 13. Main Usability Issues of EZ Ballot

Issue Descriptions	Number of Experts	Mean Severity Rating
1. Unclear visual indicators (circles) for using swiping gestures	8	2.63
2. Lack of indication of selected votes	4	2.5
3. Lack of a going back function	3	3
4. Lack of direct touch when changing votes	3	2.33
5. Unexpected sequential review pages when voters press the "Review" button	3	2.33

<u>QUICK Ballot</u>

Most experts provided positive comments regarding familiarity of the navigation and selection using the direct touch with next and back buttons, as supported with the following quotes: "It looks like a real ballot" (P01), "I like this [ballot] better immediately. More familiar with what I am used to" (P02), "It's more immediate, more direct for me because I can see all the options. I am used to that interaction" (P03), "As a visual person, I like to see all candidates at once" (P07) "I like the portrait display that you can see all of the candidates to choose them without having to scroll to the next one (P09). "I actually like this a lot better that the other one (EZ Ballot)" (P12)."

Four issues were identified by at least three experts regarding navigating and selecting candidates, and reviewing and changing votes (see **Error! Reference source not found.**).

1. Not intuitive vote changing process (n=4). Three experts stated that the vote changing process, which required deselecting one name before selecting another name, was not intuitive (mean severity rating = 3.13). The comments included the following: "I can see someone being frustrated if you have to uncheck that one before you can check the other one" (P09), and "some people would find it annoying and uncomfortable" (P06). They (P09, P11) recommended that the user be able allowed to select a new name without requiring deselecting the previous choice. On the other hand, two experts did not think this deselection process was an issue: "Forcing them to deselect one in order to select the other one is the way to go" (P13), and "deselecting is intuitive to me" (P15).

2. Disconcerting warning message for the overvote prevention (n=3). Three experts stated that the warning message popup for the overvote prevention was disconcerting and annoying. Their comments included the following: "You can't have an error message that has a dialog box just popping up in the middle of the process" (P02), "You don't want it telling you that you are making all mistakes" (P06). P02 recommended removing the warning message but keep the ability for the system to prohibit the overvote action. In this way, users can realize that overvote does not work. P12 recommended making the user touch anywhere to close the message popup instead of the close button in one fixed location.

3. Error-prone selection method for non-sighted users (n=3). Three experts identified that the selection method using the drag and lift interaction for non-sighted users could result in more errors (mean severity rating = 2.67). They recommended a different interaction for the selection method such as split-tap or double tap to which visually-impaired users who use iOS VoiceOver are already adopted. However, the other experts did not state that the drag and lift interaction would be an issue for non-sighted users: "dragging is probably the most intuitive way releasing the voice response. You can include a double tap, but I don't think that's a problem here. I think you have had a simple solution" (P15).

4. Lack of detailed audio feedback for non-sighted users (n=3). Three experts identified the lack of detailed audio feedback for non-sighted users (mean severity rating = 2.17). "No information what's been selected. You might tell them what's going to happen when they release the button" (P13). They suggested better feedback when users select the name or move to the next race. P03 also recommended adding non-speech sound to the speech sound of selection and deselection.

Table 14. Main Usability Issues of QUICK Ballot

Issue Descriptions	Number of Experts	Mean Severity Rating
1. Not intuitive vote changing process	4	3.13
2. Disconcerting warning message for the overvote prevention	3	3.33
3. Error-prone selection method for non-sighted users	3	2.67
4. Lack of detailed audio feedback	3	2.17

Experts indicated the strength of the EZ Ballot and the QUICK Ballot. Several experts (P02, P09, and P15) commented that the EZ Ballot, which displays step-by-step binary options linearly, would work better for people with vision loss, but that the QUICK Ballot, which displays all of the choices at once, would be ideal for other populations including sighted users. They encouraged testing both ballots with actual users.

Discussion

The study with experts evaluated the EZ Ballot and the QUICK Ballot as a potential ballot interface for voters with and without vision loss. Experts identified issues with severity ratings from a 0 (no usability problem) to 4 (usability catastrophe) rating scale. The issues of the EZ Ballot and the QUICK Ballot were prioritized by the number of experts with the mean severity ratings.

<u>EZ Ballot</u>

Experts commented that the linear ballot structure has great potential in the selection and navigation between contests and candidates, particularly for visually-impaired users. On the other hand, some experts were concerned about the lack of a single page with all of the options, which could increase the issue of memory load, resulting in poor voter satisfaction, particularly for sighted users. The majority of experts commented that there is no usability problem regarding navigation of the contest and candidate pages using the Yes and No and alternative swiping gesture. They commented that both the "No" button and swiping gesture as navigating contest pages and candidate pages work well. However, even if the swiping gesture is optional, they suggested to emphasize the visual and audio indicators so that users can use the gesture interaction for navigating contests and candidates.

Regarding review and vote changing, despite great features of having two confirmation steps, the lack of indication of selected votes became a major usability issue (n=4). The interface should provide visual and audio indication so that users do not think they need to start over, which could seriously affect overall voter satisfaction. As one expert (P02) recommended, when the user revisits the voted candidate, the screen should indicate something like “Do you still want to vote for X?” as an indication that they had already voted.

Issues were related to the limitation of the binary structure of the ballot design: lack of a going back function (n=3) and lack of direct touch when changing votes (n=3) from the final review page. For the experts who are sighted and have sufficient experience with touch screens, the lack of going back button and direct touch selection could be unfavorable, because they want to make fast selection and navigate freely across the ballot. However, we did not add the back button or direct touch function to the EZ Ballot since the main concept of the ballot design is that of linear progression. As one expert (P13) commented, this is our trade-off that providing linear step-by-step process rather than providing faster process for visually-oriented individuals. Thus, further study requires measurement of the voter performance and satisfaction on the linear ballot (i.e., EZ Ballot) and random access ballot (i.e., QUICK Ballot) that will better guide us in design decisions.

<u>QUICK Ballot</u>

Most experts who are sighted mentioned that they would prefer to use the QUICK Ballot to the EZ Ballot. However, they identified usability issues regarding the vote changing process and interactions for non-sighted users.

The first and second usability issues were related to the vote changing process using QUICK Ballot. Four experts complained about the deselection step before selecting another name, and three experts stated the disconcerting warning message for the overvote prevention. As a few experts recommended, if we implemented automatic deselection when the voter selects another name, it would be the simplest way to change a vote because of the fewer number of steps. However, this solution would create hazardous unintentional action (Laskowski, Autry, Cugini, Killam, & Yen, 2004). For example, when moving the hand across the screen, the voter could easily accidently touch the name that is not intentional. If the voter does not notice this error, the voter would cast this vote with the inadvertent error. P02's recommendation was making nothing happen when the voter makes another selection without deselecting the previous choice, which can prohibit the inadvertent selection. However, this solution requires the voter to determine why the system failed to respond. The system should not allow users to figure out the correct way to change the vote. Thus, we decided to keep the current way of changing the vote that is providing a massage when a voter makes more than the allowed number of selections in any given contest.

The third and fourth usability issues were related to the navigation and selection method for non-sighted users. Three experts were concerned about the selection method that likely lead to mistakes. As one expert commented, providing split-tap or double tap for the selection method like the current gesture of VoiceOver could be a safer way. However, split-tap or double tap gesture action could be difficult for people without vision loss and people with vision loss who have not been used the VoiceOver features. Thus, this issue remains for further study in measuring voter performance using drag and lift interaction for visually-impaired voters. This issue can also be resolved by providing detailed audio feedback for non-sighted users. Current audio feedback provides minimum information such as "John Smith Yellow party" when the voter is dragging, and "selected John Smith Yellow party" when the voter lifts their finger. As experts suggested, the audio feedback should be more descriptive, such as "If you want to select this name, lift your finger" followed by "John Smith Yellow party" and "Press Next button to go to next race" after lifting their finger" followed by "selected John Smith Yellow party". In addition, adding non-speech sound before “selected….” and “deselected…” would also improve the feedback when the voter did not recognize the speech sound of “selected” and “deselected.”

Experts also commented about the audio characteristics that both ballots lack of replay/pause feature. This became important issues when the screen has more information such as instruction page, referendum, and final review pages. Expert (P05) comments that we might want to try to use the gestural interaction for the play/ pause/ replay feature like Apple’s Voice Over.

Experts provided similar feedback on the use of the EZ Ballot and the QUICK Ballot. They mentioned that people with vision loss would benefit from the EZ Ballot and people without vision loss would benefit from the QUICK Ballot. These insights helped us to develop the hypotheses for the following summative evaluations. The summative evaluation will examine the effectiveness of both ballots in facilitating voting performance for individuals with and without vision loss to confirm this insight by the expert reviewers.

Design Refinements

<u>Both Ballots</u>

Audio and tactile characteristics were commonly refined in the development process for both ballots. Unfortunately, the replay/pause feature was not implemented given the limited time and resources. However, several recommendations suggested to improve the audio interface regarding different gender voices and more non-speech sounds. According to two experts’ recommendations, we changed the button sound to a female voice so that users can easily distinguish between different types of information (e.g., button sound versus other general information). In addition to this, non-speech sound was added to the current audio interface. For the EZ Ballot, a non-speech "beep" sound was added before each speech for the contest. For example, when users navigate to a page, they first hear a "beep" followed by "You are now in contest 1 of 3, President and Vice President." For the QUICK Ballot, non-speech sound was added before the speech sound of "seleted" and "deselected." The non-speech sound with a positive feeling plays before the "selected (candidate's name)" and the non-speech sound with a negative feeling plays before the "deselected (candidate's name)."

Experts complemented about the use of the tactile cover that can indicate all of the buttons. However, they encouraged some improvements of the tactile cover design. Instead of round shaped indicators (see Figure 35 left image), P13 suggested different shaped indicators that can be better associated with the instruction as pointing toward the on-screen buttons. Thus, we replaced raised icons/letters (see Figure 35 right image) to make it clearer for both voters with and without vision loss.

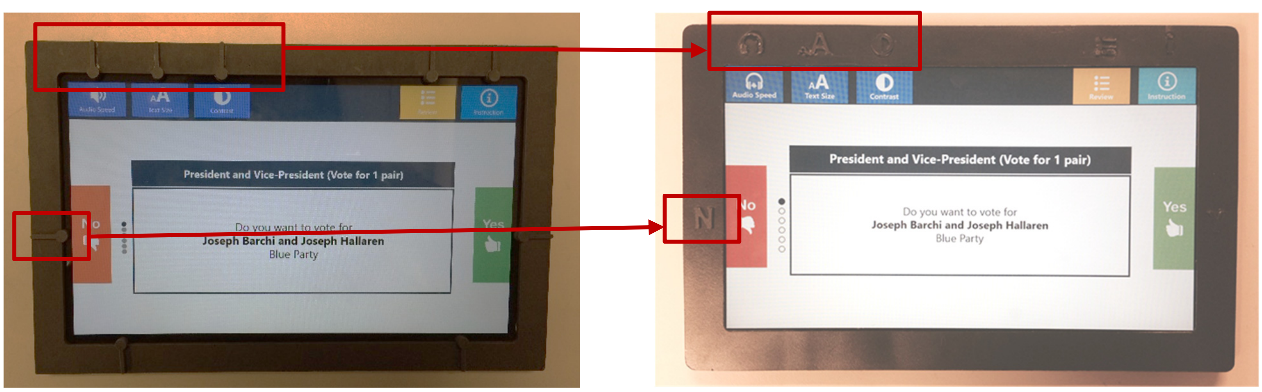


Figure 35. Previous Tactile Indicators (Left) Refined Tactile Indicators (Right)

<u>EZ Ballot</u>

According to the experts, we refined several details for the EZ Ballot regarding the indicators for gestures, review button page, and indication for the selected vote. As shown in Figure 36, we refined the indicators as larger circles that contrasted more strongly with the background without breaking out other information on the screen. In addition, the italicized texts were changed to the normal texts as one expert pointed out that italicized texts are always hard to read.

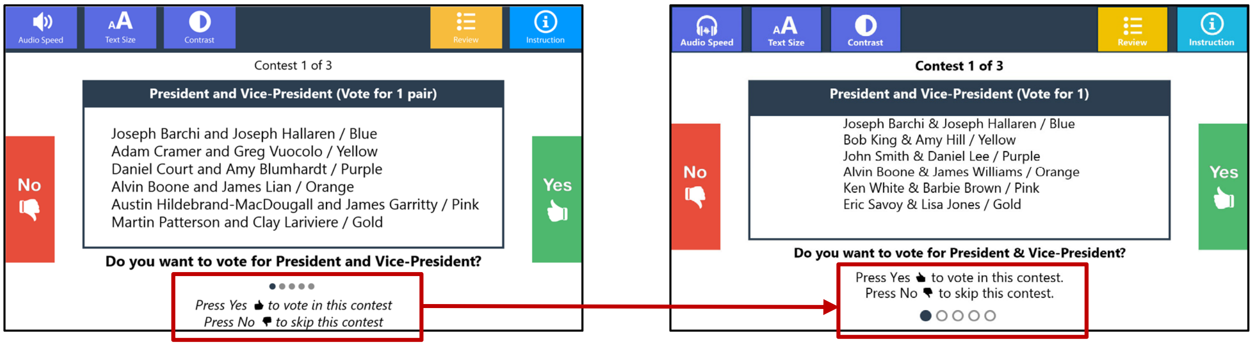


Figure 36. Refined Visual Indicators For Using Swiping Gestures (Right)

For addressing the unexpected sequential review page when pressing the "Review" button, we changed the flow of the review pages. When pressing the "Review" button, overview page shows as shown in Figure 37 right image, and sequential review page can be introduced only when the user needs to change their votes.

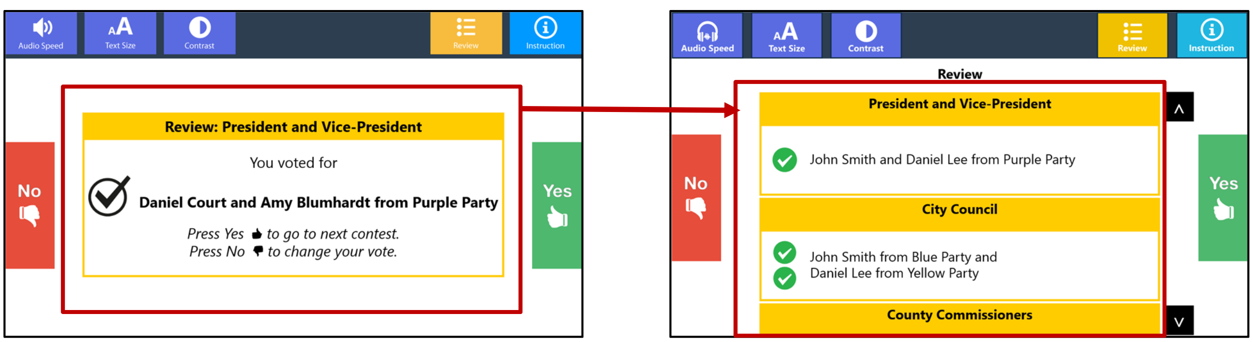


Figure 37. Refined Overview Review Page When Pressing the "Review" Button (Right)

Responding the issue "lack of indication of selected votes", we revised the question from "Do you want to vote for X" to "Do you still want to vote for X" (see

Figure 38) with check mark icon for indicating the selected votes (P02's recommendation).

Figure 38. Revised Question for Indicating Selected Vote

QUICK Ballot

Appendix B shows the whole flow chart of QUICK Ballot ver2.0. Taking experts' feedback, I refined visual look and feel for the warning message and color of the button. Despite keeping the integration of vote changing, we wanted to improve the way to present the message. Instead of creating a warning message with a serious tone, the revised warning message (see Figure 39) is better threaded into the voting process by only lightly covering the contest page. In addition, as P12 expert commented, closing the message box can be by touching anywhere instead of touching in one fixed location, particularly for visually-impaired users.

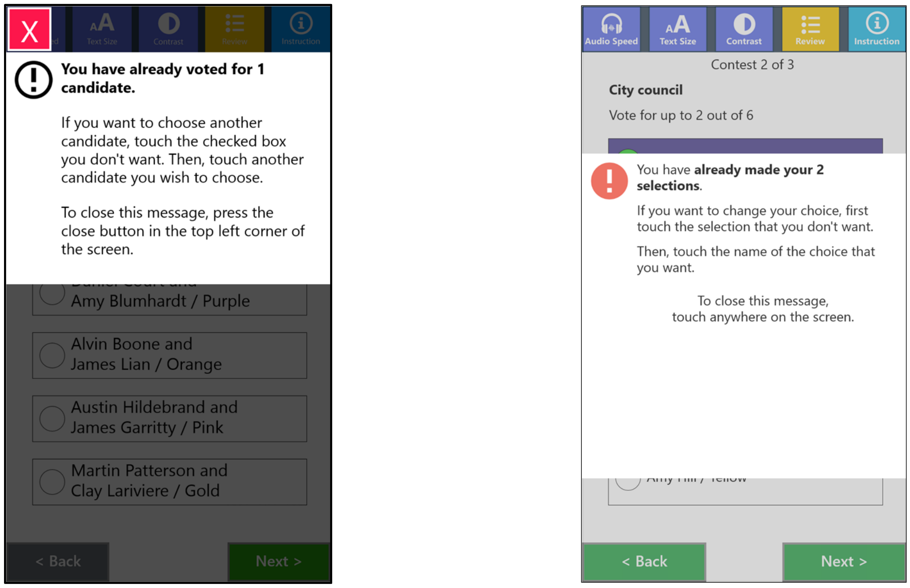


Figure 39. Refined Warning Pop-up Message (right)

One expert mentioned grey color of Back button may appear inactive for some users. Thus, we changed the background color of the Back button to green color same as the one of the Next button (see Figure 40).

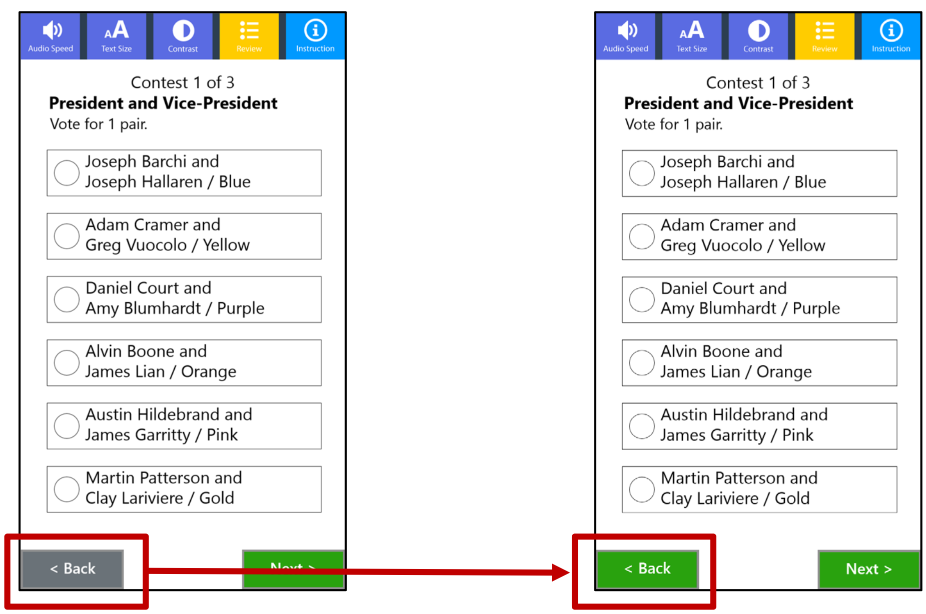


Figure 40. Refined Back Button Color

CHAPTER 6

SUMMATIVE EVALUATION

This chapter presents an empirical study of the summative evaluation to examine the effectiveness of different ballot interfaces (i.e., linear EZ Ballot vs. random QUICK Ballot) in facilitating voting performance for individuals with a range of visual abilities. The specific aims of this research were to evaluate (1) voter performance on voting tasks using two ballot interfaces measured by voting error, usability issues, assists needed, and ballot completion time; (2) voter satisfaction about the two ballot interfaces measured by perceived usability, perceived workload, and user preference; and (3) learnability about two ballot interfaces measured by voting performance over time.

Methods

Participants

A total of 32 participants, including participants with a range of visual abilities, were recruited. Table 15 shows the participants' demographics and characteristics. The sighted voter group (11 participants, 4 men and 7 women, 42–67 years old, mean age 54.3 ± 8.1 years) included participants without any vision loss.

Participants with vision loss were assigned to either a non-sighted or partially-sighted voter group based on use of audio information during the test trials. The non-sighted voter group (11 participants, 5 men and 6 women, 30–65 years old, mean age 43.9 ± 11.1 years) included participants with blindness or vision loss who primarily used audio alone as an information channel when using electronic ballots. For their vision impairments, two of them had congenital vision loss, and nine of them had acquired vision loss. They self-reported years since impairment (*M* = 21.7, *SD* = 15.3). Their cause of vision impairments included glaucoma, retinitis pigmentosa, macular degeneration, diabetic retinopathy, and uveitis.

The partially-sighted voter group (10 participants, 3 men and 7 women, 31–58 years old, mean age 46.0 ± 7.8 years) included participants with vision loss who used visual and audio as information channels when using electronic ballots. For their vision impairments, two of them had congenital vision loss, and nine of them had acquired vision loss. They self-reported years since impairment (*M* = 24.4, *SD* = 14.6). Their cause of vision impairments included glaucoma, retinitis pigmentosa, macular degeneration, diabetic retinopathy, uveitis, albinism, cataracts, and myopic degeneration.

Education

Participants self-reported their level of completed education ranging from 1 = some high school, 2 = high school or G.E.D., 3 = some college or associate's degree, 4 = a bachelor's degree or higher, to 5 = a master's degree or higher. The mean level of education was similar among the three groups: the non-sighted voter group (*M* = 3.8, *SD* = 1.1), the partially-sighted voter group (*M* = 3.7, *SD* = 0.8), and the sighted voter group (*M* = 3.6, *SD* = 1.2).

DRE Experience

Except for two participants who had used only paper ballot, most participants (30 out of 32 participants) had used DREs (direct recording electronics) in elections.

However, five needed personal assistance: four participants with vision loss needed assistance because no audio voting option was available or the audio voting option was not working, and one participant with vision loss needed help on how to use the large size text. The use of types of accessible options when the participants used DREs varied: the non-sighted voter group used the most audio voting (n = 6) and large size text (n=2); the partially-sighted voter group used the most large size text (n = 7), high contrast (n = 5), and audio voting (n=1); and only one sighted participant used large size text for voting.

Importance of the Voting Factor

Nineteen participants (59.38%) reported that "voting accurately" was more important than "voting quickly" or "voting independently." However, the importance of the voting factor varied by group. The non-sighted voter group reported "voting accurately" (n=7), "voting independently" (n=4), and "voting quickly" (n=0) as the most important voting factor. The partially-sighted voter group reported "voting accurately" (n=5), "voting independently" (n=4), and "voting quickly" (n=1) as the most important voting factor. The sighted voter group reported "voting accurately" (n=7)," "voting independently" (n=3), and "voting quickly" (n=1) as the most important voting factor.

Touch Screen Ownership and Experience

Almost all participants (29 out of 32 participants) owned touch screen devices (e.g., iPhone, iPad, Android, Windows, or Kindle). They self-reported their level of touch screen experience ranging from 1 = none, 2 = novice, 3 = intermediate, 4 = advanced, to 5 = expert. The mean level of touch screen experience was similar among the three groups: the non-sighted voter group (*M* = 3.5, *SD* = 1.2), the partially-sighted voter group

(M = 3.5, SD = 1.1), and the sighted voter group (M = 3.2, SD = 0.6). Whereas eight non-sighted participants used screen reading software (e.g., VoiceOver) with touch screen devices, only three partially-sighted participants used this software with touch screen devices.

Table 15. Participant Demographics and Characteristics

	Voters with vision loss		**Voters without vision loss**
Group	Non-sighted voter (n=11)	Partially-sighted voter (n=10)	Sighted voter (n=11)
Gender			
Male	5	3	4
Female	6	7	7
Age	43.9 (11.1) 30–65 years old	46.0 (7.8) 31–58 years old	54.3 (8.1) 42–67 years old
Years since impairments	21.7 (15.3)	24.4 (14.6)	N/A
Education	3.8 (1.1)	3.7 (0.8)	3.6 (1.2)
Some high school (1)	0	0	1
High school (2)	1	0	0
Some college (3)	4	5	4
Bachelor’s degree (4)	2	3	3
Master’s degree or higher (5)	4	2	3
DRE experience	(n=10)	(n=9)	(n=11)
Audio voting	6	1	0
Large size text	2	7	1
High contrast	0	5	0
Important voting factor			
Voting accurately	7	5	7
Voting independently	4	4	3
Voting quickly	0	1	1
Touch screen device owner	(n=10)	(n=10)	(n=9)
Screen reader on touch screen (e.g.,VoiceOver)	8	3	0
Touch screen experience	3.5 (1.2)	3.5 (1.1)	3.2 (0.6)
None (1)	0	0	0
Novice (2)	3	2	1
Intermediate (3)	3	3	7
Advanced (4)	2	3	3
Expert (5)	3	2	0

Independent and Dependent Variables

Independent variables represent the two ballot interfaces (i.e., EZ and QUICK Ballots) used to compare the voter performance and voter satisfaction. Dependent variables to evaluate the effects of the two designs, followed the objective metrics of 1) effectiveness, 2) efficiency, 3) subjective measures of satisfaction, and 4) learnability. The metrics of effectiveness, efficiency, and satisfaction were recommended by the National Institute of Standards and Technology (NIST), and the International Organization for Standardization (ISO 9241-11, 1998), used in prior research (Byrne, Greene, & Everett, 2007; Everett, 2007; Everett, Byrne, & Greene, 2006; Ted & Anna, 2006). Table 16 shows the dependent variables and types of data.

Effectiveness

Effectiveness is an objective usability metric that measures whether a user completed the task without an error, which is usually measured by the number of errors and the number of assists needed. In this study, the number of errors included voting errors indicating the actual voting results and usability issues indicating other types of non-voting errors. Types of voting errors include *undervote*, *wrong choice*, and *extra vote* errors, used in prior research (Campbell, Tossell, Byrne, & Kortum, 2011; Everett et al., 2006). *Undervote* errors occurred when voters did not make a voting selection when their intent was to do so or when they made one selection when their intent was to make two selections. *Wrong choice* errors occurred when voters made a voting selection other than the intended one. *Extra vote* errors occurred when voters made any selection when they intended to abstain from voting in a contest.

Usability issues indicate various types of errors that can be observed during the trials. Even though these errors do not indicate the actual voting results, they could potentially affect voting performance.

The number of assists needed included the number of times the researcher intervenes. Participants explicitly asked help from the researcher, as they would get the help from the poll workers in polling places.

Efficiency

Efficiency is an objective usability metric that measures whether a user achieved a goal without expending an inordinate amount of time on the task. In this study, ballot completion time was measured how long it took (in seconds) participants to complete each ballot.

Satisfaction

Satisfaction is a subjective usability metric that represents a user's subjective response to working with the system. The researcher collected quantitative and qualitative user feedback. The quantitative user feedback include the perceived usability using the system usability scale (SUS) and usability ratings for voting specific tasks, perceived workload using the NASA Task Load Index (NASA-TLX), user preferences of the ballot interfaces and reasons why. The SUS consists of ten statements including 5 positive and 5 negative statements (see Appendix D). The usability ratings for voting specific tasks consist of five positive statements regarding "easy to understand how to use the ballot," "easy to make selections," "easy to move from one page to another," "easy to review selections," and "easy to change selections" (see Appendix E). Both SUS and the usability ratings were responded with 5-point Likert scale ranging from 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, or 5 = strongly agree. The NASA TLX (Hart & Staveland, 1988) provided overall workload for the user feels while completing set of tasks as well as sub scores reflecting six dimensions to access workload: mental demand, mental demand, physical demand, temporal demand, performance, effort, and frustration (see Appendix F).

For the qualitative user feedback using the semi-structured interview, participants responded what they liked about the system, any problems they had while using the system, and ways to improve the system to make it easier to use.

Table 16. Dependent Variables and Types of Data

Metrics	Hypothesis	Measures	Types of data
Effectiveness	H2.1	Number of voting errors Number of usability issues Number of assists needed	Observed performance
Efficiency	H2.2	Ballot completion time	Observed performance
Satisfaction	H2.3	Perceived usability using System Usability Scale (SUS) and usability ratings for voting specific tasks	User feedback
	H2.4	Perceived workload using NASA Task Load Index (NASA-TLX)	User feedback
	H.2.5	User preferences	User feedback
Learnability	H3.1	Number of voting errors and usability isssues over time	Observed performance
	H3.2	Ballot completion time over time	Observed performance

<u>Learnability</u>

Learnability is another important usability metric that determines how easy the user interfaces are to accomplish tasks as the first time and how the user develops proficiency with a product over time (Nielsen, 2012). Although this metric is not typically used in prior voting research, understanding how the voter performance changes over time is important consideration in the case of trying the ballot interface before starting voting. In this study, we measured how the number of errors and time changes using two ballot interfaces over time.

Test Prototype

The test prototypes consisted of the linear EZ Ballot and the random QUICK Ballot interfaces described above in Chapter X. In this study, we used a large touch screen tablet, which is more realistically sized for a voting system in an election. The touch screen device was Dell's XPS 18 Portable All-in-One Desktop with Touch. Although this device has HD resolution 1920 x 1080, both ballot prototypes were deployed at 1366 x 768, because the initial implementation for both ballot prototypes was on a Microsoft Surface with Windows 8 with a 10.6 inch screen and 1366 x 768 screen resolution.

Experiment Setting

Testing was undertaken in center for assistive technology and environmental access (CATEA)'s Usability Lab, a controlled environment. The touch screen device was placed on a table, and participants were seated in a comfortable chair. We used a GoPro Hero 3+ Black edition camera for recording that was also connected to LCD monitors for observing the participants in real-time. Once the trial started, the researcher sat behind the wall to allow for privacy and used the cameras to observe the participant on the LCD monitors. Figure 41 shows a participant using the QUICK Ballot prototype in an experiment setting.

Figure 41. A Participant using QUICK Ballot Prototype

Tasks

Participants performed three trials of voting tasks using two ballot interfaces (EZ Ballot and QUICK Ballot). The order of the ballot interface was counterbalanced across participants. The first trial included instructions how to use the particular ballot interface, adjusting custom setting process for those who need, and voting tasks. The voting tasks contained three races (i.e., president and vice president, city council, county commissioners) and two propositions (i.e., constitutional amendment, ballot measure). The tasks included voting for one pair of candidate, voting for two candidates, and voting for two candidates in a long ballot that requires page navigation, voting for constitutional amendment and ballot measure, reviewing the votes, changing the vote, and casting a ballot. As other usability studies of voting experiences (Everett et al., 2006; Jong, Hoof, & Gosselt, 2007), participants are given the name of a candidate they should vote for based on the sample ballots (see Table 17). In this study, for reducing the memory load, they were asked to vote for candidates with the same names across each election contest each trial. For example, using a sample ballot I, participants were instructed vote for John Smith and Daniel Lee for all three contests.

The second and third trials required participants begin voting without going through instructions, but they had options to review the instructions or adjusting custom setting for those who needed.

Table 17. Sample Ballots used for the Trials

Sample Ballot I (Trial 1)	Sample Ballot II (Trial 2)	Sample Ballot III (Trial 3)
President and Vice President John Smith and Daniel Lee (Purple party)	**President and Vice President** Ken White and Barbie Brown (Pink party)	**President and Vice President** Bob King and Amy Hill (Yellow party)
City Council John Smith (Blue party) Daniel Lee (Yellow party)	**City Council** Ken White (Blue) Barbie Brown (Yellow)	**City Council** Bob King (Blue party)
County Commissioners John Smith (Blue party)	**County Commissioners** Ken White (Purple)	**County Commissioners** Bob King (Yellow party) Amy Hill (Yellow party)
Proposed Constitutional Amendment D Skip	**Proposed Constitutional Amendment D** No	**Proposed Constitutional Amendment D** Skip
Ballot Measure 101: Open Primaries Yes	**Ballot Measure 101: Open Primaries** Skip	**Ballot Measure 101: Open Primaries** No
Review Review your votes	**Review** Review your votes	**Review** Review your votes
Change vote **President and Vice President** John Smith and Daniel Lee to Bob King and Amy Hill	**Change vote** **County Commissioners** Add Barbie Brown	**Change vote** **City Council** Add Amy Hill (Yellow party)
Back to the Review **Cast Ballot**	**Back to the Review** **Cast Ballot**	**Back to the Review** **Cast Ballot**

Procedures

After signing the informed consent form approved by the Georgia Tech Institutional Review Board (IRB), pre-trial interviews consisting of demographic information including age, age of onset if any, education, DRE experience, rank order of importance of voting performance, smartphone ownership, and touch screen experiences was collected (see Appendix C). Each participant was randomly assigned to use one of the ballots first and the other second. Participants performed a total of three trials with each ballot interface. Table 18 summarizes the three trial procedures using two ballot interfaces.

Table 18. Three Trials Procedures using Two Ballot Interfaces

Ballot A			Ballot B		
Trial 1 (Sample ballot I)	Trial 2 (Sample ballot II)	Trial 3 (Sample ballot III)	Trial 1 (Sample ballot I)	Trial 2 (Sample ballot II)	Trial 3 (Sample ballot III)
Instruction Voting tasks SUS Usability ratings NASA-TLX	Voting tasks	Voting tasks Post-trial interview	Instruction Voting tasks SUS Usability ratings NASA-TLX	Voting tasks	Voting tasks Post-trial interview

For the first trial, participants had a chance to review the instructions for the ballot interface. They then performed a series of voting tasks based on the sample ballot I. Before starting the trial, participants were prompted names of candidate for whom to vote and whether they should vote yes or no for the propositions. To reduce the memory loads, participants were prompted the choice for the propositions and name for changing a vote when they were in referendum and review pages. Participants were asked to complete the voting tasks accurately. After the first trial, participants provided their feedback on the ballot interface using a SUS, usability ratings for voting specific tasks, and NASA-TLX. In a NASA-TLX assessment, they rated six workload measures and then compared which of two workload measures was more important than the other when considering the voting tasks.

For the second and the third trials, participants began voting without instructions. In the second trial, participants performed the voting tasks based on the sample ballot II. In the third trial, they performed the voting tasks based on the sample ballot III and completed a post-trial interview. After finishing the trials 1, 2, and 3 using the first ballot interface, participants had a short break. They then repeated the same process using the second ballot interface. At the end of third trial with the second ballot interface, participants answered their preferred ballot design and the reasons why. Participants' interactions with the interface were video recorded. Each session lasted approximately 120 minutes. After completion of the study, all participants were compensated $60.00 for the two-hour study.

Data Analysis

Before treating the speed (i.e., ballot time completion) and accuracy (i.e., voting error, usability issues) data separately, we wanted to check for any speed-accuracy trade off. Even though the sample size prohibited an in-depth analysis of interaction effects between time and number of errors, bivariate correlation showed a positive relationship between error and time for both EZ Ballot (r = .552, n = 32, p = .001) and QUICK Ballot (r = .864, n = 32, p <. 001), indicating no strong evidence for any speed-accuracy tradeoff. The results of the partial correlations also differed by group and ballot design. With the EZ Ballot, partial correlations controlling for group revealed significant correlations for non-sighted (r = .819, n = 11, p = .002) and sighted (r = .611, n = 11, p = .046) groups. The relationship between time and errors was not significant for the partially-sighted group. With the QUICK Ballot, partial correlations controlling for group revealed significant correlations for non-sighted (r = .824, n = 11, p = .002) and partially-sighted (r = .853, n = 10, p = .002) groups. The relationship between time and errors was not significant for the sighted group. Thus, the result of this analysis, no strong evidence of speed-accuracy tradeoff, provided the confidence for treating each following variable separately.

Effectiveness

The researcher counted the number of voting errors during trials and recorded one of three types of voting errors (i.e., under vote, wrong choice, and extra vote). These errors were then added to create a single “any type” of voting error composite score. We computed the voting errors by the number of completed ballots and the mean of total number of voting errors encountered by all participants. Participants performed three trials with each of the two ballot designs, thus the number of voting errors was computed as the average value for all three trials for each ballot. Paired samples t-tests were used to compare statistically significant differences on the number of voting errors between the two ballots.

The usability issues were observed after the session from looking at recorded video files that we used Morae Manager Software. After importing all the recorded video files (32 participants x 2 ballot design x 3 trials = 192 files), the researcher marked any usability issue that occurred during trials and annotated a description of the error. After observing recorded videos of trials, the researcher categorized the issues into one of five types of issues with accidental touch (A), changing vote (C), inactive area (I), and recovering error (R), and wrong button (W). Accidental touch (A) issues indicated an unintended action a user made while trying to do something on an interface even though the goal was intentional. For example, accidental touch issues included accidental double tapping, accidental lifting, and accidental tapping of the wrong name. Changing vote (C) issues occurred when users made mistakes while changing their votes (e.g., selecting another name without deselecting the previous one when using the QUICK Ballot, using back button to go back to previous page for changing votes, and confusion when selecting a certain race to change a vote using EZ Ballot). Inactive touch area (I) issues indicated when users directly touched an area that was not active. Recovering errors (R) indicated when the user had problems recovering the error. Wrong button (W) issues were related to problems using the buttons. Examples of button errors included pressing the physical indicator instead of the screen button and tapping the instruction button instead of the review button. We computed these issues by the frequency of unique issues and the mean of total number of issues encountered by all participants.

The number of assists incidents was counted when users explicitly asked for help during trials.

Efficiency

Ballot completion time was measured by reviewing video recordings of trials. Since the first trial included instruction pages, starting time was recorded when the first contest page (i.e., president and vice president contest) was loaded after the instruction pages and the ending time was recorded when the last page played audio "Your vote has been cast. Thank you." The ballot completion time was entered in seconds. Since participants performed three trials on each ballot, the variable of the ballot completion time was computed from the average value of all three trials for each ballot design. For the analysis, paired samples t-test were used to compare statistically significant differences on the ballot completion time between the two ballots by all and each group.

In addition, one-way ANOVA was used to compare any difference among three groups on each ballot.

Satisfaction

The SUS score was summed the score contributions from each item that ranges from 0 to 4. To obtain the overall SUS score, multiplied the sum of the scores by 2.5, which converts the range of possible values from 0 to 100 instead of 0 to 40 (Sauro, 2011). The usability ratings for voting specific tasks were organized by types of questions. The NASA-TLX was obtained for each task by multiplying the weight by the individual dimension scale score, summing across scales, and dividing by the total weight (Hart, 2006). Overall perceived workload scores were analyzed. Paired samples t-test were used to compare statistically significant differences on the perceived usability and workload between the two ballots by all and each group. In addition, one-way ANOVA was used to compare any difference among three groups on each ballot.

For the preferences data, the number of participants who preferred the EZ Ballot and who preferred the QUICK Ballot was counted. Then, Pearson's chi-square test was used to discover if there is a relationship between the ballot designs by three groups. The results of the follow-up open-ended questions regarding the satisfaction, problems, and suggestions on both ballots were categorized using content analysis.

Learnability

A repeated measures analysis of variance with within-subjects factorial design (two ballot designs x three trials) was used to evaluate statistically significant differences on voting performance (i.e., mean number of voting errors, mean number of usability issues, and ballot completion time) across trials. When significant differences were revealed ($P < 0.05$), post hoc paired samples t-tests were conducted to determine comparisons. Significance level of paired samples t-tests was adjusted (p = 0.05/ (2x3) = 0.0083) to avoid the possibility of Type 1 error.

Results

Most participants (n = 30) completed all six trials (2 ballot designs x 3 trials x 30 participants = 180 ballots): three trials with the EZ Ballot and three trials with the QUICK Ballot. Two non-sighted participants (n = 2) completed five of the six trials (5 trials x 2 participants = 10 ballots) because the total study time exceeded two hours. Thus, the total number of completed ballots was 190 ballots.

The results are organized according to the metrics of effectiveness (Hypothesis 2.1), efficiency (Hypothesis 2.2), satisfaction (Hypotheses 2.3 and 2.4), and learnability (Hypotheses 3.1 and 3.2). Table 19 shows the mean differences and standard deviations for effectiveness and efficiency metric.

Table 19. Mean Differences (with Standard Deviations) for Effectiveness and Efficiency.

Measures	Ballot	Non-sighted (n=11)	Partially-sighted (n=10)	Sighted (n=11)	All	*P* value
Mean (S.D) of Voting Error per trial	EZ	.24 (.15)	.33 (.38)	.30 (.10)	.20 (.38)	.166
	QUICK	.61 (.27)	.17 (.13)	.15 (.31)	.31 (.63)	.161
	***P* value**	.059	.453	.221	.255	
Mean (S.D) of Usability issues per trial	EZ	1.44 (2.08)	1.17 (1.29)	1.18 (.85)	1.27 (1.46)	.894
	QUICK	4.47 (3.34)	2.00 (1.39)	1.30 (1.00)	2.61 (2.54)	**.005
	***P* value**	**.001	.182	.703	**.001	
Mean (S.D) Ballot Completion Time per trial	EZ	571.8 (124.0)	467.4 (114.5)	355.7 (75.5)	464.9 (137.4)	***<.001
	QUICK	502.5 (265.0)	245.7 (113.0)	139.2 (40.2)	297.38 (227.0)	***<.001
	***P* value**	.284	***<.001	***<.001	***<.001	

* Significant level $p < .05$
** Significant level $p < .01$
*** Significant level $p < .001$

H2.1 Effectiveness

Voting Errors

By the Number of Completed Ballots

Of the total number of completed ballots (n=190 ballots), 159 ballots (83.68%) were completed without error, and 31 ballots (16.32%) were completed with at least one error: 84% (n = 80 ballots) of ballots with the EZ Ballot and 83% (n = 79 ballots) of ballots with the QUICK Ballot (see Table 20). Overall, 16% (n=15) of ballots with the EZ Ballot contained at least one voting error. The number of ballots containing at least 1 error also varied by group: the partially-sighted group (10%, n=9) had the highest number of ballots containing at least one voting error, followed by the non-sighted (5%, n = 5), and sighted (1%, n =1) group. Overall, 17% (n=16) of ballots with the QUICK Ballot contained at least one voting error. The number of ballots containing at least one error also varied by group: the non-sighted group (9%, n=8) had the highest number of ballots containing at least one voting error, followed by partially-sighted (4%, n = 4), and sighted (4%, n =4) groups.

Table 20. The Number of Ballots Containing No Error and At Least One Error

	Group	Ballot with no error	Ballot with At least 1 voting error	Total # of ballots completed
EZ Ballot	Non-sighted	27	5	32
	Partially-sighted	21	9	30
	Sighted	32	1	33
	All	80 (84%)	15 (16%)	95
QUICK Ballot	Non-sighted	24	8	32
	Partially-sighted	26	4	30
	Sighted	29	4	33
	All	79 (83%)	16 (17%)	95

Table 21 shows the descriptions of types of voting errors that occurred during trials. The most frequent voting errors was regarding the referendum choice (n=10) when using the EZ Ballot, and the undervote voting error (n=7) when using the QUICK Ballot. When using the EZ Ballot, participants skipped in a referendum when they were supposed to vote for 'No' (n=6) or made the wrong choice in a referendum (n=4).

Table 21. Descriptions of Types of Voting Errors

(n = # of ballots completed)		**All**	**Non-sighted (n=32)**	**Partially-sighted (n=30)**	**Sighted (n=33)**
EZ Ballot	Wrong choice: skipped the referendum instead of voting for no or selected wrong choice in a referendum	10	3	6	1
	Undervote: selected only one instead of 2 votes	2	2	0	0
	Wrong choice: selected wrong race for changing vote	2	0	2	0
	Undervote: accidently skipped the race	1	0	1	0
	Totals	15	5	9	1
QUICK Ballot	Undervote: selected only one instead of 2 votes	7	4	3	0
	Wrong choice: selected wrong choice in a referendum	3	2	1	0
	Wrong choice: did not follow the instruction	3	0	0	3
	Wrong choice: chose one name incorrectly for the two votes	2	2	0	0
	Wrong choice: selected wrong race for changing vote	1	0	0	1
	Totals	16	8	4	4

The other voting errors included undervote in a voting for 2 task, wrong choice for changing vote, and accidently skipped the race due to the accidental double-click. Overall, partially-sighted participants made the highest number of voting errors, followed by non-sighted and sighted participants.

When using the QUICK Ballot, participants selected only one instead of two votes, resulting undervotes (n=7). Other types of voting errors included wrong choice in a referendum, wrong choice due to not following the instruction, wrong choice of one name in two votes, and wrong choice by selecting the wrong race for changing vote. Overall, non-sighted participants made the highest number of voting errors with the QUICK Ballot, and partially-sighted and sighted participants made the same number of voting errors.

By the Number of Voting Errors

As shown in Table 19, paired samples t-tests revealed no significant difference in the mean number of voting errors on the EZ Ballot (M = .20, SD = .38) and the QUICK Ballot (M = .31, SD = .63); t (31) = -1.159, p > .05. The mean number of voting errors per trial numerically differed by group (see Figure 42). The dark bars present the EZ Ballot, and the light bars present the QUICK Ballot. Although the difference between the ballots was not significant (p = .059), the non-sighted group made about 2.5 times more voting errors using the QUICK Ballot (M = .61, SD = .27) than the EZ Ballot (M = .24, SD = .15). In contrast, the partially-sighted group made about 2 times more voting errors using the EZ Ballot (M = .33, SD = .12) than the QUICK Ballot (M = .17, SD = .13).

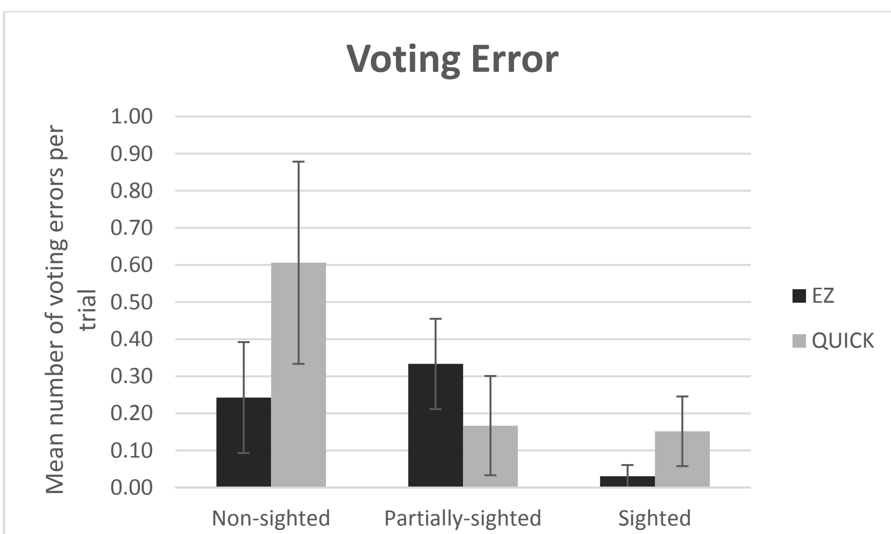


Figure 42. Mean Number of Voting Errors Per Trial for Each Ballot and Group. Error bars represent the standard errors of the mean.

Observed Usability Issues

By the Frequency of Unique Issues

Figure 43 shows the frequency of participants who experienced specific types of usability issues. More than 50 usability issues were observed on both ballots. However, the percentage of participants who encountered a specific issue was different by ballot. Using the EZ Ballot, 50% of participants (n=16) had the most problems with vote-changing, and 46.9% (n=15) had problems with tapping inactive area. In addition, they had issues with recovering from errors (28.1%, n=9), accidental touch (21.9%, n=7), and wrong button (18.8%, n=6). Using the QUICK Ballot, 87.5% participants had the most problems with accidental touch (n=28), and 75% had the problems with vote-changing (75.0 %, n=24). They also had issues with recovering errors (15.6%, n=5), tapping wrong buttons (6.3%, n=2), and tapping inactive area (6.3%, n=2).

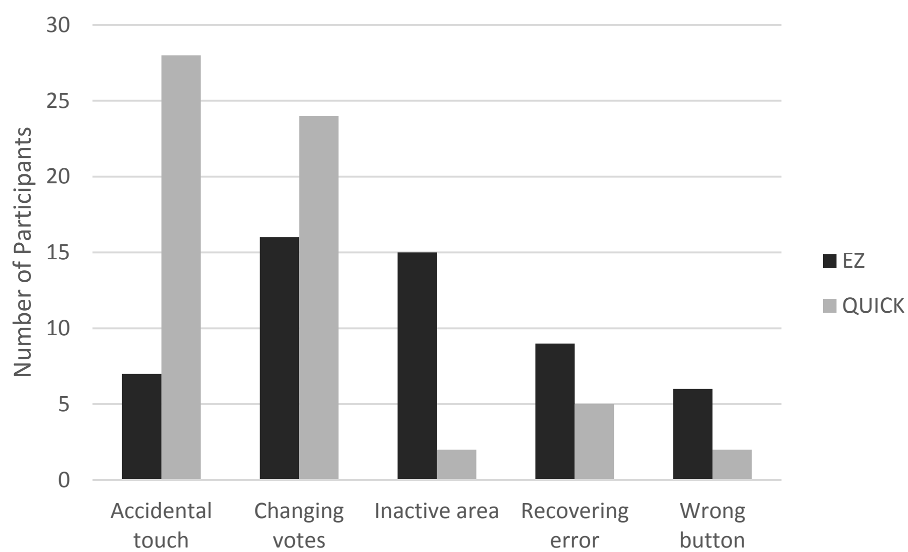


Figure 43. Observed Frequency of Unique Usability Issues

Table 22 shows the frequency of participants who experienced specific types of usability issues by group. Several types of usability issues were observed only for certain user groups. Wrong button issues were observed only from the non-sighted group. Tapping inactive area issues were observed only from the partially-sighted and sighted groups.

Table 22. Frequency of Participants who Experienced Specific Types of Usability Issues

	EZ Ballot				QUICK Ballot			
Usability Issues	**All**	**Non-sighted (n=11)**	**Partially -sighted (n=10)**	**Sighted (n=11)**	**All**	**Non-sighted (n=11)**	**Partially -sighted (n=10)**	**Sighted (n=11)**
Accidental touch (A)	7 (21.9%)	5	1	1	28 (87.5%)	11	9	8
Changing vote (C)	16 (50.0%)	5	4	7	24 (75.0%)	8	7	9
Inactive area (I)	15 (46.9%)	0	6	9	2 (6.3%)	0	1	1
Recovering error (R)	9 (28.1%)	2	5	2	5 (15.6%)	2	1	2
Wrong button (W)	6 (18.8%)	6	0	0	2 (6.3%)	2	0	0
Total Usability Issues	53	18	16	19	61	23	18	20

The majority of the number of usability issue type was the accidental touch (A) by non-sighted participants (n=11), partially-sighted (n=9) and sighted (n=8) participants, particularly when using the QUICK Ballot as compared to the EZ Ballot. Vote changing errors (C) occurred for all groups, but higher number of errors using the QUICK Ballot (n=24) than the EZ Ballot (n=16). Partially-sighted (n=6) and sighted (n=9) participants made more issues with tapping inactive area (I) when using the EZ Ballot as compared to the QUICK Ballot. Six non-sighted participants with the EZ Ballot and two non-sighted participants with the QUICK Ballot tapped wrong buttons (W), physical indicators instead of the on screen buttons. The partially-sighted participants (n=5) could not recover (R) from their errors when using the EZ Ballot than other groups.

By the Number of Usability Issues

The mean number of usability issues per trial was significantly higher on the QUICK Ballot (M = 2.61, SD = 2.54) than on the EZ Ballot (M = 1.27, SD = 1.46); t (31) = -3.537, p = .001, particularly for the non-sighted group; t (10) = -4.387, p = .001 (see Figure 44). Partially-sighted and sighted participants exhibited no significant differences in the mean number of usability issues on the EZ Ballot and the QUICK Ballot.

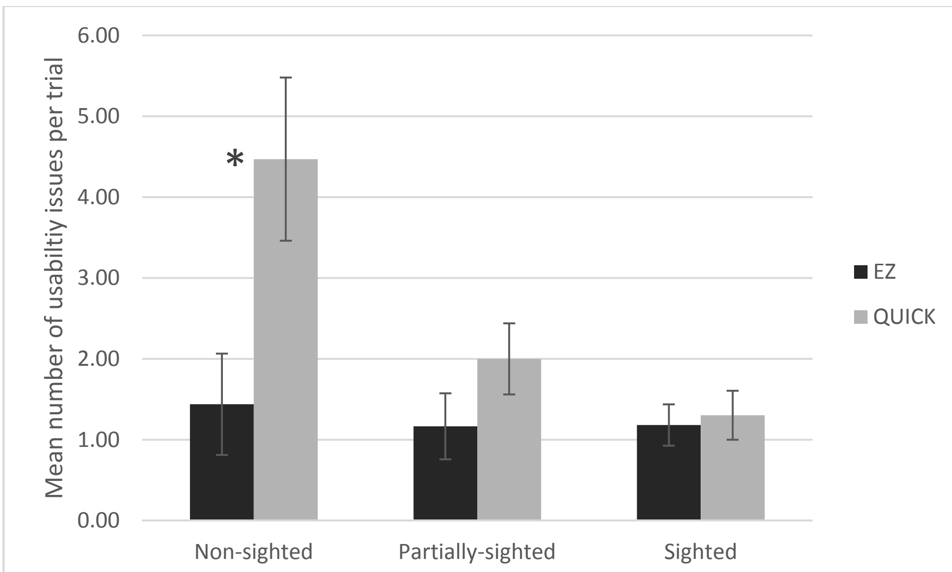


Figure 44. Mean Number of Usability Issues Per Trial for Each Ballot and Group. Error bars represent the standard errors of the mean.

<u>Number of Assists Needed</u>

Of the total number of completed ballots, over 85% of ballots of either EZ or QUICK Ballot did not need any help: 85% (n = 81 ballots) of ballots with the EZ Ballot interface and 90% (n = 85 ballots) of ballots with the QUICK Ballot interface (see Figures 45 and 46). Figure 45 shows the number of assists needed with the EZ Ballot. Overall, participants in 14% (n=14) of the ballots with the EZ Ballot needed some type of assistance: the non-sighted group (7%, n=6) needed the highest number of assists, followed by the sighted (5%, n = 5), and the partially-sighted (2%, n =2) group. Figure 46 shows the number of assists needed with the QUICK Ballot. Overall, participants in 10% (n=10) of the ballots with the QUICK Ballot needed some type of assistance; the partially-sighted group (5%, n=5), the non-sighted (4%, n = 4), and the sighted (1%, n =1) group.

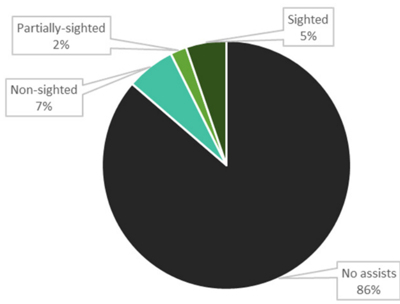


Figure 45. Number of Assists Requested With The EZ Ballot out of Completed Ballots

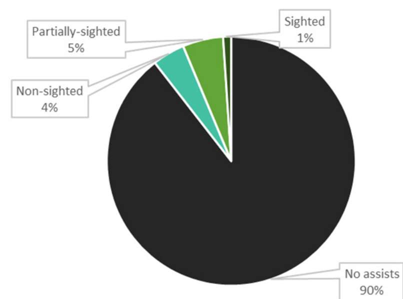


Figure 46. Number of Assists Requested With The QUICK Ballot out of Completed Ballots

Table 23 shows the types of help that participant requested relative to the total number of completed ballots, which are organized from high to low in the number of help requests. The highest number of types of assists was the vote-changing process on both ballots, six help requests on the EZ Ballot and two help requests on the QUICK Ballot. Non-sighted and partially-sighted participants needed help with the location of the buttons (e.g., review button) on both ballot screens. Non-sighted participants also requested help regarding how to use the touch gestures (i.e., drag and lift interaction) on the QUICK Ballot. They were unfamiliar with the drag and lift interaction and often requested help. In addition, three participants requested help for finding a name which was in the next page for the long ballot contest in the QUICK Ballot.

Table 23. Types of Help that Participants Requested by Completed Ballots

(n = # of ballots completed)		All	Non-sighted (n=32)	Partially-sighted (n=30)	Sighted (n=33)
EZ Ballot	How to change vote	6	2	1	3
	Where the review button is	4	2	1	0
	How to go back to the previous candidate page	1	1	0	0
	How to use the swipe gesture	1	1	0	0
	How to review the votes	1	0	0	1
	How to vote for no in referendum	1	0	0	1
	Total number of assists needed	13			
QUICK Ballot	How to find a candidate name in a long ballot	3	1	1	1
	How to use the touch gestures (e.g., drag and lift)	2	2	0	0
	Where the review button is	2	1	1	0
	How to change vote	2	0	2	0
	How to review the votes	1	0	1	0
	Total number of assists needed	10			

H2.2 Efficiency

Paired samples t-tests revealed that the mean ballot completion time by all groups was significantly higher on the EZ Ballot (M = 464.90, SD = 137.42) than on the QUICK Ballot (M = 297.38, SD = 226.99); t (31) = 6.232, p < .001 (see Table 19). The mean ballot completion time on the ballot designs also differed by the three groups (see Figure 47). The dark bars (EZ Ballot) and the light bars (QUICK Ballot) present the mean ballot completion time (in seconds). For the non-sighted group, no mean ballot completion time differences (p > .05) between the EZ Ballot (M = 571.79, SD = 123.95) and the QUICK Ballot (M = 502.48, SD = 264.98) were found. However, the mean ballot completion time was significantly higher on the EZ Ballot than on the QUICK Ballot for the partially-sighted group; t (9) = 6.331, p < .001, and the sighted group; t (10) = 12.480, p < .001.

One-way ANOVA showed a statically significant difference between groups on the EZ Ballot (F (2, 29) = 11.335, p < .001) and the QUICK Ballot (F (2, 29) = 13.312, p

< .001). A Tukey post-hoc test revealed that the mean ballot completion time on both ballots was significantly higher for the non-sighted group than for the sighted group ($p <$ .001). In addition, the mean ballot completion time on the QUICK Ballot was significantly higher in the non-sighted group than in the partially-sighted group ($p =$ .005).

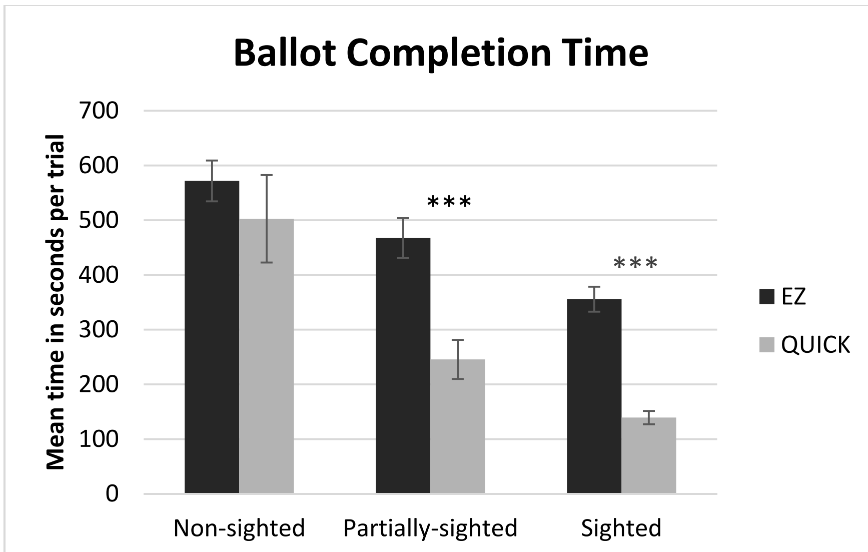


Figure 47. Mean Ballot Completion Time (in Seconds) Per Trial for Each Ballot and Group. Error bars represent the standard errors of the mean. * Significance level $p < .001$**

Satisfaction

Quantitative Results

Quantitative results include perceived usability (H 2.3) using SUS ratings and usability ratings for voting-specific tasks, perceived workload (H2.4) using NATS-TLX, and preferences (H2.5). Table 24 shows the mean differences for satisfaction.

Table 24. Mean Differences (with the Standard Deviations) for Satisfaction

Measures	Ballot	Non-sighted (n=11)	Partially-sighted (n=10)	Sighted (n=11)	All	*P* value
Mean (S.D) SUS	EZ	77.05 (20.82)	69.50 (32.25)	73.64 (15.63)	73.52 (23.03)	.767
	QUICK	62.27 (28.84)	73.25 (28.55)	74.32 (18.78)	69.84 (25.49)	.490
	***P* value**	.219	.837	.935	.614	
Mean (S.D) Usability Rating	EZ	4.51 (.60)	4.14 (1.14)	4.27 (.55)	4.31 (.79)	.264
	QUICK	3.80 (1.06)	4.34 (.60)	4.16 (.31)	4.09 (.74)	.236
	***P* value**	.079	.697	.487	.306	
Mean (S.D) NASA TLX	EZ	25.33 (25.82)	19.93 (20.43)	19.03 (12.15)	21.48 (19.80)	.737
	QUICK	33.30 (23.92)	16.90 (17.14)	16.54 (9.59)	22.42 (19.07)	.060
	***P* value**	.517	.752	.183	.851	

* Significant level $p < .05$
** Significant level $p < .01$
*** Significant level $p < .001$

H2.3 Perceived Usability

The mean SUS ratings on both ballots was above the average score which is 68 (Sauro, 2011) with the exception of the non-signed group using the QUICK Ballot. Paired samples t-tests revealed no significant difference in the mean SUS score on the EZ Ballot (M = 73.52, SD = 23.03) than on the QUICK Ballot (M = 69.84, SD = 25.49; t (31) = .509, p > .001 (see Table 24). Figure 48 presents the mean of the SUS rating for each ballot design by three groups. While the non-sighted group rated the EZ Ballot (M = 77.05, SD = 20.82) slightly higher than the QUICK Ballot (M = 62.27, SD = 28.84), the partially-sighted and sighted group rated similar scores on both ballots. Paired samples t-test showed no significant mean SUS rating difference between the ballot designs by group, indicating no significantly different perceived usability resulting from the two ballot designs across the group in this study.

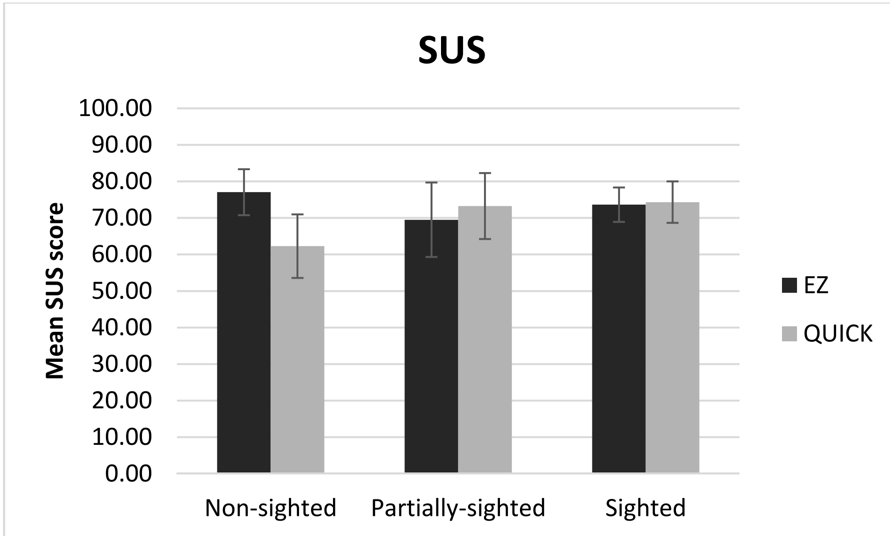


Figure 48. Mean SUS Ratings for Each Ballot and Group. Higher is better. Error bars represent the standard errors of the mean.

Table 25 shows the usability ratings on both ballots for voting-specific tasks. The mean total usability ratings on both ballots was over 4. However, the mean rating that participants reports of "easy to change my selections" was significantly higher in responses to the EZ Ballot (M = 4.19, SD = 1.09) than to the QUICK Ballot (M = 3.34, SD = 1.36); t (31) = 2.444, p = .020. In addition, the mean ratings of voting-specific tasks on both ballots was varied across the group. For the non-sighted group, the mean rating of "easy to understand how to use the ballot" was significantly higher in responses to the EZ Ballot (M = 4.82, SD = .41) than to the QUICK Ballot (M = 3.73, SD = 1.35); t (10) = 2.390, p = .038; the mean rating of "easy to make a selection" was significantly higher in responses to the EZ Ballot (M = 4.73, SD = .47) than to the QUICK Ballot (M = 3.64, SD = 1.36) ; t (10) = 2.390, p = .038. For the sighted group, the mean rating of "easy to change my selections" was significantly higher in responses to the EZ Ballot (M = 4.27, SD = .65) than to the QUICK Ballot (M = 3.27, SD = 1.10); t (10) = 2.472, p = .033.

Table 25. Usability Ratings for Voting-specific Tasks (with the Standard Deviations) (1-5). Higher is Better. Starred items were rated significantly higher for EZ ballot.

Measures	Ballot	Non-sighted (n=11)	Partially-sighted (n=10)	Sighted (n=11)	All
Easy to understand how to use the ballot	EZ	4.82 (.41)	4.10 (1.37)	4.18 (.60)	4.38 (.91)
	QUICK	3.73 (1.35)	4.70 (.48)	4.00 (.63)	4.13 (.98)
	***P* value**	***.038**	.239	.441	.333
Easy to make selections	EZ	4.73 (.47)	4.10 (1.37)	4.45 (.69)	4.44 (.91)
	QUICK	3.64 (1.36)	4.40 (.84)	4.45 (.52)	4.16 (1.02)
	***P* value**	***.038**	.638	1.000	.313
Easy to move from one page to another	EZ	4.09 (.94)	4.30 (1.06)	4.55 (.52)	4.31 (.86)
	QUICK	4.27 (1.42)	4.90 (.32)	4.55 (.93)	4.56 (1.01)
	***P* value**	.733	.140	1.000	.274
Easy to review my selections	EZ	4.64 (.51)	4.20 (1.03)	3.91 (1.30)	4.25 (1.02)
	QUICK	4.09 (1.22)	4.20 (.92)	4.55 (.52)	4.28 (.92)
	***P* value**	.082	1.000	1.90	.897
Easy to change my selections	EZ	4.27 (1.19)	4.00 (1.41)	4.27 (.674)	4.19 (1.09)
	QUICK	3.27 (1.56)	3.50 (1.51)	3.27 (1.10)	3.34 (1.36)
	***P* value**	.102	.569	***0.33**	***.020**

* Significance level $p < .05$

H2.4 Perceived Workload

Overall, paired samples t-tests found no significant mean NASA TLX score difference between the ballot designs (see Table 24). Figure 49 presents the mean of the overall perceived workload scores for each ballot design by three groups. While the non-sighted group rated the EZ Ballot (M = 25.33, SD = 25.83) lower than the QUICK Ballot (M = 33.30, SD = 23.92), the partially-sighted and sighted group rated the QUICK Ballot slightly lower than the EZ Ballot. However, paired samples t-tests found no significant mean NASA TLX score difference between the ballot designs, indicating no significantly different perceived workload resulting from the two ballot designs by group in this study.

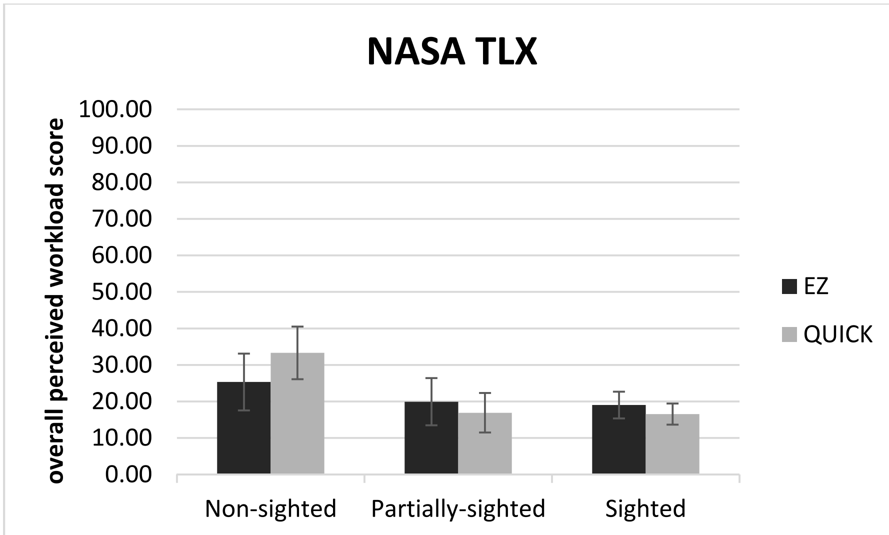


Figure 49. Mean NASA TLX Ratings for Each Ballot and Group. Lower is better. Error bars represent the standard errors of the mean.

H2.5 Preferences

As shown in Figure 50, the preference of a ballot design numerically differed by group even though a chi-square test of independence showed no significant relationship between the ballot design and the group, $\chi 2$ (2, N = 32) = 2.98, p >.05.

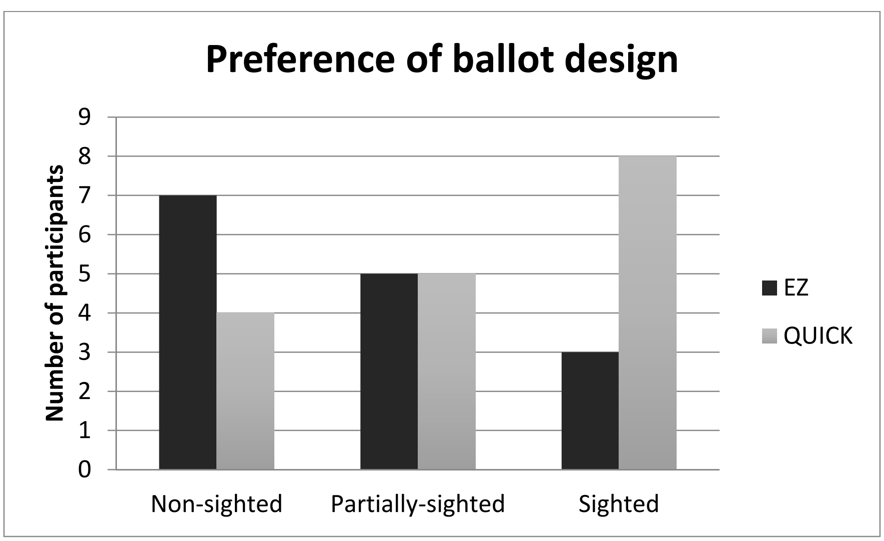


Figure 50. Preferences of Ballot Design by Group.

A higher percentage of non-sighted participants (64.3%, n=7) preferred the EZ Ballot to the QUICK Ballot (36.4%, n=4). The reasons why they preferred the EZ Ballot to the QUICK Ballot included the following: viewing the whole screen at one (n =1) was easier, press the Yes and No buttons was easier, it was easier in general, navigating was faster, navigating with Yes and No made sense, the touch area was larger, and communication was better (e.g., "Do you want to vote for…?"). The reasons why they preferred the QUICK Ballot to the EZ Ballot included the following: It was a lot faster, it was more comfortable, it was more efficient and faster, the direct touch of the screen was more convenient, and it allowed more freedom to select and make changes. Two non-sighted participants expressed positive feedback on both ballots. One participant (NS01) wished that features from both ballots could be combined: Yes and No buttons in the landscape orientation with the next and back buttons on the bottom. Another participant (NS2) mentioned that he would choose the EZ Ballot when voting for the first time, but he would choose the QUICK Ballot after voting three or more times.

Partially-sighted participants equally preferred the EZ Ballot (50%, n=5) and the QUICK Ballot (50%, n=5). The reasons why they preferred the EZ Ballot to the QUICK Ballot included the following: comfortable center focus, prompt message, and easier use. Three participants commented that they liked the center focus that showed one name at a time on each screen so that they did not have to move their eyes very much. Another three participants mentioned that they liked Yes and No selection because it was simpler and it did not require much thinking. The reasons why they preferred the QUICK Ballot to the EZ Ballot included the following: It has less information, it was straightforward, and it was easier to navigate. One participant commented, "It's easier for me to navigate. It takes more mental demand to vote with Yes and No."

A higher percentage of sighted participants (72.7%, n=8) preferred the QUICK Ballot to the EZ Ballot (27.3%, n=3). The reasons included the following: It was easy and quick, it included all the candidates on one screen, it was easier to change votes, it was more user-friendly, it had vertical orientation, it was more appealing, and it had fewer steps and fewer confirmations. The reasons why three participants preferred the EZ Ballot to the QUICK Ballot included the following: It showed the one name at a time, which was clearer, it had a landscape orientation that was easier to view, it was easier to navigate, and it was more accurate.

Qualitative Results

Follow-up questions elicited feedback regarding satisfaction, problems, and suggestions on both ballots. The responses included both similarities and differences among non-sighted, partially-sighted, and sighted groups. Tables 26, 27, and 28 show all of the responses, which are organized from higher to low in number of participant responses.

Satisfaction

Participants were asked to describe what they liked about each ballot system. Table 26 shows the satisfaction of the EZ Ballot and the QUICK Ballot. Non-sighted and partially-sighted participants praised the voice quality and detailed audio descriptions for both EZ and QUICK Ballots. They commented that the voice quality and audio feedback is much better than the existing voting systems. They also complimented on the ease of use of both ballots but for different reasons. In addition, non-sighted participants liked tactile indicator on the frame, ability to change visual/audio settings on both ballots.

For the use of the EZ Ballot, participants liked the ease of navigation through the step-by-step process (n=10) and the prompt messages (n=6) that helped to make sure their selections were what was intended. Regarding the easy of navigation, non-sighted (n =4) and partially-sighted (n=4) participants commented as follows: “I was able to do it independently. I was surprised that it (EZ Ballot) was so easy”, “It took me step-by-step. Everything was Yes and No. I would love to have this machine in my area”, and “it did not require flipping page by page. It did everything for you.” Regarding the helpful prompt message, non-sighted (n = 3) and sighted (n = 3) participants commented as follows: “It allowed me to make sure of my selections”, “not easy to make mistakes”, and “accuracy is the most important.” Participants also liked the large size of the Yes and No buttons (n=6) that allow easy access, are in the landscape orientation (n=5).

For the use of the QUICK Ballot, partially-sighted and sighted participants liked the simple and self-explanatory use (n=8). Three non-sighted and three partially-sighted participants also liked the direct touch selection: “Audio makes the touch screen accessible”, “This system is much easier than the current one in the polling place.” In addition, participants liked familiarity of ballot format that shows all the choices at once (n=2), conventional Next and Back buttons that allowed them to easily navigate the pages (n=2), quicker to make changes as compared to the EZ Ballot (n=2), and clarity of visual look (n=2), and non-speech sound (n=1). One non-sighted participant commented that this ballot accommodates for both blind and low-vision users.

Table 26. Satisfaction of both Ballots

(n = # participants)		All	Non-sighted (n=11)	Partially-sighted (n=10)	Sighted (n=11)
EZ Ballot	Voice quality and detailed audio description	10	4	6	
	Ease of navigation through the step-by-step process	10	4	4	2
	Helpful prompt "Are you sure" message	6	3		3
	Large size of Yes and No buttons	6	2	2	2
	Landscape orientation	5	2	2	1
	Tactile indicator on the frame	2	2		
	Ability to change visual/audio settings	1		1	
QUICK Ballot	Voice quality and detailed audio description	9	6	3	
	simple and self-explanatory use	8		3	5
	Direct touch selection	6	3	3	
	Familiarity of ballot look	2			2
	Ease access with Next and Back buttons	2	2		
	Quicker to make changes	2	2		
	Ability to change visual/audio settings	2	1	1	
	Clarity of visual look	2			2
	Tactile indicator on the frame	1	1		
	Non-speech sound	1		1	
	Accommodation for both blind and low-vision users	1	1		

Problems

Participants were asked to describe any problems they had while using the voting system. Table 27 shows the problems participants had while using both ballots. The most frequent problem about which participants commented was confusion with the vote changing process on both ballots but for different reasons. They also made comments regarding too many steps in the EZ Ballot and how in the QUICK Ballot required searching for the name particularly on the long ballot. Sighted participants commented that audio was distracting for them when using both ballots.

For the use of the EZ Ballot, participants (n=13) were particularly confused about the actions associated with the Yes and No selections which required one to pay more attention to the written instructions about Yes and No for direction: "was not sure what to choose Yes or No for changing the vote", "Didn't like saying No to go back", "the meaning for the Yes and No was not consistent." Several partially-sighted (n = 3) and sighted (n = 3) participants felt tired of having to go through so many steps: "Reassurance made it worse for me", "required too many steps to cast votes", "don't like the prompt question- 'are you sure..?' ". Two non-sighted participants commented that they had problems memorizing all of the button functions and locations: "The first time, I wasn't totally sure where I was supposed to touch because I didn't listen to the instructions carefully." Two non-sighted participants had problems with using swipe gestures, because they were expected the directions of swipe gestures same as the iOS VoiceOver.

Table 27. Problems of both Ballots

(n = # participants)		All	Non-sighted (n=11)	Partially-sighted (n=10)	Sighted (n=11)
EZ Ballot	Confusing review and vote-changing process	13	4	4	5
	Lots of redundancy	6		3	3
	Memorizing the different button symbols locations	2	2		
	Problem with swiping gesture	2	2		
	Distracting audio	2			2
	Slow selection process	1	1		
	Confused about changing text size	1		1	
QUICK Ballot	Vote-changing process that required deselection step	9	1	4	4
	Confused about displayed candidate names on two pages	4	1		3
	Accidental touches that were not intended	3	3		
	Had to learn how to use it	3	3		
	Confused about audio description "put your finger in the middle of the screen"	2	2		
	Required searching process	1		1	
	Distracting audio	1			1
	Afraid to take the finger off the middle of the screen	1	1		
	Confusion about skipping the referendum	1		1	
	No confirmation message	1			1

For the use of the QUICK Ballot, participants (n=9) commented that they were confused the first time around, because they did not remember that they had to deselect one name before selecting another name. Four participants were also confused about the long contest that has candidate names displayed on two pages. Three non-sighted participants said they needed more time to get used to the touch interactions, and three said they made many accidental touches that were not intended. Other problems included requiring searing process (n=1), confusion about skipping the referendum (n=1), afraid to take the finger off (n=1), and no confirmation message was provided (n=1).

Suggestions for Changes

Participants were asked to describe any ways to improve the system to make it easier to use. Table 28 shows the suggestions for both ballots. Non-sighted participants suggested more detailed audio descriptive feedback for both ballots. When selecting one name in a two vote contest, the audio description should be “You selected 1 of 2 XXX” with the order index first. One non-sighted participant also recommended that the order index of the audio description should be changed to the name (candidate’s name) first and then order index (1 of 5) instead of the order index (1 of 5), name (candidate’s name) so that the voter can skim the names easily. For both ballots, non-sighted participants recommended an additional button to indicate information about the current page so that they can easily access it anytime. For example, when pressing the button, it will play “You are now voting for city council”. Sighted participants also suggested to provide speech input for both ballots.

The most frequent suggestion for the EZ Ballot was to provide a direct touch option particularly when changing votes (n=6). Partially-sighted (n = 2) and sighted (n = 1) participants suggested to eliminate some redundancy by reducing the number of confirmation messages on the EZ Ballot. Two non-sighted participants recommended up and down arrows instead of the swipe gesture for navigating through candidates.

Table 28. Suggestions for Both Ballots

(n = # participants)		All	Non-sighted (n=11)	Partially-sighted (n=10)	Sighted (n=11)
EZ Ballot	Provide direct touch for changing a vote on the review page	6		3	3
	Provide more detailed audio description	4	4		
	Reduce redundancy	3		2	1
	Provide two arrow buttons for navigating candidates instead of the swiping gesture	2	2		
	Provide a button for the current task (e.g., "You are now voting for the city council")	1	1		
	Provide centrally located button (e.g., telephone keypad)	1	1		
	Provide detailed instructions about how to change vote	1		1	
	Knowing that you can swipe	1		1	
	Provide voice input	1			1
	Provide less information in the instructions	1			1
QUICK Ballot	Provide more detailed audio description	2	2		
	Provide a button for the current task (e.g., "You are now voting for the city council")	2	2		
	Provide double tapping instead of lifting for the selection	2	2		
	Provide a guide about where to start candidate names	2	2		
	Provide automatic deselection for changing vote	2	1		1
	Provide scrolling instead of going to the next page	2		1	1
	Provide a button for who I selected so far	1	1		
	Provide one name at a time with the next button for navigation	1		1	
	Provide more confirmation for reviewing and changing votes	1		1	
	Provide slower speed for instructions	1		1	
	Provide speech input	1			1
	Provide instruction about changing a vote on the candidate page	1			1
	More prominently display "More candidate" or "press next to see more"	1			1

Other suggestions included providing a centrally located button (e.g., telephone keypad), voice input, less information in the instructions, and knowing that you can swipe.

For the QUICK Ballot interaction, two non-sighted participants suggested double tapping instead of lifting for the selection because they are more familiar with it. Two (i.e., one partially-sighted and one sighted) participants wanted scrolling for more names instead of going to the next page. Two non-sighted participants wanted a tactile/audio guide about where to start candidate names. Two (i.e., one non-sighted and one sighted) participants recommended vote changing with automatic deselection that when the user selects a different name within the same contest, the previous choice is changed to the new choice automatically. Other suggestions included providing a button for who I selected so far, more confirmation for reviewing and changing votes, slower audio speed for instructions, instruction about changing a vote on the candidate page, and more prominently display “More candidate” or “press next to see more.” One partially-sighted suggested to provide one name at a time with the next button for navigation, which is a combination of both ballots.

Learnability

<u>H3.1 Voting Errors across Trials</u>

As shown in Table 29, a repeated measures ANOVA showed no statistical significant main effect of ballot and trial, but significant interaction effects of ballot by trial, F (2, 28) = 5.277, p = .011, η_{p2} = .274, indicating that the mean number of voting errors differed across trials.

Figure 51 shows the mean number of voting errors on the two ballot designs across the three trials. The dark lines present the EZ Ballot, and the light lines present the QUICK Ballot. The number of voting errors decreased over time on both ballots, but the number of voting errors increased between trials 2 and 3 of the EZ Ballot. Among the three trials on both ballots, no significant differences in the mean number of voting errors across trials between trials 1 and 2 or trials 2 and 3 or trials 3 and 1 were detected ($p >$ .05).

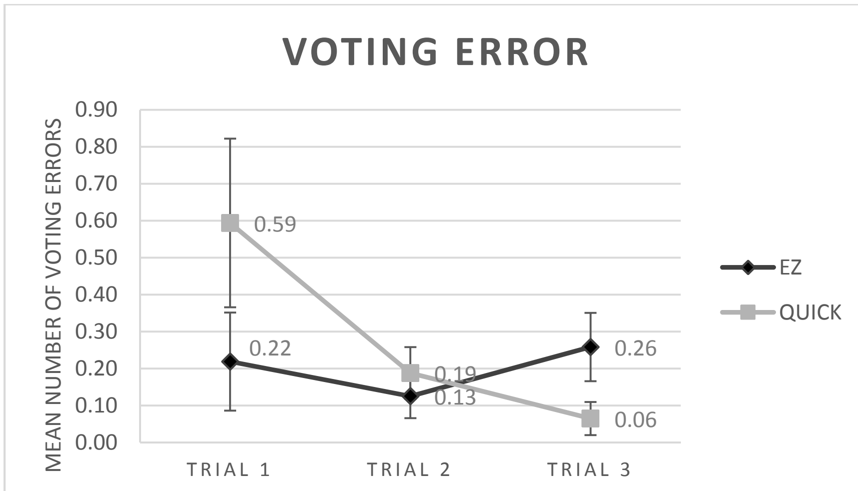


Figure 51. Mean Total Number of Voting Errors Across Trials. Error bars represent the standard errors of the mean.

Table 29. ANOVA Summary of the Main Effects and Interactions on Voting Error, Usability Issues, and Ballot Completion Time across Trials

Variable	Voting error	Usability Issues	Ballot completion time
Ballot	F (1,29) = .236 *p* =.631, ηp2 = .008	F (1,27) = 9.868 *p* =.004**, ηp2 = .268	F (1,28) = 48.792 *p* < .001***, ηp2 =.635
Trial	F (2,28) = 1.046 *p* = .365, ηp2 = .070	F (2,26) = 9.149 *p* =.001**, ηp2 = .413	F (2,27) = 26.834 *p* < .001***, ηp2=.665
Ballot x Trial	F (2,28) = 5.277 *p* = .011*, ηp2 = .274	F (2,26) = 13.164 *p* < .001**, ηp2 = .503	F (2,27) = 5.035 *p* = .014*, ηp2=.272

* Significant level $p < .05$
** Significant level $p < .01$
*** Significant level $p < .001$

H3.1 Usability Issues across Trials

As shown in Table 29, a repeated measures ANOVA showed a statistical significant main effect of ballot, F (1, 27) = 9.868, $p = .004$, $\eta_{p2} = .268$, a statistical significant main effect of trial, F (2, 26) = 9.149, $p = .001$, $\eta_{p2} = .413$, and significant interaction effects of ballot by trial, F (2, 26) = 13.164, $p < .001$, $\eta_{p2} = .503$, indicating that the mean number of usability issues differed across trials.

Figure 52 shows the mean number of usability issues on the two ballot designs across the three trials. The dark gray lines present the EZ Ballot, and the light gray lines present the QUICK Ballot. The number of usability issues decreased over time on both ballots. However, whereas the slope of the QUICK Ballot between the first and second trials was dramatic, that of the EZ Ballot was flat, indicating that participants required only one trial to maximally improve their accuracy on the QUICK Ballot, but on the EZ Ballot they started with much less number of issues starting from the very first trial.

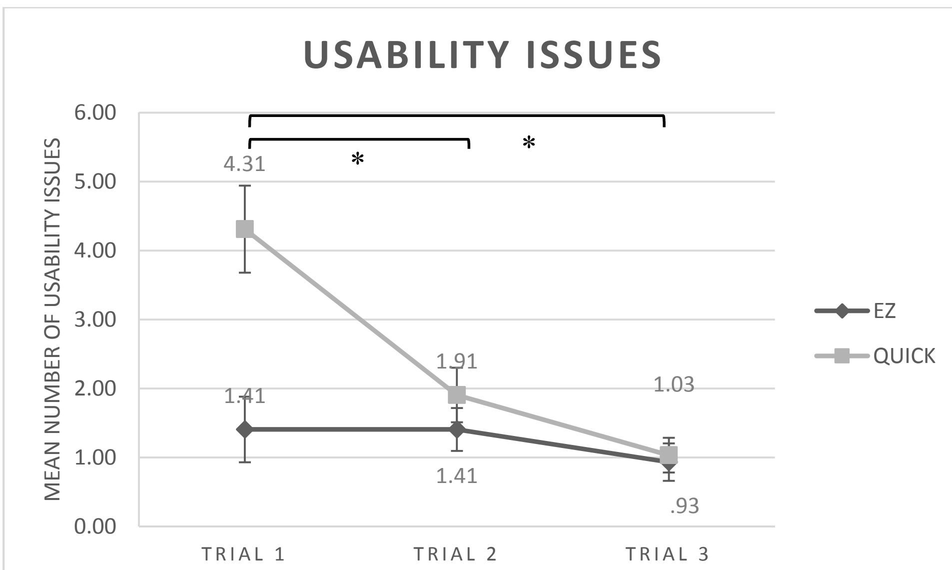


Figure 52. Mean Number of Usability Issues Across Trials.
Error bars represent the standard errors of the mean.

Among the three trials on the EZ Ballot, no significant differences in the mean number of usability issues across trials between trials 1 and 2 or trials 2 and 3 or trials 3 and 1 were detected. In contrast, among the three trials on the QUICK Ballot, the mean number of usability issues of trial 1 (*M* = 4.31, *SD* = 3.57) was significantly higher than that of trial 2 (*M* = 1.91, *SD* = 2.23); *t* (31) = 4.758, $p < .001$; and the mean ballot completion time of trial 1 (*M* = 4.31, *SD* = 3.57) was significantly higher than that of trial 3 (*M* = 1.03, *SD* = 1.38); *t* (29) = 6.114, $p < .001$. The mean number of usability issues did not significantly differ between trials 2 and 3.

<u>H3.2 Ballot Completion Time across Trials</u>

As shown in Table 29, a repeated measures ANOVA showed a statistical significant main effect of ballot, F (1, 28) = 48.792, $p < .001$, η_{p2} = .635, and a significant main effect of trial, F (2, 27) = 126.834, $p < .001$, η_{p2} = .665, indicating that the mean ballot completion time on both the EZ and QUICK Ballots is decreasing over time. Moreover, significant interaction effects of ballot by trial, F (2, 27) = 5.035, $p = .014$, η_{p2} = .272 was found, indicating the mean ballot completion time on both the EZ and QUICK Ballots is decreasing over time but are changing different ways. For the multiple comparisons among the three trials of the number of usability issues, paired samples t-tests were conducted.

Figure 53 shows the ballot completion time on the two ballot designs across three trials. The dark gray lines present the EZ Ballot, and the light gray lines present the QUICK Ballot. The ballot completion time decreased over time on both ballots. However, whereas the slope of the QUICK Ballot between the first and second trials was dramatic, that of the EZ Ballot was fairly flat, indicating that the participants maximally improved their speed with only one trial on the QUICK Ballot but required two trials on the EZ Ballot.

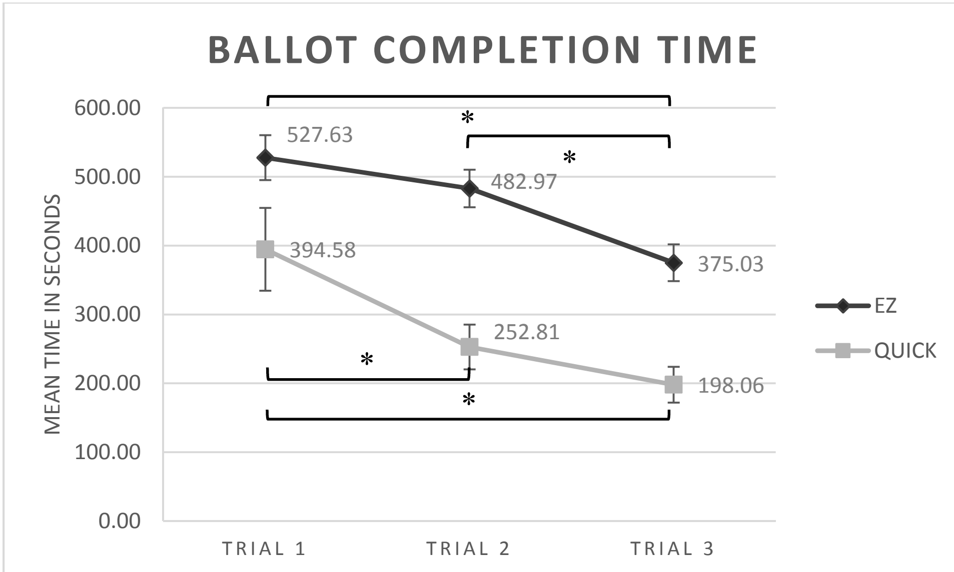


Figure 53. Mean Ballot Completion Time Across Trials.
Error bars represent the standard errors of the mean.

Among the three trials on the EZ Ballot, the mean ballot completion time of trial 2 (M = 482.97, SD = 154.42) was significantly higher than that of trial 3 (M = 375.03, SD = 146.15); t (29) = 4.476, p < .001; and the mean ballot completion time of trial 1 (M = 527.63, SD = 184.35) was significantly higher than that of trial 3 (M = 375.03, SD = 146.15); t (29) = 5.024, p < .001. No significant time difference between trials 1 and 2 was found.

Among the three trials on the QUICK Ballot, the mean ballot completion time of trial 1 (M = 394.58, SD = 334.41) was significantly higher than that of trial 2 (M = 252.81, SD = 183.41); t (30) = 3.657, p = .001; and the mean ballot completion time of trial 1 (M = 394.58, SD = 334.41) was significantly higher than that of trial 3 (M = 198.06, SD = 144.97); t (30) = 4.572, p < .001. No significant time difference between trials 2 and 3 was found.

Discussion

The study examined the effectiveness of two universal design ballots with different ballot structures at facilitating voting performance by participants with a range of visual abilities. From the results of the study, the first impression was that participants with vision loss, including non-sighted and partially-sighted participants, were able to cast their ballots using both UD ballots independently as how sighted voters vote. In the pre-trial interview, nine participants with vision loss shared their previous voting experience of needing personal assistance, because the audio voting was not available. Instead of providing a specialized ballot interface, we developed both ballots with integrated UD features (e.g., built-in speech output), resulting in a remarkable number of ballot completions without any additional assistance. All participants with a range of visual abilities cast a total of six ballots, except for two participants who ran over the study time. The results suggest that both UD ballots could be usable not only for sighted voters, but also for voters with vision loss by providing the same opportunity and access while also including independence. In fact, in the pre-trial interview, 11 of our participants reported that the second most important voting factor was "voting independently." Further, as the usability measures do not indicate that both user groups perform equally well on the two ballots, the study examined the effectiveness of the two UD Ballots in facilitating voting performance by using various metrics of effectiveness, efficiency, satisfaction, and learnability on both ballots.

Effectiveness

Effectiveness was the most important measurement as voters should be able to cast a ballot for a candidate for whom they intend to vote without making mistakes. In the pre-trial interview, about 60% (n=19) of participants also reported that "voting accurately" was the most important voting factor. The study measured the number of voting errors directly related to the outcome of the voting and number of usability issues that included other accidental errors or mistakes. While other prior voting research only measured the voting errors, measuring usability issues was more important, because the data could tell usability issues of design and how we can improve them.

The first notable data is that of the number of completed ballots, which contained no error versus those with at least one voting error. Although about 83 % of ballots with either EZ Ballot or QUICK Ballot did not contain any voting error, 16 % (n=15) of ballots with the EZ Ballot and 17 % (n=16) of ballots with the QUICK Ballot contained at least one voting error. This percentage is about ten percent lower than a previous study (Everett, 2007) that showed over 27% of ballots using the DRE which contained at least one error by voters without any disabilities. Even though the previous study used a much larger number of races (27 races) for their sample ballots than a sample ballot consisting of just 5 races, all of the ballot contests only included up to three candidates versus our ballot contests which additionally included a 6 to10 candidate contest. Although the number of voting errors that result in our study cannot be directly compared to the previous voting research due to the different number of ballots used, our results with both ballots are still nonetheless promising.

The description of types of voting errors (see Table 21) indicates the issues that are related to the design intent or the limitation of the study procedures. On the EZ Ballot, the most frequent types of voting errors occurred within the context of the referendum. The observational data illustrates the design issues of the EZ Ballot as well as the instructional issues during trials. When users were on the pre-referendum page that provided a choice about whether they wanted to vote for the referendum or not "Do you want to vote for Proposed Constitutional Amendment D", the researcher prompted the choice "You are going to disagree with this statement." Then, the users often pressed "No" at that moment, resulting in skipping the referendum unintentionally instead of choosing the disagreement. Thus, the limitation of the two user inputs, Yes and No buttons were confusing, particularly in the context of a referendum that consists of Yes (i.e., agree) and No (i.e., disagree). If the researcher carefully prompted the choice for a referendum page, the results might have been different. For example, the researcher could have prompted separately regarding whether they will vote in this referendum, and a choice of agreement or disagreement. On the QUICK Ballot, the most frequent types of voting errors were regarding undervotes when the voter selected only one instead of two votes. Although the final review page showed the visual and auditory feedback with an undervote message, ten ballots contained this error, indicating that the QUICK Ballot might need to have an undervote prevention message in addition to providing the overvote prevention message.

Interestingly, while the non-sighted group made more voting errors on the QUICK Ballot as they did on the EZ Ballot, the partially-sighted group made more voting errors on the EZ Ballot as they did on the QUICK Ballot. The possible reasons might be centered around the primary sensory channel that the participants used. The non-sighted group who used audio as the primary channel was expected to have been more comfortable with the linear fashion of the EZ Ballot. They had difficulty in using the random access ballot along with the richer touch interaction on the QUICK Ballot that was not familiar to them. In contrast, the partially-sighted group who used both auditory and visual as their primary channels became confused particularly when they were in the context of the referendum regarding the referendum choice as described above.

Although their mean voting error rates were 0.20 on the EZ Ballot and 0.31 on the QUICK Ballot, according to the literature, the cumulative impact of this rate could be striking (Byrne et al., 2007; Everett et al., 2006). The fact that about 16 % of ballots contained at least one error was a clear cause for concern, indicating that both ballots require improvements in their design. The types of usability issues are associated with the underlying causes of the problems participants made using both ballots along with the possible design recommendations. The most frequent types of usability issues were accidental touch on the QUICK Ballot, vote-changing errors on both ballots, and the direct touch errors on the EZ Ballot.

Most participants (87.5%) made accidental touch errors when using the QUICK Ballot just as they did using the EZ Ballot. We expected such results because while the QUICK Ballot provides unfamiliar touch interaction (i.e., drag and lift), the EZ Ballot provides step-by-step with limited touch areas—the Yes and No buttons. Nevertheless, the number of accidental touch errors on the QUICK Ballot was quite remarkable particularly when considering their touch screen experience (i.e., the mean level of touch screen experience was over the ‘intermediate’ level), and even screen reading software experience (i.e., 8 of 11 voiceOver users) on their touch screen devices. For those who had already adapted to screen reading touch interaction (i.e., drag to highlight and then double tap or split tap to select) could have been confused with the unfamiliar touch interaction (i.e., drag and lift) on the QUICK Ballot. Because there was no separate highlight mode, dragging and lifting could have caused accidental touch errors, resulting in unintentional selection. However, the fact that the sighted group who only need simple single touch also made quite a number of accidental touch errors on the QUICK Ballot, indicating problems with the sensitivity of touch itself. Thus, this issue could be mitigated by inducing a button de-bounce feature (e.g., approximately .75 seconds) on the same button, which prevents the system from accepting multiple inputs within a certain period of time (Gilbert et al., 2010; Vanderheiden, 2004).

Many participants (50%-75 %) across all groups made a higher number of errors when changing votes using both ballots. The QUICK Ballot required a deselection step before the voter selected another candidate. The participants, however, did not remember the deselecting step, nor did they notice that they had already exceeded the maximum number of votes they could select. Unlike the QUICK Ballot, the EZ Ballot did not require a deselection step, but instead, it removed all of the previous selections so that voters had to reselect all of the candidates. Some participants did not realize that they needed to reselect the previous candidates, resulting in undervoting. Although participants made more errors using the QUICK Ballot than they did using the EZ Ballot, both ballots need clearer instructions and detailed audio feedback regarding how to change votes. In line with the expert reviews, while some participants preferred to change the vote with automatic deselection, other participants commented that the deselection process made sense to them. Further study could help us determine an optimal solution for the vote-changing process.

Another usability issue that we observed, particularly among partially-sighted and sighted participants, was tapping inactive areas, which occurred mostly when they used the EZ Ballot. Partially-sighted and sighted participants became frustrated that the ballot is limited to touch only yes or no button. They often touched the area that stated the contest with the candidate that they voted for, which appears on the final review page, instead of the No button. For these reasons, the EZ Ballot could be improved if it had a direct touch option in addition to the Yes and No buttons. Not surprisingly, only non-sighted participants made errors involving tapping the wrong button. They actually pressed the physical indicators of the Yes or No button instead of the Yes or No touch button areas. Both types of errors indicate that the instructions should be clearer by stating that the physical indicators are only for indicating the location of the actual active buttons on the touch screen.

The data regarding the number of assists the participants required was also promising. Over 85% of ballots of either EZ or QUICK Ballot did not need any help, providing the privacy. Of the completed ballots, participants requested a total of 14 (14.74 % of the total completed ballots) assists on the EZ Ballot and 10 (10.53 % of the total completed ballots) assists on the QUICK Ballot. The number of assists differed by group, ranging from 3% to 16%, which was fairly low compared to previous research. That research (Herrnson et al., 2008) found that 18 to 24% of participants without any disabilities needed help when using the highly rated DREs (e.g., AccuVote TS). The majority number of types of help was the changing vote process on both ballots, consistent result from the previous research (Herrnson et al., 2008). Again, although the percentages of participants who needed help with the ballot system cannot be directly compared to the previous voting research due to the different sample ballots used, these findings indicate that both of our ballots could be more universal and have real potential to be adopted into use for an election. Interestingly, sighted-participants asked for help regarding the vote changing process in the EZ Ballot, but not in the QUICK Ballot. This result could indicate that the linearly structured limits imposed by the Yes or No choice in the EZ Ballot was not familiar, resulting in a number of "direct touch" errors intended for changing votes. In addition, finding a button location, how to use the touch interaction for non-sighted participants could be improved by clearer instructions. Finding the name on subsequent pages in the QUICK Ballot also should be improved better by using visual and auditory queues that indicate that there are more candidates available on the next page.

From the number of voting errors and usability issues data, we can conclude that voters, particularly non-sighted voters, make more errors using the QUICK Ballot than they do using the EZ Ballot, a finding that partially supports hypothesis 2.1. However, those errors could be eliminated when we refine the sensitivity of the touch screen and other design intent described above.

Efficiency

As expected, the results showed that the mean ballot completion time was significantly higher on the EZ Ballot than on the QUICK Ballot, particularly for the partially-sighted and sighted groups, supporting hypothesis 2.2. One explanation for this finding is that whereas the QUICK Ballot displays multiple names at once, the EZ Ballot displays one name at a time and presents names in a linear fashion, requiring more time to navigate pages. Interestingly, no significant difference between the mean ballot completion time of the two ballots was noted for the non-sighted group. Effectiveness data might explain this finding. The non-sighted group made about twice as many voting and usability issues when using the QUICK Ballot as they did when using the EZ Ballot, and the mean ballot completion time for all groups took longer in general with the QUICK Ballot. The non-sighted group's completion time on the QUICK Ballot may have increased due to the increase in errors, resulting in no difference between either ballot for this group.

Satisfaction

Unlike the performance data, with regard to participants' perception of usability measured by the SUS and workload measured by the NASA TLX, the two ballots exhibited no significant difference. This disassociation between user performance and satisfaction is not an uncommon finding because users typically prefer the design with the highest usability metrics, but not always (Nielsen, 2012). However, usability ratings for voting-specific tasks showed some interesting results. The participants rated that vote changing was significantly easier on the EZ Ballot than the QUICK Ballot. The responses also highlighted the different aspects of each ballot design from the group perspective. As expected, the non-sighted group clearly favored the EZ Ballot over the QUICK Ballot in terms of "easy to understand how to use the ballot" and "easy to make selections." In other words, at least for non-sighted participants, it was easier to make selections during the step-by-step linear process with only two inputs for voting (the EZ Ballot) and it was easier to understand than the random access process, which required gesture interaction with more user control (the QUICK Ballot). Surprisingly, sighted participants rated the EZ Ballot with a higher score regarding the "easy to change my selections" than the QUICK Ballot. They were more dissatisfied with the deselection step for changing votes (the QUICK Ballot) than they were with the reselecting step for changing votes (the EZ Ballot). It should be noted that participants responded to these questionnaires after the first trial of each ballot interface rather than comparing the usability upon having completed both ballots. If they had responded to the same questionnaires as comparing both ballots, the responses might have been different because these responses did not exactly match the number of vote changing errors on both ballots. The results indicate that the perceived usability and workload were not different between ballots, which did not support hypothesis 2.4.

Participants finally stated their favorite of the two ballot designs. As expected, a higher percentage of non-sighted participants preferred the EZ Ballot to the QUICK Ballot, and a higher percentage of sighted participants preferred the QUICK Ballot to the EZ Ballot, supporting hypothesis 2.5. Interestingly, partially-sighted participants equally preferred the EZ Ballot and the QUICK Ballot. However, because of the small sample size, we found no significant relationship between the ballot design and the group.

The reasons why they liked one or the other were related to the ballot structure, a step-by-step linear ballot structure versus a fast random access structure. However, participants also mentioned other features such as the screen orientation, number of confirmations, and communication methods. Particularly, partially-sighted participants who have limited or no peripheral vision preferred the center focus in the landscape orientation of the EZ Ballot so that they do not need to move their eyes much. Controversially, participants liked and disliked the additional confirmations and the amount of information provided on the EZ Ballot. Those who disliked the redundant confirmation messages, preferred the QUICK Ballot due to the fewer steps and confirmations. Not surprisingly, sighted participants who might be more familiar with the typical visual ballot interface, preferred the QUICK because they perceived it to be more appealing and user-friendly.

Learnability

Learnability is a unique measurement in voting research because voters typically do not often have a chance to use the system until they are actually voting. However, this measurement is a very typical measurement in a usability study, particularly for new systems (Jakob, 1993). The results of the learnability on both ballot designs show that the performance in general increased over time.

In terms of accuracy, the mean number of voting errors and usability issues showed different results across trials. In general, the number of errors decreased over time using both ballots, but the number of usability issues significantly decreased over time only on the QUICK Ballot, partially supporting the hypothesis 3.1. This data suggest that users require only one trial to significantly improve their accuracy on the QUICK Ballot. Furthermore, the flat line of the performance changes over time on the EZ Ballot could mean that there is very little room for improvement when we look at the gap between the highest and the lowest number of errors. Thus, the EZ Ballot may not require much learning as compared to the QUICK Ballot.

One unusual result was the increase in the number of voting errors between trials 2 and 3 of the EZ Ballot. There are several possible explanations of this effect. This result could be from the types of voting tasks that they performed in the third trial rather than the problems of the design intent. Participants were asked to choose disagreement with the ballot measure referendum. Inconsistency in participant understanding of this task may have resulted in a decrease in performance. Another explanation may be that participants felt comfortable with EZ Ballot after two trials. On the third trial, instead of following along with each step that EZ Ballot produced, participants may have tried to incorrectly anticipate the next step in the process based on their screen actions.

Ballot completion time across trials showed similar patterns with both ballots, a significant decrease over time, supporting hypothesis 3.2. An interesting finding was that while the QUICK Ballot took one trial to significantly improve speed, the EZ Ballot took two trials to significantly improve speed. The ballot completion time on the EZ Ballot was also consistently slower than that of the QUICK Ballot over time. This may suggest that the linear ballot structure itself has some inherent limitations regarding completion time.

CHAPTER 7

CONCLUSION AND FUTURE WORK

This dissertation involved the design of two ballot interfaces based on universal design (UD) guidelines and the examination of these interfaces by experts and voters with and without vision loss. The iterative design and evaluation activities included investigating the existing DRE voting systems, design and development of universal ballot interfaces based on UD and VVSG guidelines, refining the interfaces by experts and voters with a range of disabilities, and investigating the effectiveness of two UD ballot interfaces that no prior research has examined. These design and research processes provided the impact of UD voting system to e facilitates voting activity and promotes participation of all individuals in the voting process. In addition, this dissertation contributes to a unique multidisciplinary field of research including industrial design, universal design, human-computer interaction, and voting systems. The contribution of this dissertation has successfully led to three important short-term and long-term outcomes: 1) utilizing UD principles to design ballot interfaces that can be differentially usable by voters with a range of abilities; 2) demonstrating feasibility of two UD ballot interfaces by voters with a range of visual abilities; 3) providing impact on people with a range of visual abilities on other applications.

The first outcome is that the study successfully applied UD principles but with different weighting of principles that can be differentially usable by voters with a range of visual abilities. This approach clearly distinguishes this study from previous efforts, which have focused on developing one UD solution for everyone (e.g., one-size-fits-all).

The definition of UD, according to Ron Mace, is “the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design.” However, the study found that the definition of UD does not imply that everyone can perform equally well and that applying the UD principles are not black and white, but rather shades of grey that may require trade-offs in design that favor one principle over another. Using different weighting of various principles, this work designed two different UD ballots around hypotheses about the degree of usability according to user’s visual ability, but while still achieving equitability. The findings support that although the two ballots achieved equitability, they provided different usability and preference results depending upon user ability. This suggests that UD does not dictate a single solution for everyone (e.g., a one-size-fits-all approach), but rather supports flexibility in use that provides a new perspective into human-computer interaction (Stephanidis, 2001).

The second outcome is that the study demonstrated that both ballot interfaces, designed as UD voting systems, could feasibly be used by voters with a range of visual abilities including non-sighted, partially-sighted, and sighted voters. Regardless of visual abilities, all voters with one type of ballot interface by providing the same opportunity and access, were able to cast their ballots independently without any additional assistance. Both ballot interfaces with seemingly integrated UD features (e.g., built-in speech output, audio and visual adjustability features) resulted in a remarkable number of ballot completions. They also provide unique strengths of each design and suggestions for changes. The linearized ballot structure (i.e., EZ Ballot) helped users who had a very limited view resulting from their lack of peripheral vision, and also those who wanted to vote in a step-by-step fashion. The random ballot structure (i.e., QUICK Ballot) helped users who had remained abreast of current technology, those who were able to see all the information clearly on the screen, and those who wanted to quickly choose their selections. More importantly, this dissertation is expected to take an important step in demonstrating the feasibility of a UD voting systems that the voting process for voters with disabilities does not currently have, to eliminate the use of specially equipped voting stations that create segregation and stigmatization. Thus, for achieving the participation of all individuals in all aspects of voting in society, UD principles could be adopted into the existing voting guidelines (e.g., VVSG).

Finally, the long-term contribution includes the impact on people with a range of visual abilities and other applications beyond ballot interfaces. The study shows that the feasibility of touch inputs for visually-impaired users, as other previous research (Guerreiro, Lagoa, Nicolau, Gonalves, & Jorge, 2008; Kane, Bigham, & Wobbrock, 2008; Yatani & Truong, 2009) show the potential benefits of using touch screen input with gestural interaction for visually-impaired users. Thus, these groups should not be excluded from access to this widespread technology for public interfaces such as voting systems and kiosks. As the number of smartphone users with disabilities increases, they become more familiar with the latest technology (e.g., touch interaction for using the voice-over feature on the iPhone). Even though their visual abilities might not change or get worse, their ability with respect to the use of technology can change as they experience more. Thus, designers should not maintain that touch screens are not a feasible solution for visually-impaired users just because they have limited vision.

In addition, although these two UD ballots were designed for voting systems, the linear and random access structure could be applied to other applications (e.g., music play list, booking a flight) that require navigation and selection. Most applications require scanning of information though visual or audio media by navigating pages and making decisions through selection. Linear and random navigation structure and integrated UD features can be applied with the goal of one type of interface for all rather than providing separate solutions for individuals with different abilities. Furthermore, designers and software engineers of mobile app development should open their perspective of the use of UD and apply UD features into everyday design to include more users' needs. When products, environments, or systems are more accessible to users with limitations, they are also easier for users without limitations (Stephanidis et al., 1999; Vanderheiden, 1990b).

Despite all of the contributions of the current dissertation, future research remains to be addressed. Future directions include enhancement of features of both designs along with integration of solutions of both ballots, expansion of flexibilities of input devices and user population, and comparison of the effectiveness of the UD ballots to existing voting systems.

The first step is the enhancement of features of both ballot designs from the results of the summative evaluations. As observed usability issue data identified, the features of the sensitivity of touch input, the vote-changing process, the direct touch option in the EZ ballot, and the long race format and under-voting reminder in the QUICK Ballot should be refined. After refinement, further research could determine how to form the two UD ballots into one voting system to be a more robust, integrated interface that meets the wide range of voters' abilities and needs. Providing two UD ballots can be presented as multi-layer UI that provide users control over the sets of features available (Shneiderman, 2003). For example, first-time and novice voters can start with sets of dialog based interfaces, adopted from the EZ Ballot, that introduce a choice between linear or random ballot structures. If the voter chooses the linear ballot to start, the voter can still later choose to change to the random ballot when the contest pages get longer.

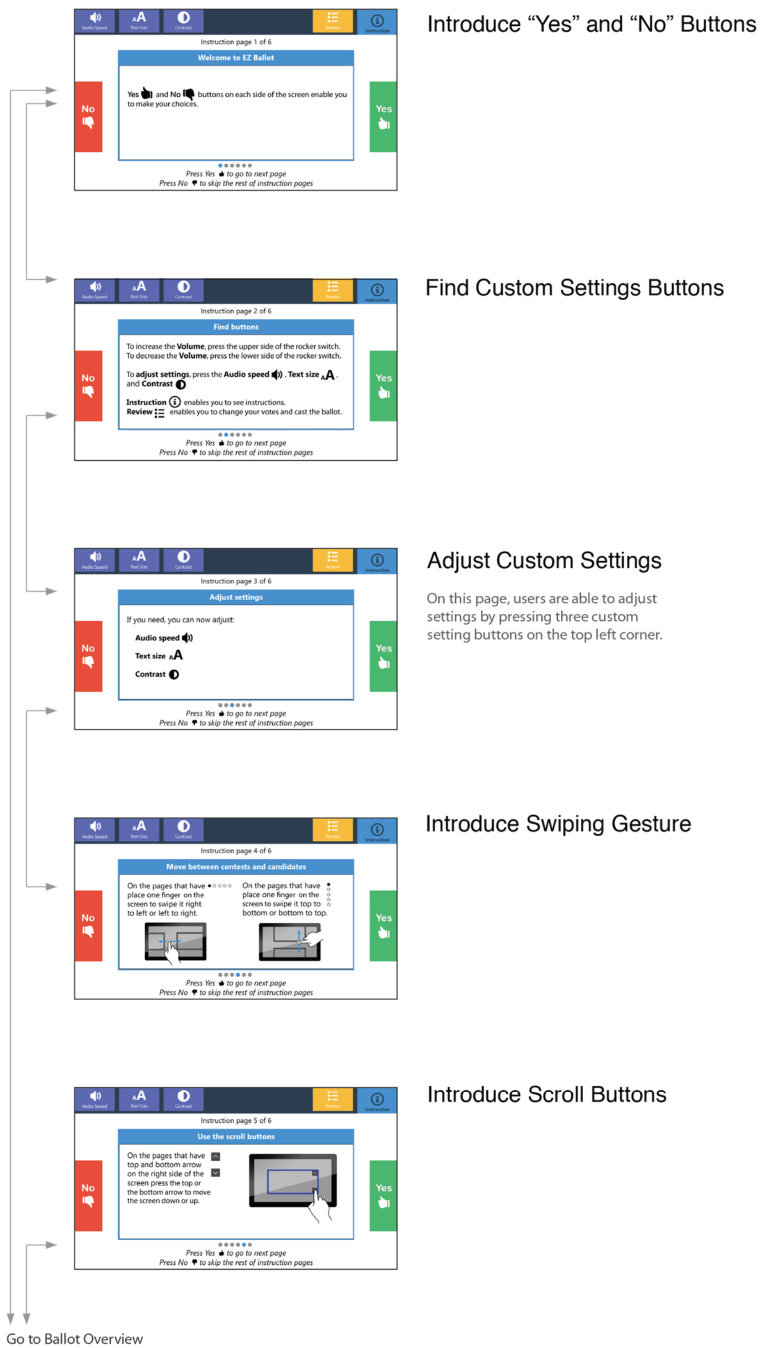
In order to serve the larger population of voters, exploration of alternative input devices, such as physical controls which may also facilitate voting for people who have issues or no experience with the touch screen, could be also be investigated. Alternative input devices include not only physical devices but also advanced inputs such as 3D air gestures that can be used to record head gesture, hand gesture (Saffer, 2008), eye gaze (Królak & Strumiłło, 2012), and speech recognition software that incorporate the latest innovations to better meet the needs of voters. In addition, to achieve the primary goal of UD voting system, the research should embrace larger populations beyond those of the visually impaired, including those with mobility and cognitive limitations.

Finally, the study needs to further examine the effectiveness of the UD voting system as compared to the existing DRE voting systems. To do so, the study needs to develop a write-in interface, which is a challenging task for many end users, and expand more number of contests and referendums to be more like real ballots in an election.

APPENDIX A

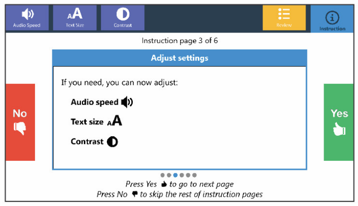
Flow Chart of the EZ Ballot Ver 2.0

Instructions

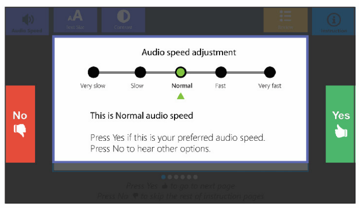


Adjust Settings

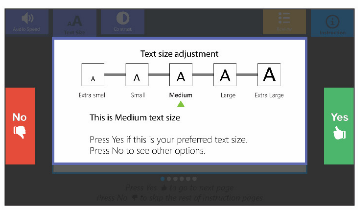
Press custom setting buttons
on any of screens



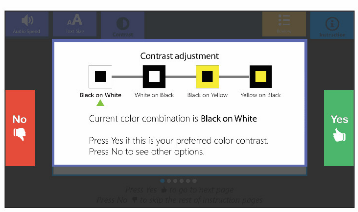
Audio Speed Adjustment



Text Size Adjustment

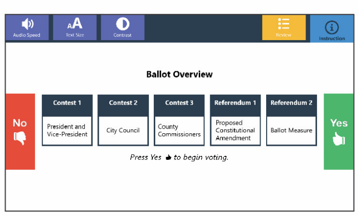


Contrast Adjustment



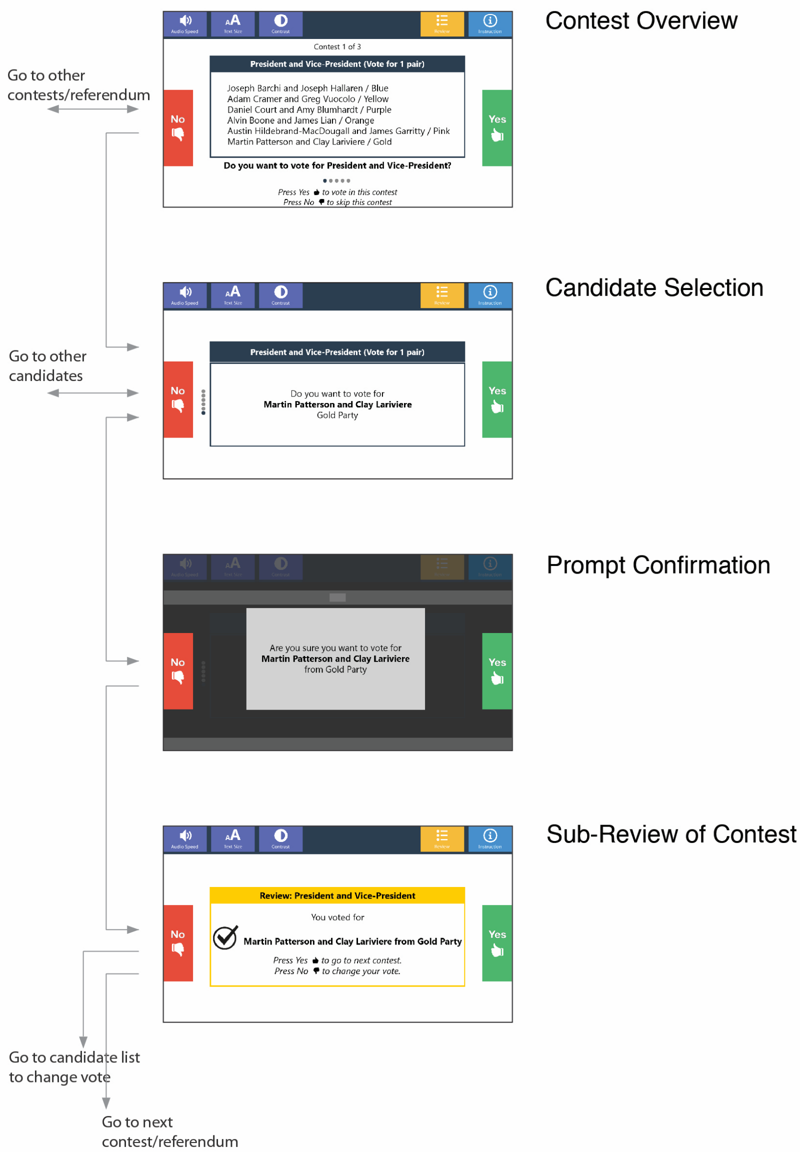
Ballot Overview

Go back to instruction

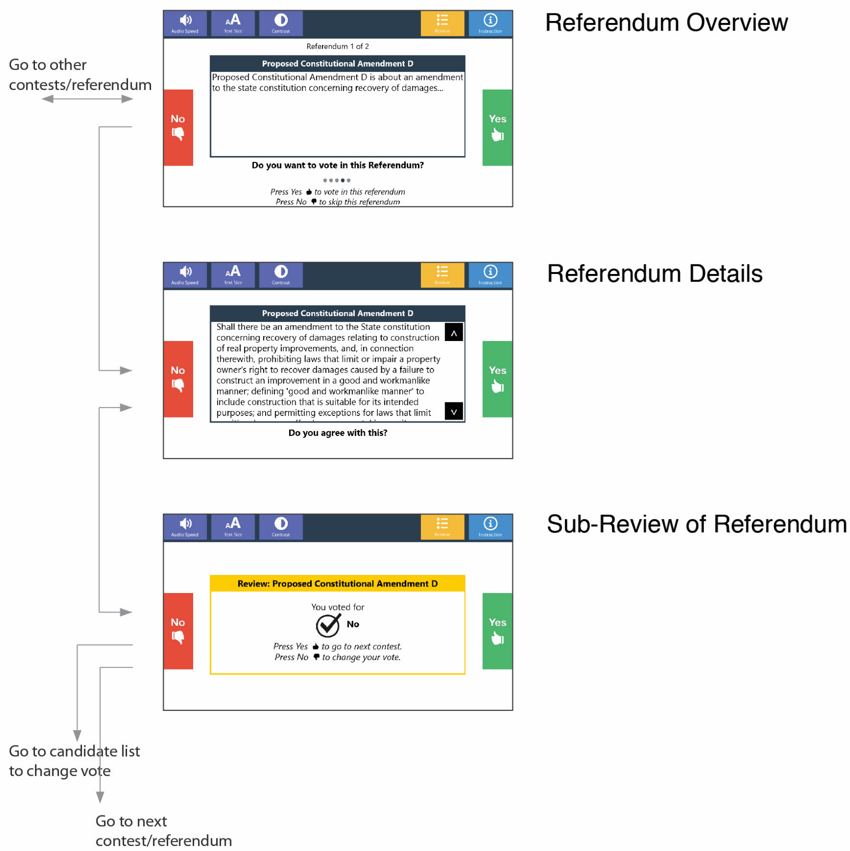


Start voting

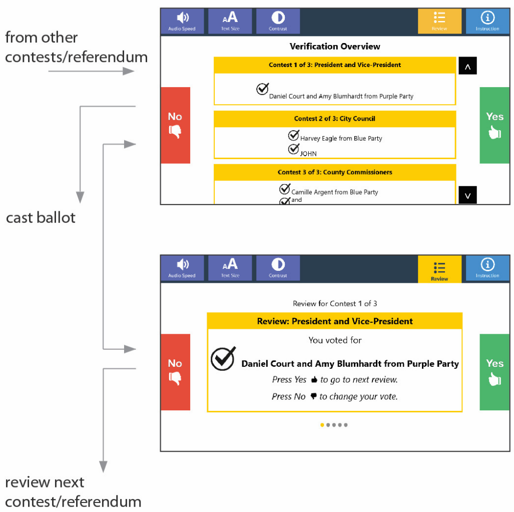
Vote in Contest



Vote in Referendum



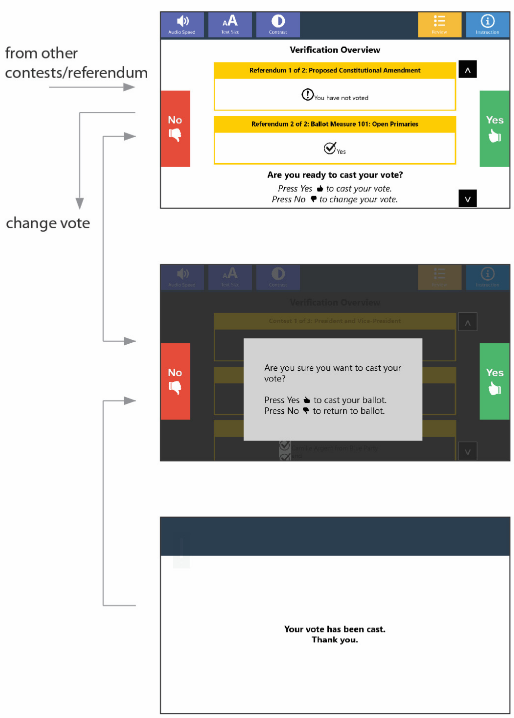
Review Ballot



Verification Overview

Sub-Review of Contest

Cast Ballot



Verification Overview

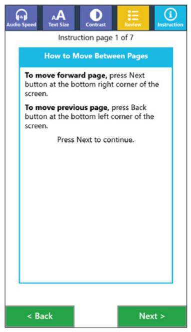
Prompt Confirmation

Cast Successfully

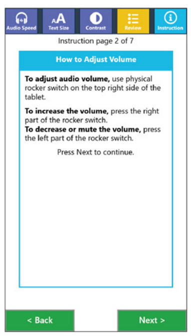
APPENDIX B

Flow Chart of the QUICK Ballot Ver 2.0

Instructions



Introduce “Next” and “Back” Buttons

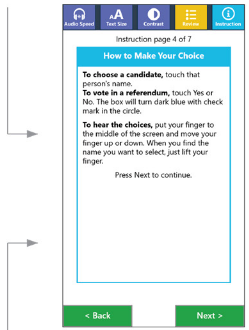


Introduce how to adjust volume

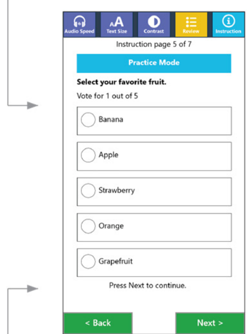
Introduce custom setting buttons

Continue Instructions

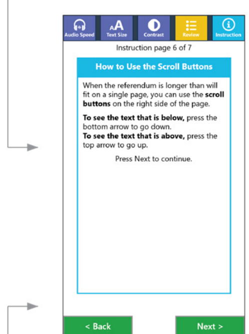
How to Make the Choice



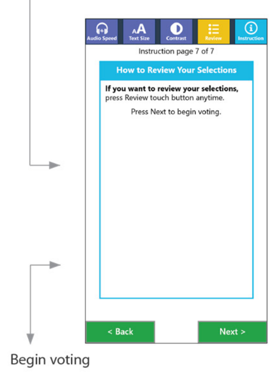
Practice Mode



How to use the scroll buttons

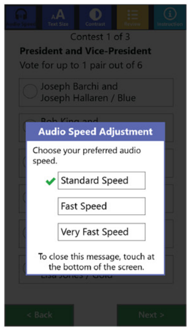


How to review

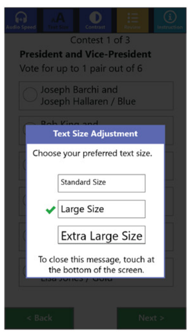


Adjust Settings

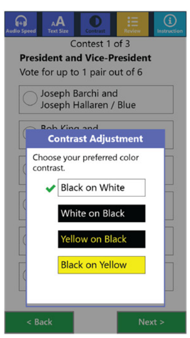
Press custom setting buttons
on any of screens



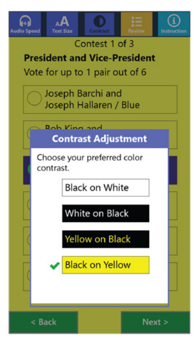
Audio Speed Adjustment

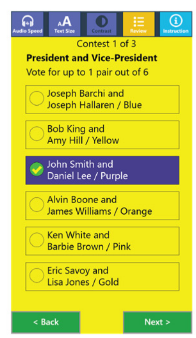


Text Size Adjustment



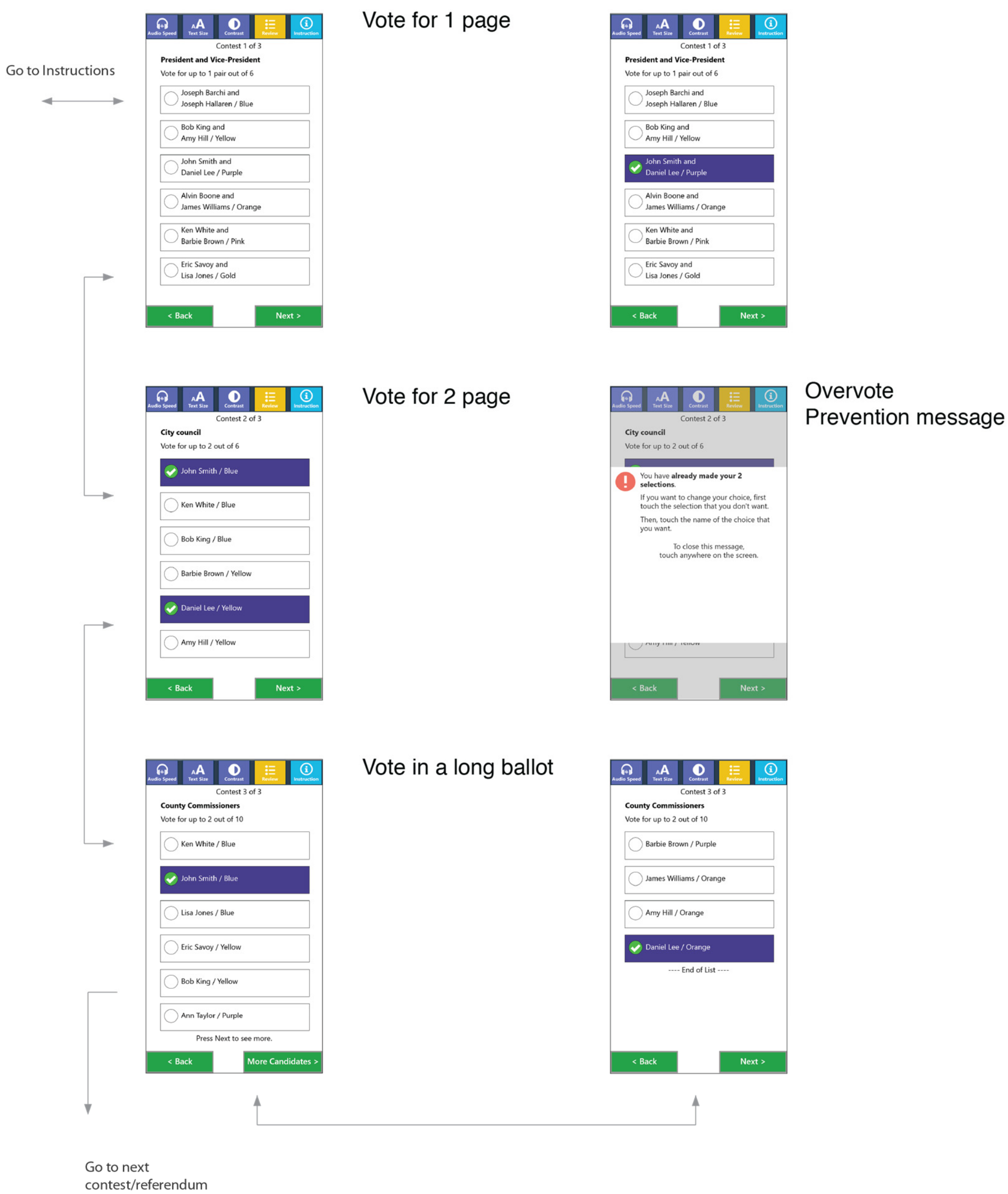
Contrast Adjustment



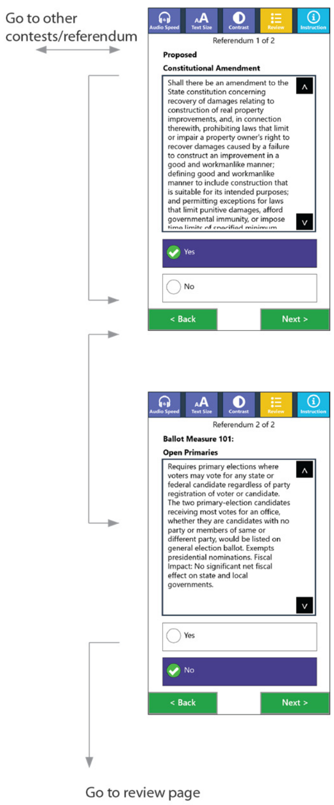


Contrast Adjustment (Black on Yellow)

Vote in Contest



Vote in Referendum

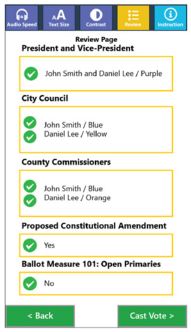


Referendum: Proposed Constitutional Amendment

Referendum: Ballot Measure 101: Open Primaries

Review Ballot

from other contests/referendum

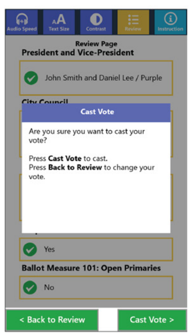


Review page

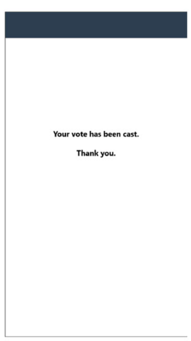
Cast vote

Cast Ballot

go back to review



Prompt Confirmation



Cast Successfully

APPENDIX C

Pre-trial Questionnaire

Section A: DEMOGRAPHIC QUESTIONS	
1. What is your age?	Age:______________
2. What is your gender?	○ Male ○ Female
3. What is the highest level of education you have completed?	○ Some high school ○ High school or G.E.D. ○ Some college or Associate's degree ○ Bachelor's degree or higher ○ Master's degree or higher ○ Other ________________________________
4. Please describe your functional limitations (e.g., legal blindness, dexterity)	
5. Have you voted in an election that used an electronic voting machine? (If no, skip ahead to #9)	Yes/ No
6. Have you used the following assistive technology devices or features to vote? (Please choose all that apply)	❑ Audio voting + keypad ❑ Large size text ❑ High contrast ❑ Sip-n-puff ❑ Paddle device with yes and no ❑ Others (Please specify) ______________________
7. How important are the following factors in voting? Please rank them. (with 1 meaning the most important, with 3 meaning the least important)	____Voting quickly ____Voting accurately ____Voting independently
8. Do you own any touch screen device? Which one?	
9. Please rate your level of touch screen experience.	1 None — 2 Novice — 3 Inter-mediate — 4 Advanced — 5 Expert
10. Have you used any screen reading software (e.g., Apple's VoiceOver) for touch screen devices? If yes, which one(s)?	

APPENDIX D

Post-trial Questionnaire: System Usability Scale

System Usability Scale (SUS)	Strongly Disagree				Strongly Agree
1. I think that I would like to use this system when voting.	1	2	3	4	5
2. I found the system unnecessarily complex.	1	2	3	4	5
3. I thought the system was easy to use.	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system.	1	2	3	4	5
5. I found the various functions in this system were well integrated.	1	2	3	4	5
6. I thought there was too much inconsistency in this system.	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly.	1	2	3	4	5
8. I found the system very cumbersome to use.	1	2	3	4	5
9. I felt very confident using the system.	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system.	1	2	3	4	5

APPENDIX E

Post-trial Questionnaire: Usability Ratings

Usability Ratings	Strongly Disagree				Strongly Agree
1. It was easy to understand how to use the ballot?	1	2	3	4	5
2. It was easy to make selections.	1	2	3	4	5
3. It was easy to move from one page to another.	1	2	3	4	5
4. It was easy to review my selections.	1	2	3	4	5
5. It was easy to change my selections.	1	2	3	4	5

APPENDIX F

Post-trial Questionnaire: NASA TLX

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

REFERENCES

Bederson, B., Lee, B., Sherman, R. M., Herrnson, P. S., & Niemi, R. G. (2003). *Electronic voting system usability issues*. Paper presented at the Proceedings of the SIGCHI conference on Human factors in computing systems, Ft. Lauderdale, Florida, USA.

Bederson, B. B. (2001). *PhotoMesa: a zoomable image browser using quantum treemaps and bubblemaps*. Paper presented at the Proceedings of the 14th annual ACM symposium on User interface software and technology, Orlando, Florida.

Björk, E. (2009). Many become losers when the Universal Design perspective is neglected: Exploring the true cost of ignoring Universal Design principles. *Technology & Disability, 21*(4), 117-125. doi: 10.3233/tad-2009-0286

Bühler, C. (2001). Empowered participation of users with disabilities in universal design. *Universal Access in the Information Society, 1*(2), 85-90. doi: 10.1007/s102090100011

Burton, & Uslan. (2002). Cast a Vote by Yourself: A Review of Accessible Voting Machines. *Access World, 3*(6).

Burton, & Uslan. (2004). The Ballot Ballet: The Usability of Accessible Voting Machines. *AFB AccessWorld, 5*.

Byrne, M. D., Greene, K. K., & Everett, S. P. (2007). *Usability of voting systems: baseline data for paper, punch cards, and lever machines*. Paper presented at the Proceedings of the SIGCHI conference on Human factors in computing systems, San Jose, California, USA.

Campbell, B. A. (2013). *The Usability Implications of Long Ballot Content for Paper, Electronic, and Mobile Voting Systems.* (Doctor of Philosophy), Rice University, Houston, Texas.

Campbell, B. A., Tossell, C. C., Byrne, M. D., & Kortum, P. (2011). Voting on a Smartphone: Evaluating the Usability of an Optimized Voting System for Handheld Mobile Devices. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 55*(1), 1100-1104. doi: 10.1177/1071181311551230

CDC. (2014). Summary Health Statistics for U.S.Adults: National Health Interview Survey, 2012 *Vital and Heath Statistics*.

Chaudry, B. M., Connelly, K. H., Siek, K. A., & Welch, J. L. (2012). *Mobile interface design for low-literacy populations*. Paper presented at the Proceedings of the 2nd ACM SIGHIT International Health Informatics Symposium, Miami, Florida, USA.

Chen, K. B., Savage, A. B., Chourasia, A. O., Wiegmann, D. A., & Sesto, M. E. (2013). Touch screen performance by individuals with and without motor control disabilities. *Applied Ergonomics, 44*(2), 297-302. doi: http://dx.doi.org/10.1016/j.apergo.2012.08.004

Chisnell, D., Davies, D., & Summers, K. (2013). Any device, anywhere, any time: A responsive, accessible ballot design. The Information Technology and Innovation Foundation.

Clarkson, J. (2009). Designing a more inclusive design. In T. Vavik (Ed.), *Inclusive buildings, products & services: challenges in universal design*

Cohan, H., & McBride. (2008). Blind Voters Experience Assessment Syudy Research Summary National Federation of the Blind.

Cohen, S. B. (2005). *Auditing technology for electronic voting machines.* Massachusetts Institute of Technology, Massachusetts Institute of Technology.

Connell, B. R., Jones, M., Mace, R., Mueller, J., Mullick, A., Ostroff, E., . . . Vanderheiden, G. (1997). *The Principles of Universal Design*. NC State University, The Center for Universal Design. Retrieved from http://www.ncsu.edu/project/design-projects/udi/center-for-universal-design/the-principles-of-universal-design/

Connell, B. R., & Sanford, J. A. (1999). Research Implications of Universal Design. In E. Steinfeld & G. S. Danford (Eds.), *Enabling Environments: Measuring the Impact of Environment on Disability and Rehabiliation*. New York: Kluwer Academic/ Plenum Publishers.

Cook, D., & Harniss, M. (2012). Accessible Voting Technology : Analysis and Recommendations. The Information Technology and Innovation Foundation: University of Washington.

Emiliani, P. L., & Stephanidis, C. (2005). Universal access to ambient intelligence environments: Opportunities and challenges for people with disabilities. *IBM Systems Journal, 44*(3), 605-619. doi: 10.1147/sj.443.0605

Everett, S. P. (2007). *The Usability of Electronic Voting Machines and How Votes Can Be Changed Without Detection.* RICE UNIVERSITY.

Everett, S. P., Byrne, M. D., & Greene, K. K. (2006). Measuring the Usability of Paper Ballots: Efficiency, Effectiveness, and Satisfaction. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 50*(24), 2547-2551. doi: 10.1177/154193120605002407

. Experience of Voters with Disabilities in the 2012 Election Cycle. (2013). National Council on Disability.

Gilbert, J. (2005). PRIME III: One Machin, One Vote for Everyone. from http://www.juangilbert.com/

Gilbert, J., McMillian, Y., Rouse, K., Williams, P., Rogers, G., McClendon, J., . . . Cross, E. (2010). Universal access in e-voting for the blind. *Universal Access in the Information Society, 9*(4), 357-365. doi: 10.1007/s10209-009-0181-0

Golden, D. C. (2013). Accessible Voting Systems: Can Demonstrations Improve User? Assistive Technology Act Programs.

Guerreiro, T., Lagoa, P., Nicolau, H., Gonalves, D., & Jorge, J. A. (2008). From Tapping to Touching: Making Touch Screens Accessible to Blind Users. *Multimedia, IEEE, 15*(4), 48-50.

Harley, L., Kline, K., Ray, J., Bell, C., Baranak, A., Price, C., . . . Fain, B. (2013). The Evaluation of a Voting Web Based Application. In M. Kurosu (Ed.), *Human-Computer Interaction. Users and Contexts of Use* (Vol. 8006, pp. 285-294): Springer Berlin Heidelberg.

Hart, S. G. (2006). Nasa-Task Load Index (NASA-TLX); 20 Years Later. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 50*(9), 904-908. doi: 10.1177/154193120605000909

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In A. H. Peter & M. Najmedin (Eds.), *Advances in Psychology* (Vol. Volume 52, pp. 139-183): North-Holland.

Herrnson, P. S., Bederson, B. B., Niemi, R. G., Conrad, F. G., Hanmer, M., & Traugott, M. (2007). The Not So Simple Act of Voting: An Examination of Voter Errors With Electronic Voting.

Herrnson, P. S., Niemi, R. G., Hanmer, M. J., Francia, P. L., Bederson, B. B., Conrad, F. G., & Traugott, M. W. (2008). Voters' Evaluations of Electronic Voting Systems: Results From a Usability Field Study. *American Politics Research, 36*(4), 580-611. doi: 10.1177/1532673x08316667

Huyck, C. (2011). Dialogue based interfaces for universal access. *Universal Access in the Information Society, 10*(3), 267-274. doi: 10.1007/s10209-010-0209-5

Indrani, M., Somani, P., Emma, B., Gautama, S. N. N., William, T., & Kentaro, T. (2011). Designing mobile interfaces for novice and low-literacy users. *ACM Trans. Comput.-Hum. Interact., 18*(1), 1-28. doi: 10.1145/1959022.1959024

Iwarsson, S., & Stahl, A. (2003). Accessibility, usability and universal design--positioning and definition of concepts describing person-environment relationships. *Disability & Rehabilitation, 25*(2), 57.

Jakob, N. (1993). *Usability Engineering*: Morgan Kaufmann Publishers Inc.

Jastrzembski, T. S., & Charness, N. (2007). What Older Adults Can Teach Us About Designing Better Ballots. *Ergonomics in Design: The Quarterly of Human Factors Applications, 15*(4), 6-11. doi: 10.1518/106480407x255198

Jin, Z., Plocher, T., & Kiff, L. (2007a). Touch Screen User Interfaces for Older Adults: Button Size and Spacing. In C. Stephanidis (Ed.), *Universal Acess in Human Computer Interaction. Coping with Diversity* (Vol. 4554, pp. 933-941): Springer Berlin Heidelberg.

Jin, Z. X., Plocher, T., & Kiff, L. (2007b). Touch Screen User Interfaces for Older Adults: Button Size and Spacing. In C. Stephanidis (Ed.), *Universal Acess in Human Computer Interaction. Coping with Diversity* (Vol. 4554, pp. 933-941): Springer Berlin / Heidelberg.

Joines, S. (2009). Enhancing quality of life through Universal Design. *NeuroRehabilitation, 25*(3), 155-167. doi: 10.3233/nre-2009-0513

Jong, d. M., Hoof, v. J., & Gosselt, J. (2008). Voters' Perceptions of Voting Technology. *Social Science Computer Review, 26*, 399-410.

Jong, M., Hoof, J., & Gosselt, J. (2007). User research of a voting machine: Preliminary findings and experiences. *Journal of Usability Studies, 2*(4), 180-189.

Kane, S. K., Bigham, J. P., & Wobbrock, J. O. (2008). Slide rule: making mobile touch screens accessible to blind people using multi-touch interaction techniques. *Proceedings of the 10th international ACM SIGACCESS conference on Computers and accessibility*, 73-80.

Kimball, D. C., & Kropf, M. (2005). Ballot Design and Unrecorded Votes on Paper-Based Ballots. *Public Opinion Quarterly, 69*(4), 508-529. doi: 10.1093/poq/nfi054

Królak, A., & Strumiłło, P. (2012). Eye-blink detection system for human–computer interaction. *Universal Access in the Information Society, 11*(4), 409-419. doi: 10.1007/s10209-011-0256-6

Laskowski, S. J., Autry, M., Cugini, J., Killam, W., & Yen, J. (2004). Improving the Usability and Accessibility of Voting Systems and Products.

Lee, S., Liu, Y., Xiong, X., & Sanford, J. (2012). Winning Idea: EZ Ballot. from https://openideo.com/challenge/voting/winning-concepts/ez-ballot

Lee, S., Xiong, X., Yilin, L., & Sanford, J. (2012). *EZ ballot with multimodal inputs and outputs*. Paper presented at the Proceedings of the 14th international ACM SIGACCESS conference on Computers and accessibility, Boulder, Colorado, USA.

Lee, S., & Zhai, S. (2009). *The performance of touch screen soft buttons*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Boston, MA, USA.

Leporini, B., Buzzi, M. C., & Buzzi, M. (2012a, 2012 / 01 / 01 /). *Interacting with mobile devices via VoiceOver: Usability and accessibility issues*.

Leporini, B., Buzzi, M. C., & Buzzi, M. (2012b). *Interacting with mobile devices via VoiceOver: usability and accessibility issues*. Paper presented at the Proceedings of the 24th Australian Computer-Human Interaction Conference, Melbourne, Australia.

McLaughlin, A. C., Rogers, W. A., & Fisk, A. D. (2009). Using direct and indirect input devices: Attention demands and age-related differences. *ACM Trans. Comput.-Hum. Interact., 16*(1), 1-15. doi: 10.1145/1502800.1502802

Nielsen, J. (1992). *Reliability of severity estimates for usability problems found by heuristic evaluation*. Paper presented at the Posters and Short Talks of the 1992 SIGCHI Conference on Human Factors in Computing Systems, Monterey, California.

Nielsen, J. (2012). User Satisfaction vs. Performance Metrics. from http://www.nngroup.com/articles/satisfaction-vs-performance-metrics/

Norden, L., Kimball, D., Quesenbery, W., & Chen, M. (2008). Better Ballots.

Oliveira, J., Guerreiro, T., Nicolau, H., Jorge, J., & Gonçalves, D. (2011). *Blind people and mobile touch-based text-entry: acknowledging the need for different flavors*. Paper presented at the The proceedings of the 13th international ACM SIGACCESS conference on Computers and accessibility, Dundee, Scotland, UK.

Ott, B. R., Heindel, W. C., & Papandonatos, G. D. (2003). A survey of voter participation by cognitively impaired elderly patients. *Neurology, 60*(9), 1546-1548.

Parikh, T., Ghosh, K., & Chavan, A. (2003). *Design studies for a financial management system for micro-credit groups in rural india*. Paper presented at the Proceedings of the 2003 conference on Universal usability, Vancouver, British Columbia, Canada.

Park, Y. S., Han, S. H., Park, J., & Cho, Y. (2008). *Touch key design for target selection on a mobile phone*. Paper presented at the Proceedings of the 10th international

conference on Human computer interaction with mobile devices and services, Amsterdam, The Netherlands.
Pierce, K. (2005). Accessibility Analysis of Four Proposed Voting Machines.
Piner, G., & Byrne, M. (2011a). *Accessible polling places for the visually impaired: a compilation of survey results*. Paper presented at the Proceedings of the 2011 conference on Electronic voting technology/workshop on trustworthy elections, San Francisco, CA.
Piner, G. E., & Byrne, M. D. (2011b). The Experience of Accessible Voting: Results of a Survey among Legally-Blind Users. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 55*(1), 1686-1690. doi: 10.1177/1071181311551351
Quesenbery, W., & Chisnell, D. (2009). Testing ballots: Real names or fictional? Direct how to vote or not?   , from http://civicdesigning.org/uncategorized/testing-ballots-real-names-or-fictional-direct-how-to-vote-or-not/
Redish, J., Chisnell, D., Newby, E., Laskowski, S. J., & Lowry, S. Z. (2009). Report of Findings: Use of Language in Ballot Instructions. National Institute of Standards and Technology.
Redish, J. G., Chisnell, D. E., Laskowski, S. J., & Lowry, S. (2010). Plain language makes a difference when people vote. *Journal of Usability Studies, 5*(3), 81-103.
Rogers, W. A., Fisk, A. D., McLaughlin, A. C., & Pak, R. (2005). Touch a Screen or Turn a Knob: Choosing the Best Device for the Job. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 47*(2), 271-288. doi: 10.1518/0018720054679452
Roth, S. K. *Human Factors Research on Voting Machines and Ballot Designs: An Exploratory Study*. Human Interfaces with Election Technology.
Runyan, N. (2007). Improving Access to Voting *A Report on the Technology for Accessible Voting Systems*.
Runyan, N., & Tobias, J. (2007). Accessibility Review Report for California Top-to-Bottom Voting Systems Review.
Sanford, J., Harris, F., Yang, H.-y., J.Bell, C., Endicott, S., Salisbury, L., & Baranak, A. (2013). Understanding Voting Experiences of People with Disabilities. The Information Technology and Innovation Foundation
Sanford, J. A. (2009). Assessing Universal Designi in the Physical Environment. In E. Mpofu & T. Oakland (Eds.), *Rehabilitation and Health Assessment: Applying ICF Guidelines*: Springer.
Sanford, J. A. (2012). *Universal Design as a Rehabilitation Strategy: Design for the Ages* (1 Ed.): Springer.
Sarah, P. E., Kristen, K. G., Michael, D. B., Dan, S. W., Kyle, D., Daniel, S., & Ted, T. (2008). *Electronic voting machines versus traditional methods: improved preference, similar performance*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Florence, Italy.
Sauro, J. (2011). Measuring Usability With The System Usability Scale (SUS). from http://www.measuringusability.com/sus.php
Scott, P. R., Palakorn, A., James, L. G., Sang Joon, P., Nan, Z., & Matthew, J. C. (2005). *Voting and political information gathering on paper and online*. Paper presented

at the CHI '05 Extended Abstracts on Human Factors in Computing Systems, Portland, OR, USA.

Selker, T. (2007). Technology of Access: Allowing People of Age to Vote for Themselves. *McGoerge Law Review, 38*.

Selker, T., Hockenberry, M., Goler, J., & Sullivan, S. (2005). Orienting Graphical User Interfaces Reduces Errors: The Low Error Voting Interface. http://www.vote.caltech.edu/

Sesto, M. E., Irwin, C. B., Chen, K. B., Chourasia, A. O., & Wiegmann, D. A. (2012). Effect of Touch Screen Button Size and Spacing on Touch Characteristics of Users With and Without Disabilities. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 54*(3), 425-436. doi: 10.1177/0018720811433831

Shneiderman, B. (2003). *Promoting universal usability with multi-layer interface design*. Paper presented at the Proceedings of the 2003 conference on Universal usability, Vancouver, British Columbia, Canada.

Stephanidis, C. (2001). User interfaces for all: New perspectives into human-computer interaction. *User Interfaces for All-Concepts, Methods, and Tools, 1*, 3-17.

Stephanidis, C., Salvendy, G., Akoumianakis, D., Arnold, A., Bevan, N., Dardailler, D., . . . Ziegler, J. (1999). Toward an Information Society for All: HCI Challenges and R&D Recommendations. *International Journal of Human-Computer Interaction, 11*(1), 1-28. doi: 10.1207/s15327590ijhc1101_1

Summers, K., Chisnell, D., Davies, D., Alton, N., & Mckeever, M. (2014). Making Voting Accessible: Designing Digital Ballot Making for People with Low Literacy and Mild Cognitive Disabilities. *USENIX Journal of Election Technology and Systems, 2*(2).

Sun, X., Plocher, T., & Qu, W. (2007). An Empirical Study on the Smallest Comfortable Button/Icon Size on Touch Screen. In N. Aykin (Ed.), *Usability and Internationalization. HCI and Culture* (Vol. 4559, pp. 615-621): Springer Berlin Heidelberg.

Tao, Y., Prathik, G., Robert, M., & Davide, B. (2013). *Bypassing lists: accelerating screen-reader fact-finding with guided tours*. Paper presented at the Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility, Bellevue, Washington.

Ted, S., & Anna, P. (2006). A methodology for testing voting systems.

Theofanos, M. F., & Redish, J. (2005). Helping Low-vision and Other Users with Web Sites That Meet Their Needs: Is One Site for All Feasible? *Technical Communication, 52*(1), 9-20.

Tobias, J. (2003). Information Technology and Universal Design: An Agenda for Accessible Technology. *Journal of Visual Impairment & Blindness, 97*(10), 592-601.

United States. Election Assistance Commission. (2002). *The Help America Vote Act*.

Vanderheiden. (1990a). Thirty-Something Million: Should They Be Exceptions? *Human Factors: The Journal of the Human Factors and Ergonomics Society, 32*(4), 383-396. doi: 10.1177/001872089003200402

Vanderheiden, G. (2000). *Fundamental principles and priority setting for universal usability*. Paper presented at the Proceedings on the 2000 conference on Universal Usability, Arlington, Virginia, United States.

Vanderheiden, G. (2001). Fundamentals and priorities for design of information and telecommunication Technologies *Universal Design Handbook* (pp. 65.63-65.15).

Vanderheiden, G. C. (1990b). Thirty-Something Million: Should They Be Exceptions? *Human Factors: The Journal of the Human Factors and Ergonomics Society, 32*(4), 383-396. doi: 10.1177/001872089003200402

Vanderheiden, G. C. (2004). Using extended and enhanced usability (EEU) to provide access to mainstream electronic voting machines. *Information Technology and Disabilities, X*(2).

Wand, J. N. (2001). The Butterfly Did It: The Aberrant Vote for Buchanan in Palm Beach County, Florida. *American Political Science Review, 95*(04), 793-810. doi: doi:null

Yatani, K., & Truong, K. N. (2009). SemFeel: a user interface with semantic tactile feedback for mobile touch-screen devices. *Proceedings of the 22nd annual ACM symposium on User interface software and technology*, 111-120.