RICE UNIVERSITY

CHILVote:
The design and assessment of an accessible audio voting system

by

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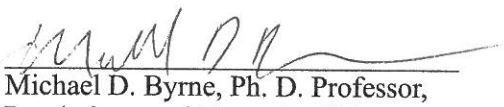

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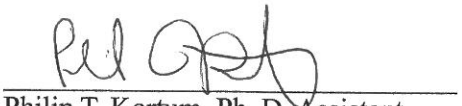

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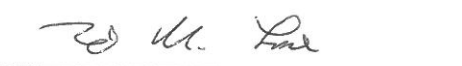

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Abstract

The Help America Vote Act, passed into law in 2002, mandated that all polling places provide privacy and independence to all voters. Given this, many jurisdictions have been forced into making a choice between providing traditional voting methods (such as paper ballots) and offering newer electronic voting systems. Electronic voting machines have been seen as the solution to many usability and accessibility problems, but very little literature exists to indicate whether this is the case among specific populations such as disabled, elderly, and non-English speaking voters. An audio accessible voting interface for visually disabled voters (CHILVote) was designed using specifications from both the Voluntary Voting System Guidelines and a large-scale survey of blind individuals conducted by Piner and Byrne [in proceedings of *The Human Factors and Ergonomics Society 55th Annual Meeting*, pp. 1686-1690 (2011)]. CHILVote's interface utilizes the given design guidelines and includes use of a male text-to-speech voice, a flexible navigation structure, adjustable speed and volume, and an optional review section. Relatively low error rates (M=1.7%) and high SUS scores (M=89.5) among blind subjects are consistent with previous findings. Error rates and satisfaction are not significantly different than those of sighted voters using both paper and DRE, and blind voters using a non-electronic interface. CHILVote significantly reduced the time it takes for blind subjects to vote, from 25.2 minutes (VotePAD) to 17.1 minutes (CHILVote). This is an improvement, but still over 2.5 times slower than sighted subjects voting on an identical ballot. The integration of accessibility into mainstream technology often has benefits beyond allowing more of the population access to a system. This research provides a comparison point and guidelines for future studies of accessibility solutions.

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Introduction

Creating a usable voting system is a challenge that has not been well met by existing systems. This challenge is made even more difficult when considering populations with special needs. With 1.3 million legally blind individuals in the United States (and 20% of the population living with one or more disabilities), this represents a substantial segment of the population. The government mandates equal voting opportunities for all US citizens. On the surface, DREs (Direct-Recording Electronic voting systems) appear to have great potential in this regard, and while they have almost certainly improved the situation for voters with a wide variety of disabilities, current implementations are often far from the ideal in terms of accessibility (Runyan, 2007). Audio instructions are often long and tedious, and interaction with the voting system requires voters to listen to repetitive selections with no way to quickly navigate through sections of the ballot in which they have no interest. The physical buttons and keypads used for tactile interaction can be poorly designed (such as having similar keys that are not easily distinguished by the button's shape or some other marker or keys that are so close together that they are often mistakenly pressed) and poorly labeled (Cross et al., 2009). One difficulty in usable design is the lack of systematically collected, publicly available data on usability of voting systems for different groups. This research extends the voter usability literature, specifically regarding blind voters, to the realm of DREs and electronic voting solutions.

"Universal access" is an approach to usability that is targeted towards providing equal access to computer-based applications for users with disabilities. It aims to consider human diversity and provide technology without excluding users, while at the same time improving the quality of products for use by the general population (Stephanidis, 2009). Universal access mandates that there should be a study of both human characteristics and requirements in the

development process.

When designing a user interface, consideration must be made for individuals who may not be able to interact with a technology in the same way as the general population. If a user is unable to interact with a device or an environment, there are three things that may be done to alter this. First would be to change the individual, through the likes of medicine or surgery, so that they can use the world as it is. Second would be to focus on a single, individual product and change it in a way to make it accessible to the specific user considered here. The final option would be to change the world, so that existing technologies and interfaces are easier for people to use regardless of the details of their disabilities (Vanderheiden, 2009). Ideally, utilizing the information from previous work with blind voters (Piner & Byrne 2010, 2011) will allow us introduce a research-driven voting system design for providing access to visually impaired and blind individuals.

Previous research on voting has focused mainly on the effect of voting technology on election outcomes. Nichols and Strizek (2005) examined how ballot roll off (the tendency for races higher on the ballot to receive more votes than those races located lower on the ballot) could be influenced by a change in the technology. Moving from non-electronic to electronic voting methods noticeably increased the rate of voter participation in these lower electoral races. Nichols and Strizek hypothesized that this was because undervoted races were made more salient on the electronic voting machines through the use of blinking lights, and some voters may have felt obligated to resolve these contests before casting their ballot. The issues raised by the voting problems in the 2000 U.S. presidential election in Florida spurred several papers that looked at the shortcomings of the specific ballots used there. Mebane (2004) focused on the lack of a system to caution voters that over votes (making too many marks on a ballot, and thus voiding

the ballot) were present on their ballots. Wand et al. (2004) assessed other systematic voting errors that occurred on certain ballot types (such as the now-infamous "butterfly" ballots) that could cause either invalid ballots or ballots that did not correctly represent the voter's intention.

Perhaps the most significant impediment to a fair and just democratic process, and the biggest obstacle that voting technology needs to overcome, is that the ability to vote must generalize to the extremely diverse population of all Americans over eighteen years of age. Voters with disabilities make up a sizable portion of this population. The Americans with Disabilities Act (United States Government, 1990) defines a disability as "a physical or mental impairment that substantially limits one or more major life activities." According to the U.S. Census Bureau Americans with Disabilities report (2005), 19% of the US population lives with one or more disabilities. A fifth of those Americans with disabilities (more than eight million people) have been unable to vote in presidential or congressional elections due to barriers at or getting to the polls (National Organization on Disability, 2004). The Help America Vote Act (HAVA) was the federal government's response to this situation, and mandated that all polling places have an accessible method of voting available for those wishing to vote in federal elections (United States Government, 2002). These rights extend to two crucial aspects of voting: privacy and independence. Voter privacy encompasses a person's right to anonymity during the process, including the transmission, receipt, and processing of ballots. Voter independence means that an individual with disabilities has the same opportunity for access and participation as others, without requiring the assistance of another party.

Manufacturers of voting systems have been tasked with making these changes. Current manufacturers make bold claims that their systems allow everyone to vote without assistance. Hart InterCivic (2010), the company that manufactures the eSlate electronic voting system

explicitly states on their website “The eSlate enables private, independent voting for persons with disabilities.” However, many DREs seem to share fundamental shortcomings, some of which are outlined by Cross et al. (2009). The AccuVote-TSX, an optical scan voting system that reads and tabulates marked paper ballots, requires a voter to insert an identification card that they receive from a poll worker. All voters are expected to locate the slot and correctly insert the card before they can even begin the process of voting. The eSlate has buttons that are located close together and this could cause accidental selection of undesired keys. There are potentially confusing labels on the eSlate. It provides voters with both a “select” dial and an “enter” button. The AVC Edge is a touch-screen electronic voting system for most voters, but provides Braille buttons for the visually impaired. Because fewer than 10% of legally blind Americans are Braille readers, it is critical that the audio interface be made a priority when developing accessible systems, rather than relying on a misguided notion that everyone with visual impairments is also a Braille reader (National Federation of the Blind Jernigan Institute, 2009). To voters who are less knowledgeable about physical interfaces, these small things may become insurmountable challenges during the process of voting.

A majority of states utilize several levels of testing that are designed to insure that a voting machine adheres to standards for accuracy and reliability (Mulligan and Hall, 2004). The EAC (Election Assistance Commission) provides voluntary testing and certification of voting systems for the states (United States Election Assistance Commission, 2007). The manufactures first submit their software program and coding to an independent testing authority, to be tested against the VVSG (Voluntary Voting System Guidelines). States may also require that voting systems undergo additional testing before the equipment is certified for use in a given state. But the final burden rests on the individual jurisdictions, whose election authorities are charged with

determining if "the equipment meets the needs of the citizens under their jurisdiction" (Citizen Advocacy Center, 2004). Many governmental bodies do not have the information, understanding, or resources to provide the thorough and rigorous tests that are needed.

Considerable modifications are required to make existing voting technologies accessible to specific populations of disabled voters, especially those with visual disabilities. These range from purely audio instructions, inputs, and feedback to tactile and Braille interfaces to magnification and large print materials. Because of the unique alterations that need to be made and the large portion of the population that is affected, the design of a DRE should accommodate this range of legally blind individuals. "Legally blind" is defined as having "central visual acuity of 20/200 or less in the better eye with the use of a correcting lens" and/or having "the widest diameter of the visual field subtend an angle no greater than 20 degrees" (National Federation of the Blind, 1986).

HAVA strongly encourages the implementation of the newer, computerized technology, DREs (Runyan, 2007). Although DREs have been seen as a solution to many of the current problems existing in the voting world, laboratory studies have found that upwards of 10% of voters still have significant concerns about the systems' ease of use, their ability to change votes, and the correct recording of their intended votes (Bederson, Lee, Sherman, Hermson, & Niemi, 2003). Election officials sometimes consider DREs to be a panacea for all existing accessibility, usability, and security problems. However, very little data exist which permits a quantifiable comparison of DREs to the older, traditional voting systems (paper ballots, lever machines, and punch cards) that they would be replacing.

A series of several laboratory experiments has attempted to address this limitation and provide the groundwork for improving voting technology in ways that can be studied, quantified,

and understood (Piner & Byrne 2011, Everett et al., 2008, Byrne et al., 2007; Everett et al., 2006; Greene et al., 2006). The National Institute of Standards and Technology's (NIST) recommended solution to measuring the usability of voting systems is through the use of the International Organization for Standardization's (ISO) usability metrics: effectiveness, efficiency and satisfaction (Laskowski, 2004). Effectiveness is evaluated by how well voting methods represent a user's intent, and can be measured by error rates. This is the essence of voting: are people's ballots truly representing the candidate they want to vote for, and if not, what kinds of errors are made? Efficiency is captured in the amount of time it takes a user to vote. This is important because voting is a voluntary activity and takes place over a limited period of time during which many people must be accommodated. And finally, a subjective measure of overall user satisfaction provides insight to people's personal preferences of different voting systems.

Studies have evaluated the usability of paper ballots, lever machines, and punch cards (Everett et al., 2008; Byrne et al., 2007; Everett et al., 2006; Greene et al., 2006). Overall, voters (both college undergraduate students and a more representative sample of the general population) preferred the paper ballots to the other two traditional voting methods. The many benefits of paper ballots include voters' general experience of interacting with paper, a direct mapping of actions onto candidates, and a simpler configuration. The major limitation of paper ballots is their inaccessibility to those with both visual and physical impairments. Recent innovations in voting technology have produced ballot-marking aids, which allow people with a wide range of disabilities the opportunity to vote independently and privately on paper ballots (Runyan, 2007). Figure 1 presents several examples of tactile ballots.

Figure 1A

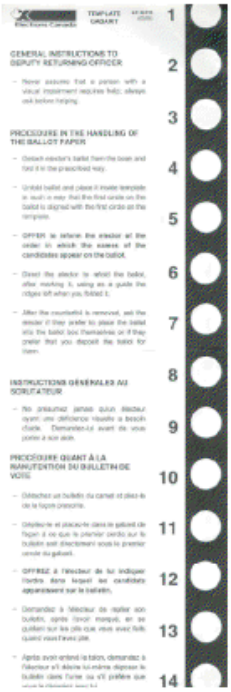

Figure 1B

Figure 1C

Figure 1D

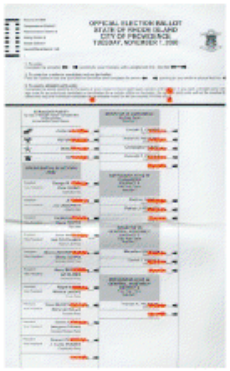

Figure 1E

Figure 1. Examples of tactile ballots. (a) Vote-PAD (b) Braille and tactile ballots being used by the state of Rhode Island, (c) Peru (d) Republic of Sierra Leone (e) Canada.

Piner and Byrne (2010) addressed the usability of tactile ballots by blind voters in their mock election laboratory experiment. Vote-PAD and paper ballots used by sighted voters had

similar user satisfaction ratings and per-contest error rates, but blind voters took considerably more time to cast their ballots. The fact that they are slower is not particularly surprising; NIST estimates that a blind individual using the audio version of a completely accessible interface will take, at the minimum, 50% longer than a sighted user interacting with the visual display. That estimate is based on an optimal scenario, in which a blind user who is familiar with the alternative interface is taking a standardized test. The authors of the NIST document, based on their personal correspondence with individuals with visual disabilities, state that taking 3 to 4 times longer than a sighted user is probably more accurate (Laskowski et al., 2004). Piner and Byrne (2010) produced comparable results, showing that blind voters using Vote-PAD take 5 times as long to vote, and blindfolded voters take more than 6 times as long to vote relative to sighted users voting on an identical bubble ballot. This significant difference in time may be reduced by an accessible audio DRE that allows for faster text-to-speech output, flexible navigation, and the option to skip entire contests if desired.

To determine the best course of action for implementing accessible voting systems, a comparison needs to be made between more traditional voting systems and the newer, electronic voting systems. In the 2007 top-to-bottom review of voting systems conducted by California, the human factors design weaknesses that make certain DRE systems too complex were highlighted. "The setup of these machines in audio access mode is still too complicated for the average poll worker, marking and reviewing the ballot is too complex and takes a very long time for the audio voter, the physical privacy shielding is much worse than it used to be with punch-card systems, and audio voters do not have any way of verifying the paper audit trail privately or otherwise" (Runyan, 2007, p. 12).

Voting DREs are not the only accessible, stand-alone, walk-up-and-use systems that need

to be designed to accommodate a wide range of users with disabilities. These types of systems can also be found in our daily environment in the forms of public kiosks. A review of accessible systems literature found that most research focuses on very general, well-known usability principles. For example, Camilli, et al. (2010) were interested in improving "the 'findability' of the most frequently used functions" in ATMs (Automatic Teller Machines) and results from a cell phone usage study (Watanabe, et al., 2008) found "that many visually impaired users, even print enabled persons, were making use of speech output to e-mail and access the internet. Accordingly, improvement in speech output was hoped for by many users." Johnson and Coventry (2001) also noted a lack of research in regards to what they call "traditional self-service interfaces," attributing it to the fact that systems like ATMs have a narrow task scope and wide user population. The existing research tends not to focus on the specifics of the individual interfaces in the details that the VVSG addresses interactions with a voting machine.

Usability and accessibility in the public domain are increasingly important as our society moves from a service-oriented community to a self-service community (Stephanidis, 2009). ATMs, the oldest and most common type of public kiosks, number over 1.5 billion globally. There is a rapid penetration of a variety of public access terminals into everyday life. Access considerations for a diverse community (consisting of, but not limited to, the elderly, disabled, and non-English speakers) should be considered when attempting universally accessible designs.

An example of an interface used in multiple public access kiosks is the EZ Access system (Trace Center, 2007). EZ Access, developed by the TRACE center, is a set of standard enhancements that provide interactive techniques to support the use of the electronic product by users with a variety of disabilities. Public kiosks that utilize this system include Amtrak Quik-Trak Ticket Machines, IBM Accessible Travel Self Service Kiosks, United States Postal Service

Automated Postal Centers, World War II Memorial Information Kiosks, and the Phoenix Sky Harbor Airport Paging System.

The most relevant piece of technology for visually disabled users is the EZ Access keypad (see Figure 2). The keypad differentiates between different function keys using both shape and color along with a tactile ridge on the up button. These general interactions allow a user to move forwards and backwards through pages, up and down through lists, to access context specific help, and to confirm a selection (or some other form of action).

Figure 2. EZ Access keypad.

Audio can be provided either though a telephone type handset attached to the machine or a jack that allows a user to plug in his personal set of headphones or other listening device. Speech output combined with button navigation would allow a blind user to navigate through whatever information appears on the screen.

Automatic Teller Machines (ATMs) are similar to voting systems in that a level of privacy must be maintained for the user, regardless of his or her disabilities. Often these kiosks

are used in locations or at times when assistance is not available. Because of this, the system must provide a comprehensive range of features to allow an individual access, regardless of his ability. The function of an ATM is to complete a specific transaction and allow users to obtain this result quickly and safely. A heterogeneous set of users in terms of age, skills, and experience must be accommodated and the design of the system should focus on "easy-to-use functions, comprehensible information and linear and safe navigation modalities" (Camilli, et al., 2010).

The usability of ATMs has been a work in progress over the past decade or so. A blind individual reporting for the National Federation of the Blind mentions that in the early 1990s, ATMs in their area of the country were fully equipped with Braille touch pads, but those with visual disabilities were given no means of reading the screen's text display to determine what input was required from them (Kuell, n.d.). Even among "truly" accessible ATMs (those that include a way for the visually impaired to receive output and give input), Kuell reports there being difficulty with learning new commands and the lack of consistency between machines.

Criticisms for existing ATM technology included the system's lack of feedback and error prediction when a user had to enter digits (bank account number, credit card number, etc.), no way to quickly recover from errors (restarting the transaction was often required), and lack of instructions in some cases. Camilli, et al. (2010) suggested a redesign of the ATM system that included an option for personal profiles to make reoccurring transactions (for example, withdrawing a set amount of money) easier to access. It is also feasible to imagine these personal profiles could extend to usability options that would be in place when an ATM recognized its user.

Manzke (1998) examined how to provide access to cash dispensers by using speech output and modified graphics and function access. Manzke's research provided details of

improving an accessible interface for ATMs. For low vision users who may still be able to use the screen to some extent (and also to improve usability for sighted users) a blue background with white text (to reduce the glare) in a sans serif font to maintain legibility was recommended. Speech output was provided in a synthesized male voice (easier to understand for people with a hearing impairment and in a noisy environment) at approximately 120 words per minute. An acoustic signal (like a gong) was used at the beginning of sections of text to signal important information. The keypad was a 4x4 grid of telephone-like keys, each labeled in Braille. The preexisting security feature of a time-out limit on the ATMs (the amount of time the user has to input a selection or their information before the system reset) was increased five fold for these users, and if they reached the halfway point in this time-out limit, the instructions would automatically repeat.

Johnson and Conventry (2001, p. 168) saw the future of public access terminals as "novel, contactless, and voice based," such as their proposed ATM, Stella. Interaction between human and machine is triggered by a proximity sensor so that the dialogue beings when the customer approaches the machine. Stella uses biometrics verification (iris of the eye) to identify the customer. This is an attempt to lessen the cognitive load of remembering a PIN or needing to bring a physical bankcard. Stella interacts through speech synthesis (a female IBM Via Voice) and voice recognition of the customer's input. A clear downside to speech input is that it opens a realm of security and privacy concerns, both of which appear in the banking and voting domains. A benefit of removing touch inputs reduces issues of use for those with physical mobility problems, but at the same time this system does not accommodate those with speech or hearing impairments.

The 2010 ADA Standards for Accessible Design required ATMs to be in compliance with

the new guidelines by March 15, 2012 (Department of Justice, 2011). These standards state that audio headphone jacks must be labeled in Braille to let blind users know where the jack is located. Other options for making audio jacks easier to find could include standardizing their location, landmarking the jack against another control (such as always locating it beneath the input buttons), or creating a much larger tactile area centered around the jack to guide a blind user's explorations. Bank of America ATMs have a large raised platform that contains the audio jack, a tactile headphone symbol, and large print "Audio," arrow, and headphone symbol indicating where the jack is (see Figure 3).

Figure 3. Bank of America ATM's audio jack

A survey of existing "talking" ATMs, including Wells Fargo bank, TCF Financial Corporation, and Bank of America, found that these companies all mention their accessible ATMs online. Their internet-available resources gave little more information than the type of audio jack used, and none addressed where a blind individual was supposed to locate the jack on the device itself. Instead, it seems to be taken as a given that locating the audio jack should not present any problem for the user. TCF (2012) states "Talking ATMs deliver audio information through any standard personal headset (3.5mm), making it possible for people with visual

impairments to use the ATM while ensuring their security." Wells Fargo (n.d.) advises "The ATMs are equipped with audio jacks and deliver voice information privately through the user's earphone to prevent others from hearing the transaction." Even the most detailed website, from Bank of America (2003), which offers a large print PDF guide to their ATMS only says that "After plugging your headset into the audio jack, you'll hear a description of the layout of the components for the particular Talking ATM you're using."

Another ADA standard (707.4 Privacy) for kiosk design is the blanking of the screen when headphones are connected. This provides privacy for "blind or visually impaired, people with limited reach who use wheelchairs or have short stature, who cannot effectively block the ATM screen with their bodies" (Department of Justice, 2011). In voting system design, the ability to blank out the screen should be an option that the user is made aware of to further increase their privacy. However, the screen blanking should not automatically happen when an audio device is connected, because there are many users (low vision, elderly, cognitively disabled, or Non-English speakers) that can benefit from a dual audio and text modality.

Public access kiosks, like ATMs, are similar to voting systems in that they must provide "walk up and use" access to a large portion of the population, regardless of an individual's ability. CHILVote's design, as well as that of any other accessible DRE, should be based around the best available current technology that can be found in screen readers, public kiosks, and improved naturalistic synthesized voices. It is also important to adhere to guidelines set forth by the ADA and VVSG. Ultimately, an accessible voting system should be flexible enough to cater to the needs of a broad spectrum of disabled individuals.

CHILVote

Preliminary Research

Piner and Byrne (2011) surveyed 202 legally blind adults to collect their opinions and recommendations as blind voters. Topics addressed included obstacles at the polling place, preferences for system audio, multiple modality systems, voting confidence, and input devices. This survey focused primarily on a proposed audio-based system of interaction because an audio interface allows the highest level of accessibility across individuals with some form of visual impairment. Five proposed guidelines were developed, based both on an analysis of response data as well as the ideas and thoughts presented by voters via the open-ended portions of the survey. These guidelines were designed to be flexible enough to be applied across devices, regardless of any specific details relating to input devices, screen size, audio equipment, etc. The Piner and Byrne (2011) guidelines, in addition to lessons learned from voting on existing accessible systems, was used as the basis for designing CHILVote.

In December, 2011, I had the opportunity to visit the National Institute of Technology's Usability and Accessibility of Voting Systems Group (Gaithersburg, MD) and the National Federation of the Blind's Jernigan Institute (Baltimore, MD) and to use several of the current accessible DREs and ballot marking devices that are being used in elections throughout the country. These included the AutoMARK, iVotronic, Unisyn, and eSlate.

An informal heuristic review of these systems revealed many shortcomings in their ability to provide an independent and private voting experience for individuals with disabilities. The number of design flaws and usability issues found in a given system should not be taken as an absolute indication of the most usable system among the ones reviewed here. The issues discovered in the systems was addressed by a range of changed functionality in CHILVote, the

voting system used in this study.

The ES&S AutoMARK is generally considered to be the current leader in providing an accessible voting experience to the blind community (Runyun, 2007). The AutoMARK is an electronic ballot-marking device. A paper ballot needs to be fed into the machine to start the voting process, but the machine gives no audio feedback about what is happening (ballot being scanned). A button on the keypad is used to change the tempo of the voice, but changing the voice tempo during the instructions restarts the instructions from the beginning. The AutoMARK has a repeat button, but there is a 2-3 second noticeable pause before the machine says anything. No information is given about the total number of races in the election or the amount of contests remaining. Instructional messages use specific electoral terminology like "undervote," without clearly explaining the definition. If the volume button is pressed when the machine is silent, there is no feedback given, although the volume change still occurs.

The ES&S iVotronic is a touch screen DRE, which offers both a full audio mode and an audio-assist ("touch to hear") mode. This system offers no ability to change the speed of the audio. During the audio instructions, the physical layout of the device is described, noting that the vote button located at the top of the screen. If a voter were to explore the machine with his hands to try to locate the vote button, he would most likely inadvertently touch the touch screen. Touching the screen causes the instructions to restart from the beginning. If the voter goes idle during the voting process, there is approximately a 5 second time-out message that is not descriptive. The system simply states: "We did not record an action."

The Unisyn OpenElect Voting Interface is a DRE with a hand-held keypad. There are options to adjust both the volume and tempo of the audio, but there is a great amount of lag when trying to change the tempo. No audio confirmation or warnings are given when a voter

undervotes a contest; the audio interface informs the user that under voted races will be displayed in red. There is no information given regarding the number of races on the ballot or the number of candidates/choices in each race. If a voter goes back to change his vote during the review process, he is placed back into the full ballot and has to scroll through all subsequent contests to get back to the review screen.

The Hart eSlate is a DRE with a scroll wheel and button interface. It offers no ability to change the speed of the audio. There are discrepancies between what is offered to the voter by text versus by audio, for example "Press Help for Instructions" is written out on the write-in votes page, but the audio gives no equivalent information. When voting in a race that allows for the selection of multiple candidates, the voter is returned back to the top of the choices list after each selection. The review screen does not spell out or attempt to pronounce any write-in votes that were made.

Apparatus Design

CHILVote is a DRE interface that provides an audio analog of the existing VoteBox graphical interface in order to accommodate users with visual disabilities, although, by necessity, the instructions are somewhat different (Rice University Computer Security Lab, n.d.). This interface provides logical and consistent navigation through the many steps that comprise the act of voting including introduction, instructions, voting, changing votes, reviewing votes, and casting the ballot. CHILVote's navigation, input, and design are based on the five accessible DRE guidelines obtained from a large survey of blind individuals and proposed by Piner and Byrne (2011). These include providing an audio-only mode, using a male synthesized text-to-speech voice, allowing users to adjust the audio volume and speed, allowing users to skip or repeat sections of audio, and providing a way of reviewing the ballot.

Although every attempt was made to make this interface "accessible" in the broadest sense, the focus here in on the large population of visually impaired users. Other physical and cognitive disabilities were considered when possible. CHILVote is designed for use with a similar ballot to the one used in numerous studies by both sighted and blind voters (Piner & Byrne 2011; Everett et al., 2008; Byrne et al., 2007; Everett et al., 2006; Greene et al., 2006). Because of this, the interface did not address the issues of write-in votes, straight party voting, or "k of n" contests in which the voter can select more than one candidate.

Six keys are used to interact with the voting system (4 arrow keys, a menu key, and a select key). For this study, these keys are directly mapped onto the button input box (see Figure 4), but it would also be possible to utilize a telephone keypad or a standalone number pad in order to test different input devices. The button box, purchased from RJ Cooper & Associates, Inc. was one of the few commercially viable options to use for input, without using a keyboard. The button box was originally designed to allow users to control a mouse using the buttons shown in Figure 4. The mouse input was run through an interpretation program "JoyToKey" which took the mouse input from the button box and converted it back to button presses that were used to communicate with CHILVote. This was not an ideal setup, but it worked well enough to test users in a mock election. Possible improvements to the input device are recommended in the discussion section.

Figure 4. Large, tactile button box used for the DRE input method

The large, tactile button box provides multiple cues for distinguishing keys. Different colors are provided to support low-vision users (although the colors are never mentioned in the instructions, since the assumption is that most users will not be able to use this cue). Raised, tactile markers (a direction triangle for each arrow key, a single dot for the menu key, and two dots for the select key) are provided to support blind users.

Blind subjects in a previous study were given the opportunity to interact with the button box and to feel and explore it tactilely (Piner & Byrne, 2011). 85% of respondents (17 out of the 20) said that they felt the six different buttons on the button box were easy to discriminate and tell which one performed which function. 1 respondent felt this task was difficult, and the final 2 respondents rated the level of difficulty as average. Most respondents (75%, 15 out of 20) felt the button size was fine. 4 respondents would have preferred to have smaller buttons, and 1 respondent would have preferred to have larger buttons.

Piner and Byrne's (2011) guideline 1 recommends that an accessible DRE interface should include an audio mode that can be used in conjunction with the standard visual display. CHILVote is currently designed as an audio interface only, which provides instructions, lists races and candidates, gives feedback about selected choices, and allows for ballot review. The audio files for CHILVote were created using the NaturalReader text-to-speech program. The voice is a synthesized US English-speaking male, NeoSpeech's "Paul." Piner and Byrne's (2011) guideline 2 suggests that a male synthesized text-to-speech voice that can be sped up without distortion should be used. This was chosen over the slightly preferred human voice due to the highly desired ability to speed up the audio (requested by more than 90% of respondents), and the ability of individuals with co-occurring visual and auditory impairments to hear and understand a deeper (male) voice better. In accordance with the VVSG 1.1 3.3.3 c guideline (p.

73), speech will be provided in speeds ranging from "75% to 200% of the nominal rate" and "adjusting the rate of speech shall not affect the pitch of the voice." Normal conversational English falls in the range of approximately 180 wpm (words per minute). The text-to-speech program, NaturalReader, has audio speed settings ranging from -10 to +10 with no additional information. Voters are provided with 5 audio speed choices, approximately 135 (75%), 180 (100%), 240 (133%), 300 (166%), and 360 (200%) wpm. The equivalent wpm rate of the NaturalReader settings were obtained by using the average wpm measured by three text passages: one adult literature article, generally used for pronunciation and dialect study ("Comma Gets a Cure"), one children's literature article ("Arthur the Rat"), and one general scientific article ("The Rainbow Passage") (for full text, see Appendix C). An experiment by Asakawa, Takagi, Ino, and Ifukube (2003) aimed to find the highest and the most suitable listening rates for blind users. Results from objective and subjective methods indicated that most suitable listening rate was about 1.6 times faster (~288 wpm) than the "normal" speaking rate of 180 English wpm, with advanced users being able to understand at least 50% of information presented at a rate of 500 wpm. A default speed of 133% (240 wpm) was used, erring on the slower side of Asakawa et al.'s (2003) suitable listening rate. Using the 133% speed as a default also allowed the user to have two slower speed choices and two faster speed choices should they decide to utilize the change audio speed function.

In voting, comprehending the audio information and instructions is of utmost importance. Information on how to change the speed of the audio is addressed early in the voting process, during CHILVote's preliminary introduction and instructions, to allow users to find a comfortable speed as early in process as possible. Voters listened to all audio through JVC HA-V570 Supra-Aural headphones with disposable sanitary covers to maintain privacy, as specified by VVSG 1.1

3.2.3.1 c.

The importance of adjustable audio is supported by Piner and Byrne's (2011) guideline 3; the system should provide the ability to adjust audio speed and volume. A physical switch on the headphone cord allows the subject to control the audio volume in this experiment. By offloading the task of volume control to a piece of hardware, this solution allows for an abbreviated menu in the CHILVote system.

Navigation through the audio interface is accomplished primarily by using the four arrow keys (Figure 5). The audio's flexibility is designed support a voter's intentions and desires and not hinder them with unnecessary instructions or obtrusive audio. This is in response to Piner and Byrne's (2011) guideline 4 that navigation should allow users to skip through sections of speech that are not important to them as well as allow them to replay any parts they may have missed or not comprehended the first time. Additionally, VVSG 1.1 3.3.3 b guidelines (p. 71) are very clear in emphasizing the flexibility of navigation by requiring that the system "allow the voter to pause and resume the audio presentation," "allow the voter to skip to the next contest or return to previous contests," and "allow the voter to have any information provided by the voting system repeated." When a button is pushed in CHILVote, that action will interrupt the current message and move on to whatever command was just given. This barge-through feature allows a user to quickly navigate through races they are not interested in with the quick, repeated press of a key. The left and right arrow keys move a voter forward and backwards through the 27 races. The up and down arrow keys scroll through the list of candidates or choices provided in a race. Navigating to the top header of a contest repeats the race's introductory information as well as gives detailed navigation instructions and instructions on how to select a candidate or choice in the current race.

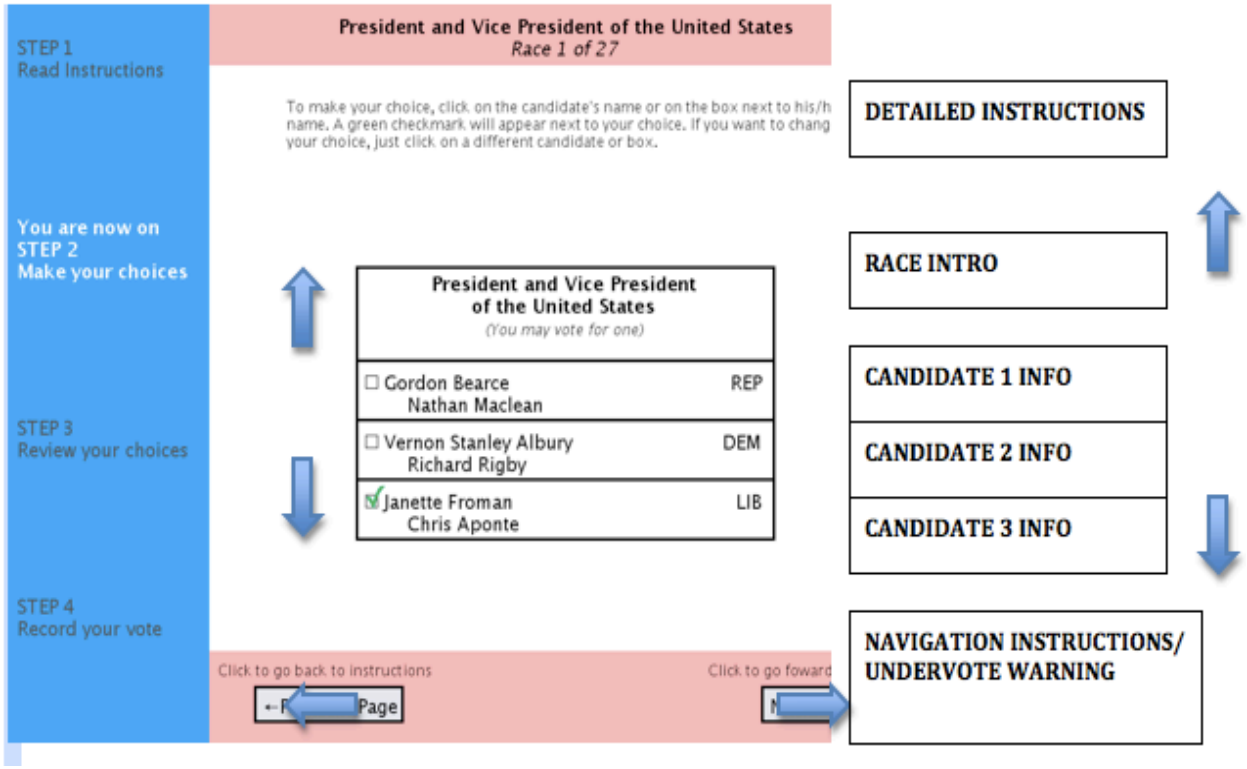

Figure 5. CHILVote's audio navigation model using the four arrow keys, based on a screenshot of VoteBox

The introductory audio is the first section of CHILVote that the voters hear. Instructions play when the select key is pressed (to allow the experimenter time to get the voter set up with the system). This key press also starts the voting timer running. VVSG 1.1 3.2.4 b (p. 53) recommends that the system provide "a means for the voter to get help directly from the system at any time during the voting session." Additional help and instructions can be obtained by the voter at any time by navigating to the top of a contest (the contest number and title will be repeated as well as more detailed instructions on how to make a selection).

In a candidate contest (races 1-21), the voter is given the choice of one or more candidates that are running for an office and asked to indicate which of these individuals they would like to

vote for. All contests are labeled as "Contest X out of 27." This is the first audio information that a voter hears when they move to a new contest and is provided to help differentiate between races, aid with navigation, and give voters an idea of where they are in the ballot. Each candidate contest includes the number of the contest ("Contest 1 of 27"), the title of the contest ("President and Vice President of the United States"), how many choices there are in the contest and how many choices are to be made ("There are three choices. Vote for one."), and brief navigational instructions ("Use the down arrow key to hear the name of each candidate or choice listed."). This is followed by a list of candidates and their political parties that the user navigates through individually, with each choice's corresponding audio playing only when the user indicates that they want to advance through the list (by pressing the down arrow in most cases). When the user selects a candidate, their choice is repeated and the word "selected" played after the candidate name, and they are instructed on how to navigate to the next contest on the ballot. If the user selects a previously selected choice, the system deselects the choice and the word "deselected" will play.

In some situations, a voter may try to advance to the next contest without selecting any candidates in the current contest. In order to differentiate between instances in which a voter intentionally leaves a contest blank and an accidental button press or navigation error, the voter is alerted whenever they attempt to leave a contest in which they have not chosen a candidate.

> *Alert! You have selected fewer than the number of candidates or choices that you are permitted to select for this contest. If you wish to return to this contest and select additional candidates or choices, please press the left arrow key. If you wish to confirm your desire to undervote and move on to the next contest, you can continue by pressing*

the right arrow key.

This alert dialogue is written ambiguously in order to account for contests that allow users to vote for more than one candidate, even though that particular situation is not addressed on the experimental ballot. If the voter presses the left arrow, they are returned to the top of the undervoted contest in order to re-orient them to their location within the ballot and what contest they are currently voting for. The voting then proceeds in the same fashion as if this were the first time they had navigated through the given contest.

When a voter scrolls through a contest in which they have already voted and reaches the candidate they selected, the audio "selected" is added to the end of the candidate title. For example, "*Janetta Froman and Chris Aponte, Libertarian party. Selected*."

In a proposition contest (races 21-27), the voter is presented with an issue and can either vote "Yes" or "No" on the given proposition. Although different in format from the candidate races, the propositions are also be labeled as contests and appear at the end of the ballot. Navigation on the proposition screens is identical to the candidate races, although only two options (Yes or No) will be in the selection list. In accordance with the VVSG 1.1 3.3.3 b guideline (p. 71), a system "shall allow the voter to skip over the reading of a referendum so as to be able to vote on it immediately." As with all other parts of the ballot, the voter can barge through the audio introduction and move immediately to the selection list.

Reviewing a completed audio ballot is a complex and often tedious interaction with the voting system. Piner and Byrne's (2011) final guideline points out that a way of reviewing the ballot must be included but should not be required to end the voting process. Very clear instructions must be provided in order to support the voter's mental model of how the system

works and provide an intuitive method of skipping around the ballot rather than the previously forced linear navigation. In CHILVote, each contest review exists independently. For example, if a voter wishes to change their vote for Governor (Contest 4), they are taken *only* to that contest. Left and right arrow keys will then bring them back to the Review screen, rather than to contests 3 and 5. This interaction prevents the voter from having to page through all of the subsequent contests following the one that they wish to review. Instructional wording on the review screen attempts to clearly and concisely communicate this to the user.

> *This is the review choices section. Listed below are the choices you have made. Use the up and down arrow buttons to scroll through each contest and hear the choices that you have made. If you would like to make a change, press the select button to return to that contest. Press the down arrow button now to review the first contest. If you do not want to make any changes, press the right arrow button to proceed.*

When a voter navigates to the review section, the audio always plays "This is the Review Choices section" first, but the detailed instructions are only included if the user is at the top of the section. If the user is returning to the review section after selecting a contest, they are returned to that contest so they can confirm that any changes they made in the ballot are reflected in the review section. This is intended to prevent overly repetitive navigation through sections of the ballot that have already been determined by the voter as being correct. During the review process, the propositions only state "Proposition #," not the full text of the proposition. The voter can access the full text by pressing the select button and returning to that proposition.

Once the review process has been completed, subjects must confirm that they wish to

record their vote. Subjects are instructed to use the left arrow if they need to review or change any of their votes or the select key to confirm that they wish for their vote to be officially recorded. Two important instructions are emphasized in this section: after the select key is pressed no more changes to the ballot can be made, and the vote is NOT recorded until the voter presses the select key.

Finally, voters receive a message confirming that their vote has been recorded. In a real election, it is recommended that this message also include instructions with how to contact a poll worker if the user needs any further assistance exiting the voting booth or polling place (such as the voter raising their hand to indicate their request for aid). The wording of these final instructions should be carefully considered in order to provide helpful information to those who truly need assistance and avoid any condescending language.

Study

A mock election using CHILVote was designed to provide a benchmark for accessible voting solutions utilizing a computerized DRE system, measuring voting time, error rates, and user satisfaction. Any future methods that intend to address the needs of the visually impaired should have to show that they can perform at least as well on these three baseline measures. A direct comparison to the non-electronic accessible Vote-PAD as well as sighted voters use of a DRE are both made possible by this research. The development and testing of a DRE using an auditory interface with blind voters is essential to understanding the strengths and limitations of the platforms currently deployed in many polling places. Only after comparisons are made between DREs and other technologies can a viable course of action for providing equal voting rights to the entire population be determined.

Method

Subjects

21 blind subjects were recruited from the National Federation of the Blind's 2012 Texas state convention. Subjects were paid for their time. All subjects were fluent in English and legally blind. Ages ranged from 19-65 years, with a mean age of 45.2 (*SD* = 15.0 years). 11 males and 10 females participated.

All subjects reported being legally blind. "Legally blind" has a fairly broad definition that encompasses many levels of impairment. The *low vision* respondents are individuals retaining residual vision that may allow them to read larger point text or regular text with the assistance of a magnifying glass. The *light perception* respondents are individuals that are able to tell light from dark and the general direction of the light source. The *no vision* respondents are individuals with no vision or light perception. Table 1 displays the breakdown of respondents by magnitude of vision loss.

Table 1

Magnitude of Vision Loss among Respondents

	Number of People	Percentage of People
Low Vision	6	28.6%
Light Perception	3	14.3%
No Vision	12	57.1%

Several measures of technological ability and comfort were collected. These included self-reported computer expertise, a measure of time spent using a computer per week, frequency of ATM usage, and smartphone ownership. Computer expertise measures ranged from 1-10, with 1 indicating a novice and 10 indicating an expert. The mean level of expertise for blind subjects

was 6.60 (*SD*=2.52). 3 subjects had little experience (rating 1-3), 7 subjects had moderate experience (rating 5-7), and 11 subjects had a large amount of experience (rating 8-10). All subjects reported using a computer for at least 5 hours a week. Their computer usage frequency can be seen below in Table 2.

Table 2

Computer usage per week

	Number of People	Percentage of People
Between 5-20 hours	3	14.3%
Between 20-40 hours	8	38.1%
Over 40 hours	10	47.6%

ATM usage served as both a measure of technological competency and independence. Blind subjects' ATM usage can be seen below in Table 3. Most blind subjects (76.2%) owned smartphones.

Table 3

ATM usage

	Number of People	Percentage of People
Never	6	28.6%
Very Infrequently	3	14.3%
Occasionally (1-4 times a year)	2	9.5%
Often (~once a month)	5	23.8%
Frequently (~once a week or more)	5	23.8%

Table 4 shows the frequency of the subjects' ethnicity. Sighted data are from Everett, et al. (2008).

Table 4

Ethnicity of Survey Respondents

	Sighted	Blind
African American	31.3% (10)	23.8% (5)
American Indian	--	--
Asian American	--	--
Caucasian	56.3% (18)	57.1% (12)
Mexican American or Chicano	6.3% (2)	4.8% (1)
Multiracial	6.3% (2)	9.5% (2)
Other	--	4.8% (1)

Data were also collected using blindfolded subjects. Blindfolded subjects were not, and were not intended to be, an analog for blind individuals. In some sense, they represented a worst-case scenario that an accessible voting system might have to deal with: a person who has recently lost their eyesight and has little to no experience using assistive technologies. This is a very real possibility, as the World Health Organization reports that age-related macular degeneration (AMD) accounts for 50% of the causes of blindness in the United States (Resnikoff S, Pascolini D, Etya'ale D, et al., 2004). The blindfolded subjects were all college undergraduates, so they make up a very different demographic than do individuals with age-related visual degeneration. The blindfolded subjects in this experiment may represent a best-case scenario of results because they have not experienced any of the effects of aging and slowing on cognitive performance. Measuring any degradation in their performance and satisfaction can determine how well equipped a voting system is to handle the challenges of a newly blind individual.

The 30 blindfolded subjects for this study were Rice University undergraduates who received credit towards a course requirement. Ages ranged from 18-21 years, with a mean age of 19.4 years (*SD*=1.0). 27 males and 3 females participated.

The 32 sighted subjects using DREs and the 23 sighted subjects using paper ballots in this comparison are from data previously collected and published in a similar experiment on voting by Everett et al. (2008).

Design

A five-way between subjects design was used. The between subjects variables were visual condition, voting system, voting method, information condition, and level of education. This experiment allows for a comparison between four distinct groups: blind voters using a paper method, blind voters using a DRE, sighted voters using a paper method, and sighted voters using a DRE. Several variations of the between-subjects design were analyzed using a number of variables. Visual condition was a 3-level variable. Voters using CHILVote either had no vision (including light perception), low vision, or were blindfolded. Visual condition was reduced to a 2-level variable, blind and sighted, when the overall groups of blind and sighted subjects were compared. Voting system consisted of 2 levels; CHILVote and VoteBox. The voting system variable was synonymous with vision, since only blind subjects used CHILVote and only sighted subjects used VoteBox. Voting method was a 2-level variable, either paper or DRE. Information condition was a 2-level variable, consisting of directed and undirected conditions. Blind voters' information condition was dependent on their Braille reading ability. Those voting using only the audio interface were in the *directed* condition, and received verbal prompts that told them for whom they should vote. Those voting using the Braille voter's guide were in the *undirected* condition, and were instructed to make their own selections. Due to a limited number of subjects, only one information condition was used for each voting method. All blindfolded voters were in

the audio-only directed interface. Sighted voters were randomly assigned to be in one of the two conditions. Education was a 4-level variable, a self-report measure that consisted of four categories: did not complete high school, high school diploma or GED, some college or Associate's degree, and Bachelor's degree or higher. Table 5 shows the frequency for each category.

Table 5

Frequency of education level by visual condition

	Sighted	Blind	Blindfolded	General Population
High school or less	21.9% (7)	19.0% (4)	--	44.6%
Some college	46.9% (15)	52.4% (11)	100.0% (30)	28.3%
Bachelor's degree or higher	31.3% (10)	28.6% (6)	--	27.1%

Both sighted and blind subjects shared a similar background in both education and voting . Table 5 additionally contains information about the educational background of the general population of voters from the 2008 national election (U.S. Census Bureau, 2010). Both sighted and blind subjects also shared a similar background in voting history and unsurprisingly the younger, blindfolded subjects had far less experience voting (Table 8). This research was conducted in the October before the 2012 U.S. presidential election, which, for a vast number of the subjects, would have been the first national election in which they would be eligible to participate. Seven out of 30 (23.3%) undergraduate subjects had never participated in any type of election.

Table 6

Blind voter's average number of elections in previous voting experience

	None	1 to 8	9 to 15	More than 15
National Elections	14.3% (3)	42.9% (9)	9.5% (2)	28.6% (6)
Governmental Elections	33.3% (7)	19.0% (4)	4.8% (1)	38.1% (8)
Other Elections	47.6% (10)	9.5% (2)	9.5% (2)	28.6% (6)

Table 7

Sighted voter's (DRE) average number of elections in previous voting experience

	None	1 to 8	9 to 15	More than 15
National Elections	12.5% (4)	40.6% (13)	12.5% (4)	34.4% (11)
Governmental Elections	21.9% (7)	28.1% (9)	12.5% (4)	34.4% (11)
Other Elections	28.1% (9)	28.1% (9)	6.3% (2)	28.1% (9)

Table 8

Undergraduates' (blindfolded, using DRE) average number of elections in previous voting experience

	None	1 to 8	9 to 15	More than 15
National Elections	86.7% (26)	13.3% (4)	0.0% (0)	0.0% (0)
Governmental Elections	73.3% (22)	26.7% (8)	0.0% (0)	0.0% (0)
Other Elections	23.3% (7)	56.7% (17)	13.3% (4)	6.7% (2)

Subjects were self-selected into an information condition based on their ability to read Braille. Those who chose to read Braille were in the undirected condition. This was done out of necessity to keep the experiment at a reasonable length. The voter guide encompasses 22 single-spaced pages printed in font size 10. An audio version of the voter guide would be extremely

long. In addition, subjects listening to an audio version of a voter guide would not have the ability to skim sections or easily skip to the contest they were most interested in, in the way that both the sighted users in previous studies and Braille readers in the current study were able to. Blind subjects were asked to self-report their proficiency using Braille on a scale of 1-10, with 1 representing "I've never used it" and 10 representing "I'm an expert." On average, blind subjects rated themselves 6.67 (*SD* = 3.1). Subjects who chose to use the audio interface (10 subjects) rated themselves as having a Braille proficiency of 5 (*SD* = 3.0). Subjects who chose to use the Braille voters guide (11 subjects) rated themselves more highly proficient Braille readers, with an mean of 8.18 (*SD* = 2.6).

Determining error rates was challenging. In this study, the same method as was used for VotePAD was used for measuring error rates. Measuring effectiveness in the directed condition was a simple task of comparing the slate (a text version of the verbal prompts that told participants for which candidates to vote) to the marked ballot (how the participants actually voted). Attempting to determine voter intent in the undirected condition was much more difficult. Everett et al. (2006) solved this problem by having their participants vote three times, on three different types of ballots. A simple majority rules criterion was established. For example, if a participant voted for Candidate A on ballots 1 and 2, but Candidate B on ballot 3, it was determined that the voter intended to vote for Candidate A, and ballot 3 would be marked as having an error. Everett et al. (2008) used a similar method for determining voter intention when using more time-intensive voting methods. In Experiment 1 of their study, participants voted only twice, making it impossible to determine voter intent if there were inconsistencies between the two ballots. However, the experimenters added a third measure of voter intent (an exit

interview), that carried equal weight with the other two ballots, and allowed them to determine errors.

In the current study, subjects in the undirected condition were asked to vocalize the choices they were making during the voting process. This could be as simple as saying the candidate's first name or the party name. This allowed experimenters to determine that the votes on CHILVote's ballot which were consistent with the verbal record did correctly represent voter intent. For inconsistent votes, the subject's verbal record was counted as the definitive measure of voter intent. Having subjects vote multiple times would have been too lengthy for a single experimental session.

This use of in-line verbal error reporting is one of the largest changes in the methodology used between otherwise identical ballots, and may have impacted subject error rates. In future work, it would be interesting to see if sighted voters' error rates are affected by the kind of error reporting used in the experiment. In-line error reporting provides subjects with a close temporal association between the subject's selection and the ballot. Immediate error reporting means that there is no need for the subject to remember or associate any significance with the individual candidate or proposition after completing a race. Subjects using in-line reporting can completely focus on the next race, whereas sighted voters (using the "majority rules" error measurement) had to remember the way they were voting from race to race and ballot to ballot. However, these sighted voters used ballots with real political parties. Sighted voters' ballots adhered to Texas state law. These ballots presented the candidates in order of political party, with each race ordered in the same fashion. Although sighted subjects were not able to immediately report their choices, they did vote for candidates associated with real political parties. Political parties come

with their own internal meanings and significance, allowing subjects to more directly identify with the candidate selections than they would have been able to had fictional candidate parties been used (as they were with visually impaired voters). The differing use of error reporting methods should be kept in mind when comparing error measurements between blind and sighted groups.

Errors can be classified into three categories: overvotes, undervotes, and wrong choice errors. An overvote error occurs if a voter chooses two candidates for a race in which only a single selection is allowed. This type of overvote error is part of the standard "residual vote" rate and can be measured by looking at the results in actual elections. Overvotes of this type cannot occur when using a DRE as the software is designed to prevent them. A different type of overvote error occurs if a voter makes a selection for a race s/he had originally intended to skip (either due to instructions in the directed information conditions, or personal preference in the undirected condition). These are referred to as extra votes. A distinction is also drawn between two types of undervotes: omissions and abstentions. An omission occurs if a voter fails to choose a candidate for a race in which s/he had intended to vote. An abstention occurs when a voter omits a race on purpose; this is not actually an error. Finally, a wrong choice error occurs when a voter makes a selection other than the one intended (Everett et al., 2008).

Materials and Procedure

Subjects who were comfortable with reading Braille were placed in the undirected condition. Those in the undirected condition received a voter guide (based on guides produced by the League of Women Voters), and were instructed to use it like they would in a real election

(either by reading it completely, skimming it, or not using it at all). The voter's guide was transcribed in Braille, and provided additional information about the candidates and their position on certain issues. Subjects in this condition made their own choices about what candidates and propositions to vote for.

In the directed condition, subjects were given a scenario by the experimenter before voting. This scenario directed them to vote for all members of a given party (National party), except for in one race where they strongly favored the opposing candidate (Jeffersonian party). Subjects were told to skip and leave blank any races where a National candidate party was not running (there were 2 such instances on the experimental ballot). This small number of omissions was included to be more representative of real-world voting patterns, in which people do not always vote for every race presented on the ballot. Subjects were told to vote No for all propositions. These instructions were summarized again and subjects were asked for verbal confirmation that they understood how they were being asked to vote. They were also informed that this was not intended to be a memory test and that they should ask for a reminder of the information if needed (indeed, several subjects did).

Both the voter guide and the verbal voting scenario (synonymous with the slates used in sighted experiments) were as similar as possible to those used in previous studies (Byrne et al., 2007; Everett et al., 2006; Greene, 2008; Greene et al., 2006). One difference was the modality in which they were provided (either tactilely with Braille or orally by the experimenter). In the current study, the political parties of the candidates were changed to fictional ones. National, Jeffersonian, Liberty, and Independent parties were used. This was to prevent any dissent among the subjects who were adverse to voting for an individual whose party they may not support in a

real election. Sighted subjects were given a paper that tells them for who them should vote and vote in a private room. This dynamic changes quite a bit when working with blind subjects, as there was more interaction between subject and experimenter. Blind subjects were verbally instructed for whom to vote, which itself feels like a different interaction than being handed a piece of paper. Relying on fictional political parties prevented any superfluous questioning by the subject and was intended to support the researcher's goals to make this experiment as similar as possible to an actual election.

The paper bubble ballot used in this study was identical in content to the ballot used in previous studies. They were very similar in layout. They presented the races and propositions in the same order. The candidate names were fictional, and created by a random name generator. The ballot was based on actual optical scan ballots in use in the United States (Byrne et al., 2007). Real ballots used in the state of Texas are required to have candidates arranged by political party (for example, all Republican candidates must be listed first in a race). The laws governing the order of candidates on a ballot vary across the United States. Because it is not practical to hand the blind subjects a list of whom to vote for (a large percentage do not read Braille, an audio list would interfere with the audio voting system, etc.), additional changes on the ballot had to be made. The candidates were randomized based on party, so sometimes a National candidate would be listed first, sometimes a Jeffersonian candidate, etc. This was done so that subjects who were told to vote for "all National candidates on the ballot" did not simply have the easy task of always voting for the first person. Instead, they had to pay attention to each individual candidate in order to vote without errors. The order that the candidates were placed matched up with the slates from previous studies, so that the blind subjects would still be voting

for candidate #2 in race one, candidate #3 in race two, candidate #1 in race three, etc. By reordering the parties, it became possible to reduce the cognitive load on the voters, since they only had to remember National party, not a list of 21 individual candidate names.

To begin the study, subjects gave their informed consent and were given the button box to explore tactilely and with any residual vision they may possess. A brief description of the layout of the buttons and their functionality was provided. All voting audio was played through headphones. Subjects were given the headphones to adjust and familiarized with the volume control location on the headphone cord. Subjects in the directed condition were informed about their voting scenario, and those in the undirected condition were provided with the voter guide and time to read through it, if desired. Subjects were given an opportunity to ask any questions before they began voting. Voting was timed by the CHILVote program. Time started as soon as the audio instructions began playing, and ended when the subject confirmed their desire to cast the ballot by pressing the select button. Subjects sat during the entire voting process, and were provided with ample table space to allow them to arrange the button box, headphone cord, and voter guide (if in the undirected condition) in any way they desired. The screen depicting the races and candidates faced away from the subjects, so low vision subjects did not have any advantage in that sense.

Blindfolded subjects were blindfolded using sleep masks after reading and signing the consent form, but before beginning the experiment. All blindfolded subjects were placed in the directed voting scenario condition, which proceeded in an identical manner to the blind subjects in the directed condition.

After subjects completed voting, they were provided orally with several surveys by the

experimenter. Blindfolded and sighted subjects received these surveys in writing. A general survey asked demographic questions and voting experience questions. The System Usability Scale (SUS), a ten item Likert scale, assessed subject's agreement or disagreement with statements about the voting method, such as "I thought the system was easy to use" (Brooke, 1996).

Results

No Vision vs. Low Vision vs. Blindfolded (CHILVote)

The first question this research sought to address is if CHILVote equally serves the needs of individuals with different levels of vision. This included individuals with some residual vision as well as newly blind voters, to see if CHILVote provides an interface that serves these groups in the same way as voters that may be acquainted with using accessible technology. This was a 3x3x2 ANOVA looking at levels of vision (no vision, low vision, or blindfolded), the levels of education (high school or G.E.D, some college or associate's degree, or a bachelor's degree or higher), and experimental condition (directed or undirected).

Errors

Error rates can first be considered on a per-race basis. There were 27 races (21 offices and 6 propositions), which meant voters had 27 opportunities to make an error. Per-race error rates were calculated by summing the total errors and dividing by the possibilities for errors. The overall error rate for CHILVote was 1.1% (SD = 2.8). Overall error rates are shown in Figure 6.

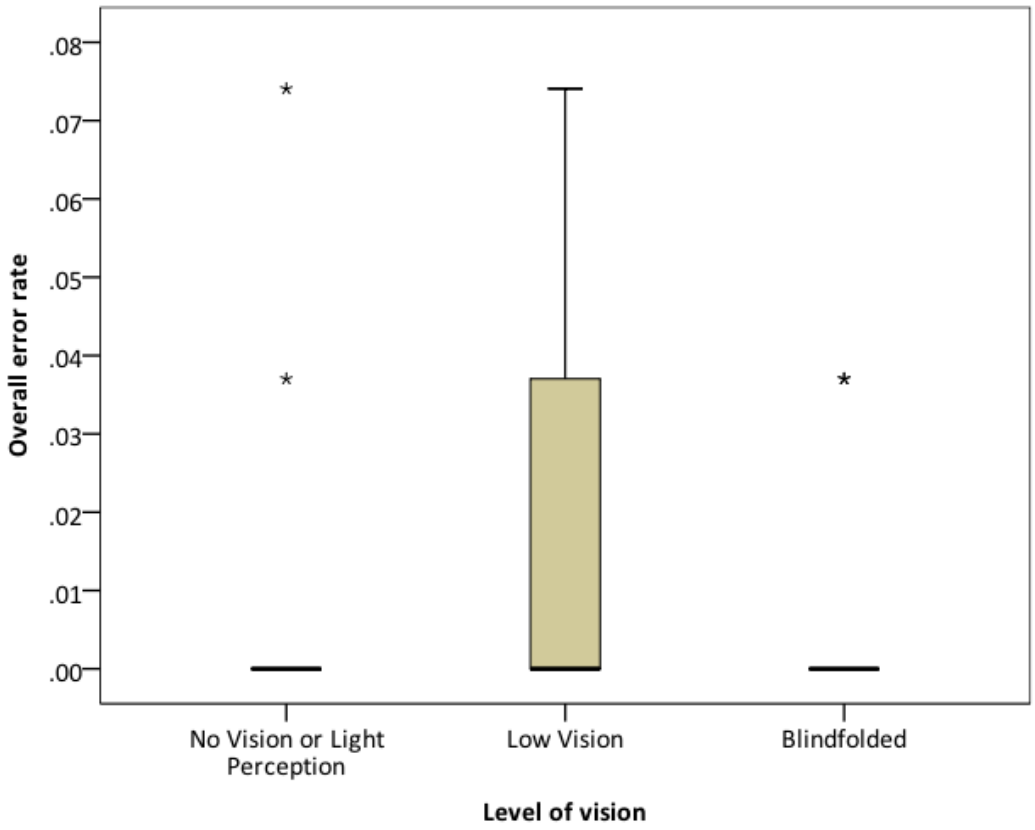

Figure 6. Distribution of overall error rates by level of vision

Two blindfolded subjects were excluded from the analysis because there were issues recording the data. One blind and one blindfolded subject were excluded due to both having an inflated overall error rate of 22% (greater than 3 standard deviations above the mean, the calculation used here to indicate an outlier). This specific blind subject was more focused on testing what the voting system was capable of rather than treating their experience as an analog to a real election, so their high error rate was unsurprising to the experimenter, and they were justifiably removed from the analysis of error rates. The per-race error rates by error type are displayed in Figure 7.

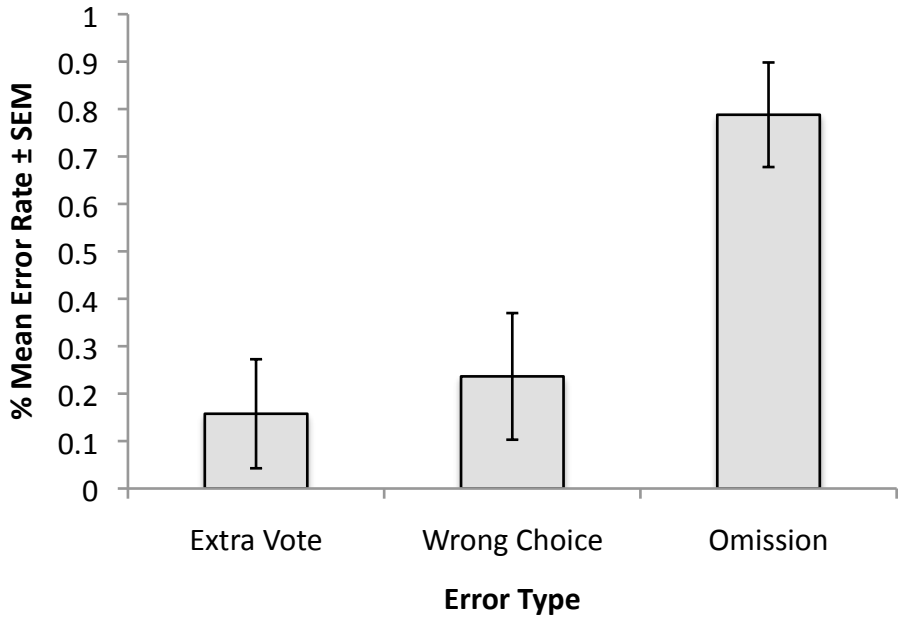

Figure 7. Error rate by type among blind and blindfolded voters using CHILVote

Blind subjects choosing their own votes in the undirected condition made no errors compared to blind subjects in the directed condition (M = 3.70%, SD = 4.14%). Subjects with no vision had a mean error rate of 1.59% (SD = 3.47%), subjects with low vision had a mean error rate of 1.85% (SD = 3.10%), and blindfolded subjects had a mean error rate of 0.82% (SD = 2.97%). Experimental condition was highly significance, $F(1, 47) = 13.32$, $MSE = .55$, $p = .001$, $\eta^2 = .17$. This is driven by the fact that all blindfolded subjects were in the directed condition. There was also a significant effect of visual condition $F(2, 47) = 5.08$, $MSE = .55$, $p = .01$, $\eta^2 = .13$. There was no statistically-reliable difference between error rates as a function of education ($p = .138$).

As seen below in Table 9, reviewing could take anywhere from less than half of a minute to upwards of twelve minutes. There were 10 blind subjects in the directed condition, but one

was excluded from the error analysis. Among the 9 ballots in the directed condition (the only condition where errors occurred), 5 ballots contained one or more errors, and the average error rate was 3.70% (*SD* = 4.14%). Omission errors occurred most frequently, 1.65% (*SD* = 3.26%). Wrong choice errors occurred at a rate of 1.24% (*SD* = 1.85%). Extra vote errors, which could only be made on races 7 and 14 which subjects were originally instructed to skip, occurred at rate of 0.82% (*SD* = 1.63%). To put this in perspective, among the 5 ballots containing errors, there were a total of 9 errors: 4 omissions, 3 wrong choices, and 2 extra votes.

Out of 5 subjects with errors on their final ballot, 2 had reviewed their choices. Out of 3 subjects with no errors on their final ballot, 2 had reviewed their choices. None of the subjects with errors ever went back and fixed them, even after hearing them in the review choices section, but for one subject the review process introduced two omission errors that otherwise would not have occurred. When using the review choices section, they entered back into the ballot, and it appears that they tried to select their vote again. This actually caused the system to deselect their vote, which played the message “deselected.” When the subject was returned to the review screen, the contest that they had just changed was played for review again, with the message “No selection was made.” This happened for contests 8 and 9, the two contests following contest 7, where subjects were required to intentionally abstain because of the lack of a National party candidate. After these two sequential errors, the subject continued reviewing as normal and made no further errors. Had it not been for these two introduced omissions, the subject would not have had any errors on their final ballot, and would have reduced the overall error rate to 2.88% (*SD* = 4.05%).

The directed condition itself seems to have introduced most of the errors into these results. To best simulate a real voter in an actual election, with the intention of reducing mental load and memory requirements, subjects were given a simple voting scenario to remember. Three races were affected by these requirements. Races 7 and 14, subjects were to make an intentional abstention, because there was no National candidate running for office. For race 4, subjects were supposed to select the candidate of the other major party (the Jeffersonian party), since this was not intended to be a straight-party ballot. Three subjects made a wrong choice error in race 4, all voting for the National party, which is the affiliation they were intended to choose to every other race *except* 4. Two subjects made an extra vote on race 7, choosing the independent candidate instead of abstaining from the contest. Races 4 and 7 account for 55.6% (5 out of 9) of the directed condition errors, and 100% of the wrong choice (3 out of 3) and extra vote errors (2 out of 2). If these two races had been ignored in the error analysis, the overall error rate would have been 1.64% (*SD* = 3.27%), which is much more similar to the overall error rates that have been seen in previous studies with sighted individuals using DREs (for example, Everett et al., 2008).

Finally, if both known sources for error (review screen deselections and directed condition oddities) are eliminated, only 1 of the 9 directed condition ballots contains errors. The overall error rate would fall to 0.82% (*SD* = 2.47%), consisting of only omission errors made by a single subject.

Ballot Completion Time

Blindfolded students (n=30) took an average of 885.4 seconds (*SD* = 395.4), about 14.8 minutes. Subjects with no vision or only light perception (n=14) took an average of 981.3 seconds (*SD* = 345.6), about 16.4 minutes. Subjects with low vision (n=6) took an average of

1129.9 seconds (*SD* = 515.3), about 18.8 minutes (see Figure 8). However, there were no reliable effects of visual condition, experimental condition, or education on ballot completion time (all p values > .35).

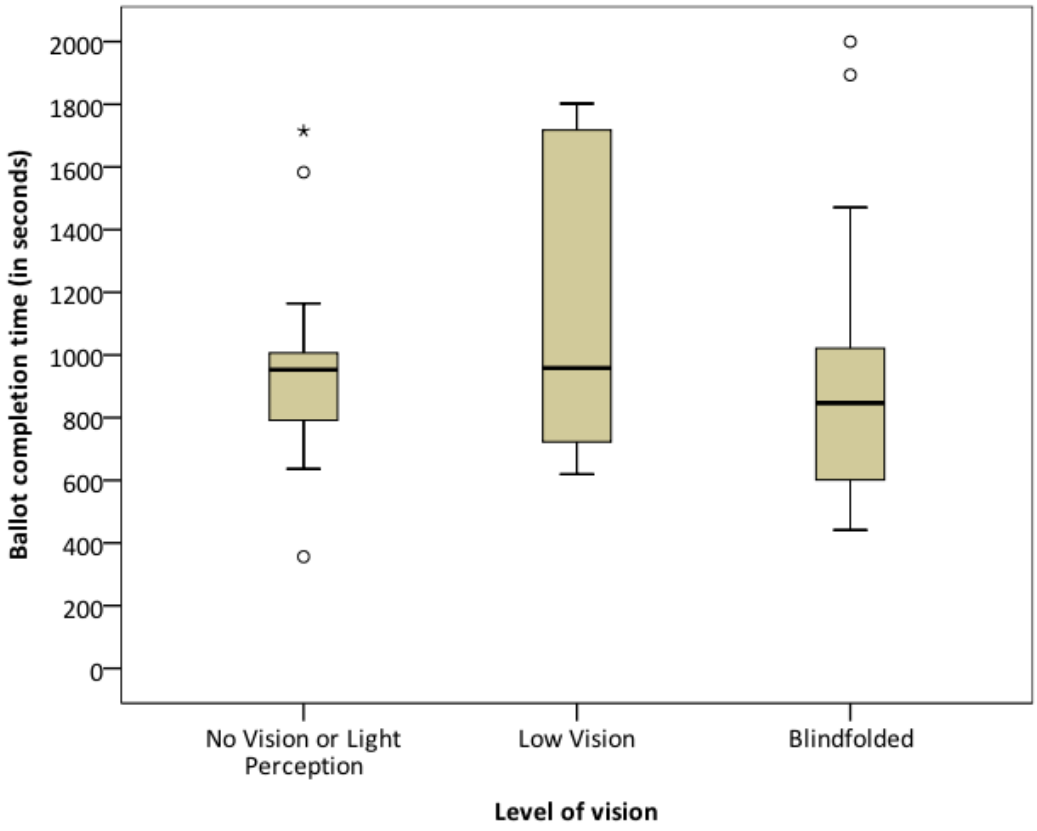

Figure 8. Distribution of ballot completion times by level of vision

Total voting time was broken down into two components: voting time and reviewing time. On average, voting time among the blind subjects took 882.4 seconds (*SD* = 326.2) and reviewing time took 143.4 seconds (*SD* = 181.5). There was quite a range of speeds, and the fastest and slowest overall, voting, and reviewing times can be seen in Table 9. In both cases, the fastest and slowest subjects in the voting portion were also the fastest and slowest overall voters. However, neither of these individuals were either the fastest or slowest reviewers.

Table 9

Fastest and slowest voting times among blind subjects

	Fastest Subject	Slowest Subject
Overall	356.2 sec (5.9 min)*	1,802.5 sec (30 min)**
Voting	322.5 sec (5.4 min)*	1,763.2 sec (29.4 min)**
Reviewing	15.6 sec (0.3 min)	743.2 sec (12.4 min)

* = Both times belong to subject 310
** = Both times belong to subject 319

The blind subjects utilized the change audio speed menu much more than the blindfolded subjects. 52% of bind subjects (11 out of 21) accessed the change audio speed menu. 8 ended up making it faster (6 chose the 166% speed and 2 increased the audio speed all the way to the maximum 200%). 2 subjects slowed down the speed to 100%. The final subject that accessed the audio speed menu ended up leaving it as the same speed as it was set to by default (133%).

Out of 28 blindfolded subjects, only 1 individual (3.5%) accessed the change audio speed menu. This one person made the speech rate faster by increasing the speed to 200%.

Subjective Usability

Figure 7 depicts the mean SUS rating as a function of visual condition. Both no vision (M = 86.3, SD = 17.9) and low vision voters (M = 97.5, SD = 4.2) showed high ratings, with blindfolded subjects rating the usability as slightly worse (M = 72.0, SD = 24.9), see Figure 9. However, there was no reliable effect of visual condition, experimental condition, or education (all p values > .12)

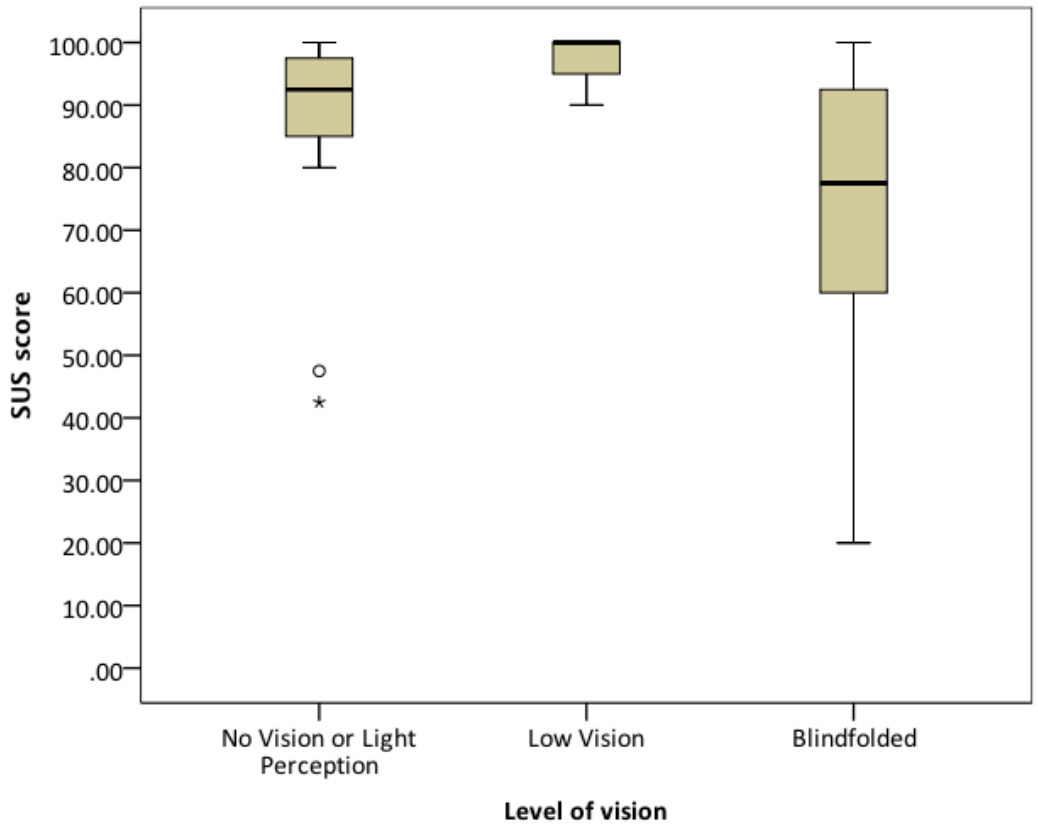

Figure 9. Distribution of subjective usability score (SUS) by visual condition.

Blind vs. Sighted (DRE)

The second question that can be asked is what difference, if any, exist between sighted and blind voters using a DRE. A 2x2x3 ANOVA was used. The first variable, level of vision (blind vs. sighted) was equivalent to the type of system used, as only blind voters used the auditory CHILVote interface and only sighted voters used the visual VoteBox interface. Data from the sighted subjects used in this analysis was previously collected by Everett et al. (2008). Blindfolded subjects were excluded from this analysis. Again, the ballots were nearly identical in content between these two interfaces. Information condition was a two level variable, with voters either being directed or undirected. Finally, education was the three level variable.

Errors

Sighted subjects in the undirected condition (*M* = 2.31%, *SD* = 2.76*%)* had more errors than in the directed condition (*M* = 0.19%, *SD* = 0.83%). Blind subjects showed the opposite pattern, with more errors in the directed condition (*M* = 3.29%, *SD* = 3.43%) than in the undirected condition in which they made no errors (Figure 10).

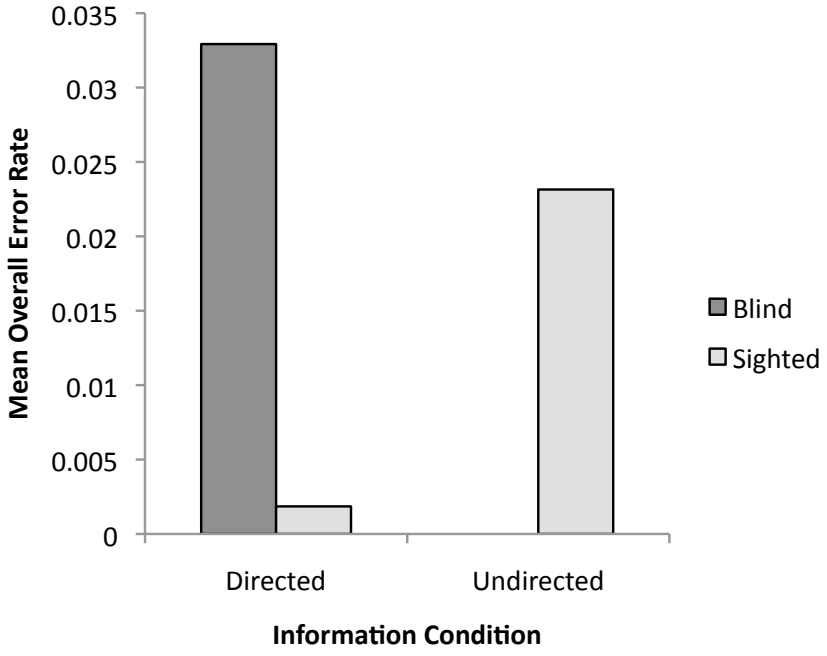

Figure 10. Crossover interaction of error rates between visual and information condition.

When examining per-race error rates there were no main effects of visual condition (*F(*1, 48) = 1.21, *MSE* = .0004, *p* = .28, η^2 =.02), information condition (*F(*1, 48) = 1.73, *MSE* = .0004, *p* = .20, η^2 =.03), or level of education (*F(*2, 48) = 0.64, *MSE* = .0004, *p* = .28, η^2 =.02). However, there was a significant crossover interaction, *F*(1, 48) = 13.62, *MSE* = .0004, *p* = .010,

η^2 =.21, as shown in Figure 8. This may be due to the fact that blind subjects in the undirected condition had no errors.

Ballot Completion Time

Overall ballot completion times are presented in Figure 11. As expected, there was an overall effect of visual condition on ballot completion time, with blind voters having much longer times than sighted voters, $F(1, 51) = 32.36$, $MSE = 114{,}935.33$, $p < .001$, $\eta^2 = .39$. None of the effects of information condition or education were reliable, nor were there any interactions (all p values > .23).

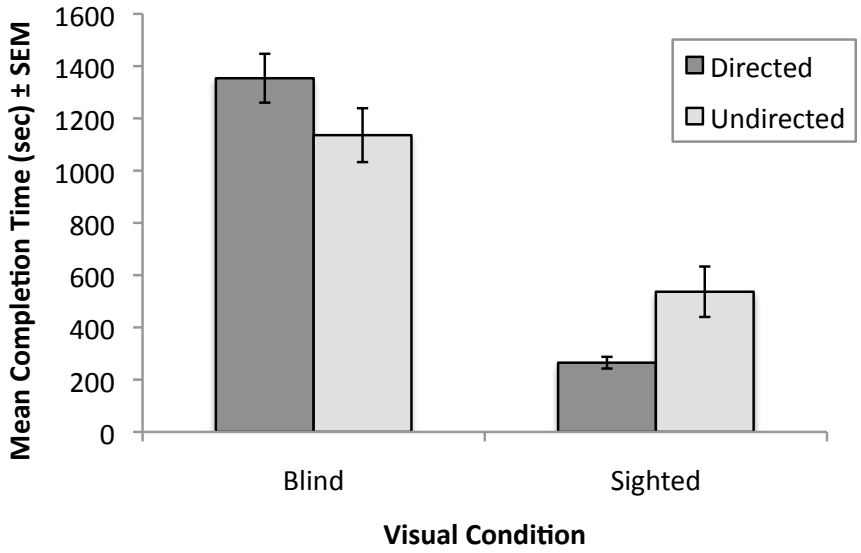

Figure 11. Mean voting time by visual condition and information condition when voting by DRE

Subjective Usability

Both sighed and blind voters showed a similar high ratings of DRE methods, both bordering on a score of 90. Sighted voters gave VoteBox an average SUS score of 90.1 (*SD* =

17.1) and blind voters gave CHILVote an average SUS score of 89.5 (*SD* = 16). There was no reliable effect of visual condition, information condition, or education (all p vales > .22).

Blind vs. Sighted (paper vs. DRE)

Finally, an overall assessment of voting when considering both group of voters (blind and sighted) across both methods of voting (both DRE and paper) was addressed. This 2x2 ANOVA aimed to answer the question of the differences in these groups and where future systems will need to improve on equality. Data from the sighted subjects used in this analysis was previously collected by Everett et al. (2008).

Ballot Completion Time

Time was found to be the separating factor between blind and sighted voters using paper ballots (Piner & Byrne, 2010). The same appears to be true across voting methods, with blind voters taking consistently longer than sighted voters, see Figure 12. Listed in Table 10 are the average voting times, given in minutes. Sighted subjects were slightly faster when using a paper ballot (a difference in means of 0.95 minutes). Blind subjects were much faster when using the DRE (a difference in means of 8.1 minutes).

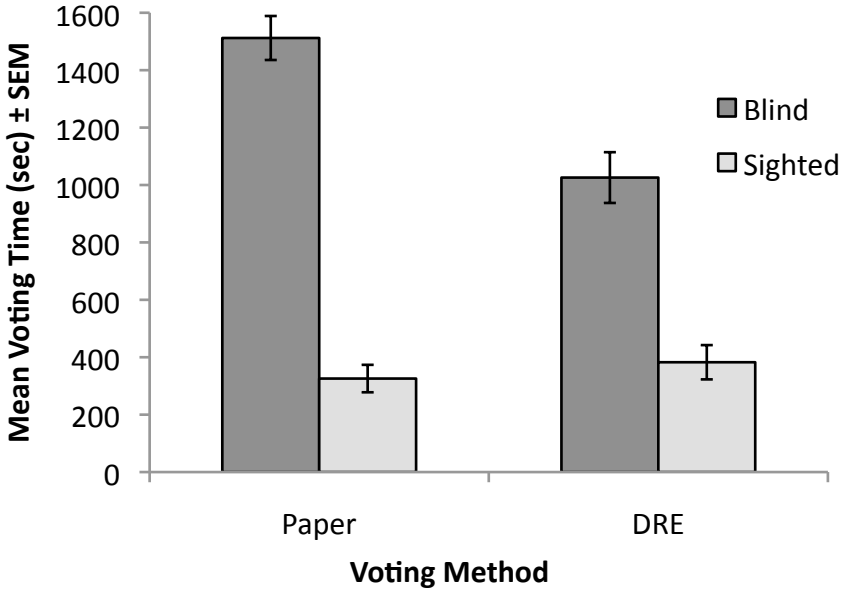

Figure 12. Interaction between voting method and visual condition on overall ballot completion time.

Table 10

Mean voting time by visual condition and voting method. Bold numbers indicate the faster times among different levels of vision.

	Sighted (min)	Blind (min)
Paper Ballot	**5.43**	25.20
	(*SD* = 3.82)	(*SD* = 5.42)
DRE	6.38	**17.10**
	(*SD* = 5.63)	(*SD* = 6.59)

In this study, there was a significant interaction between vision and voting method, $F(1, 93) = 15.39$, $MSE = 106{,}340.34$, $p < .001$, $\eta^2 = .05$, see Figure 10. Sighted voters actually take slightly longer when using DREs, but there is an enormous improvement (on the scale of 8 minutes) when blind voters use a DRE rather than traditional paper method. A significant main

effect of both visual condition and voting method was found. As expected, there was a large, significant main effect of vision, $F(1, 93) = 174.61$, $MSE = 106{,}340.34$, $p < .001$, $\eta^2 = .61$, with blind subjects taking longer to vote than sighted subjects.

Errors

Sighted voters using paper ($M = 1.23\%$, $SD = 4.11\%$), sighted voters using a DRE ($M = 0.79\%$, $SD = 1.85\%$), blind voter using paper ($M = 1.74\%$, $SD = 3.24\%$), and blind voters using a DRE ($M = 1.49\%$, $SD = 2.79\%$) were all around the same level of per-race errors. The per-race error rates are displayed in Figure 13. There was no statistically-reliable difference between error rates as a function of visual condition or voting method (all p values > .85).

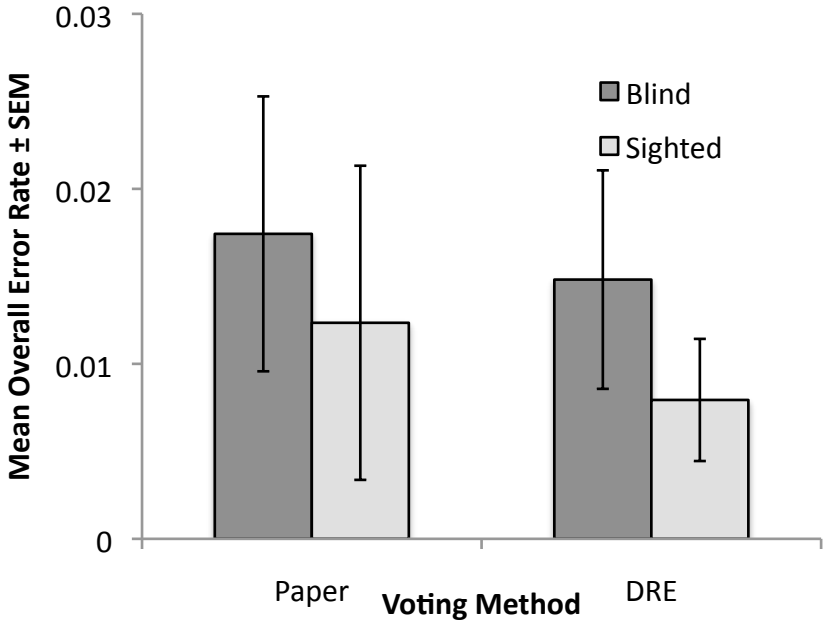

Figure 13. Mean error rate by visual condition and voting method.

Subjective Usability

Both sighed and blind voters, across voting methods, showed similar high ratings of DRE methods, from the high eighties to the low nineties. Blind subjects gave paper ballots a mean

score of 87.36 (*SD* = 15.4) and DREs a mean score of 89.52 (*SD* = 15.89). Sighted subjects gave paper ballots a mean score of 85.00 (*SD* = 19.80) and DREs a mean score of 90.08 (*SD* = 17.14). Although both groups had slightly higher SUS ratings for DREs than paper ballots, there was no reliable effect of voting method or visual condition (all p values > .11).

Interface Design

Among the voters who used the button box in conjunction with CHILVote, 81% of respondents (17 out of the 21) said that they felt the six different buttons on the button box were easy to discriminate and tell which one performed which function. 1 respondent felt this task was difficult, and the final 3 respondents rated the level of difficulty as average (Figure 14). This provides a nice confirmation that the button box was working as intended among a wide range of users and provided tactilely distinctive inputs.

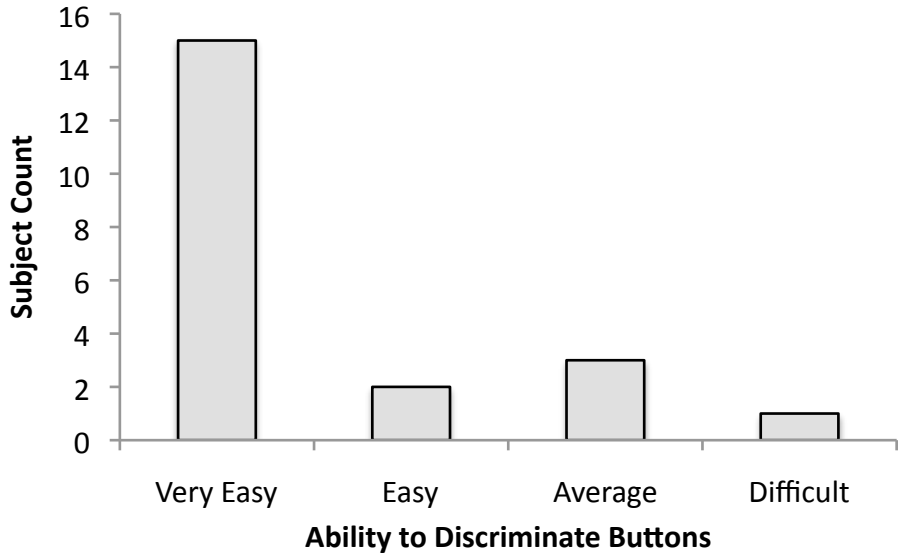

Figure 14. Blind subjects' ability to discriminate between the different interface buttons on the button box input device.

Preliminary survey questions (Piner & Byrne, 2011) indicated that a majority of blind individuals (85.4%) were familiar and comfortable using and understanding synthesized voices. Most respondents had no preference regarding the gender of the audio voice, but among those with a preference male voices were significantly more preferable. The ability for the user to be able to change audio volume and speed were both highly desired aspects of a computerized audio interface (83.9% and 79.4%, respectively). Combining all of these preferences resulted in the decision to use the male NeoSpeech voice "Paul" with CHILVote.

After listening to "Paul" in the context of CHILVote's interface, subjects responded about their ability to understand the system's synthesize voice on a scale of 1 to 10 (with 10 meaning the voice was easy to understand), see Figure 15.

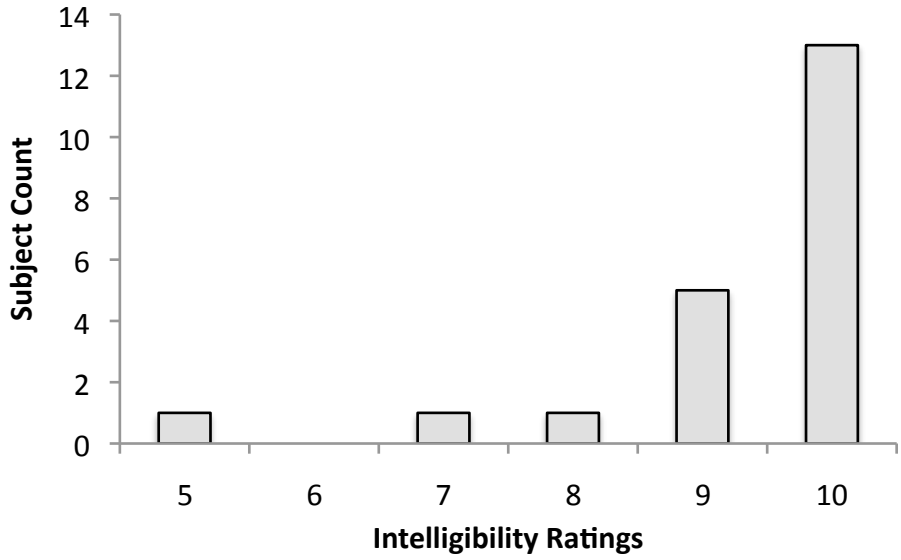

Figure 15. Intelligibility ratings given to the synthesized voice by blind subjects, with higher numbers indicating higher levels of intelligibility.

90.5% of subjects (19 out of the 21) rated the voice as easy to understand, as an 8 or higher on the 10 point scale. In fact, nearly two-thirds of the subjects (61.9%, 13 out of the 21) gave the voice a 10 out of 10 as far as understandability. The remaining two subjects rated the voice as a 5 and a 7, indicating a moderate level of understandability.

The results from the button box and audio serve to confirm the choices made in the interface design and are a good indication that the design of this voting method does in fact serve the needs of the widely varied blind population.

Per Race Timing Data

Individual race timing data were collected for each blind subject. This encompassed everything from the time the subject entered the race and heard the first instruction to the time they navigated either forwards or backwards to the next race or section. Outliers were defined as any data point more than 1.5 interquartile ranges (IQRs) below the first quartile or above the third quartile. The intention was to filter out only abnormally fast or slow races, not entire subjects. This was first approached by subtracting the subject's race mean or proposition mean from each race time. The remaining times were then used to filter outliers. All instances of races that fell more than 1.5 IQRs below the first quartile were checked for completion. If the subject had voted in the race or listened to the complete audio, this race was left in. If, from the audio transcript, it appears the subject accidentally skipped the race, it was removed from analysis.

The directed and undirected conditions show different time profiles due to the differential nature of the tasks being performed by the voters (Figure 16).

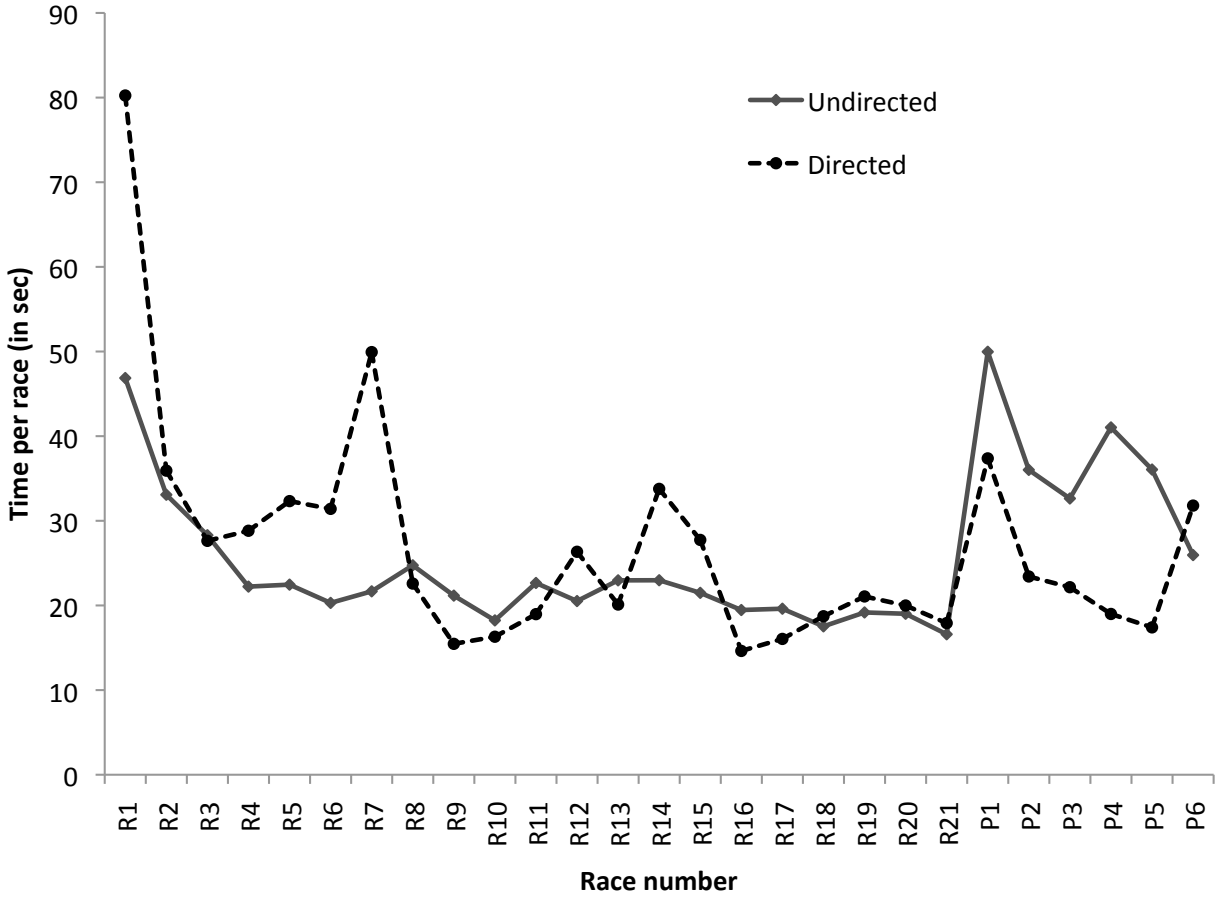

Figure 16. Progression of per-race times by information condition

It can be seen that a subject's progression through the ballot is not a linear experience (Figure 14). The patterns of voting for the directed subjects differs quite a bit from the undirected subjects because of the instruction set they were given. Both groups spend quite a bit of time on race 1, exploring the interface, possibly replaying the instructions, and getting a feel for the system. This large spike is also due to time spent in the audio speed menu; many subjects listened to part of the first race and then decided to alter their audio speeds. Undirected subjects, voting as if this were an actual election, appear to quickly get used to using the interface, and level out at spending around 20 seconds per race. Directed subjects are also in this pattern until

they reach race 7, the first race without a National candidate, where they were originally told to make an omission and intentionally undervote.

Multiple behaviors may have contributed to the race 7 spike. Subjects moved through the candidate names multiple times, searching for a National candidate they may have overlooked on the first pass. If they decided to proceed with the omission, the undervote warning audio was played. The warning message itself not only takes time to convey (23 seconds at the middle speed) but requires an additional action from the subject to either confirm their desire to undervote and move on to the next contest, or to return to the previous contest. They may also pause here and ask the experimenter to verify that they are supposed to leave contest blank. This situation reoccurs during race 14, where a second spike in time appears for directed subjects, although it is not as large as the first. Presumably, subjects are still searching the candidates to make sure that they did not miss something, but the undervote warning is not a surprise this time and they may not choose to listen to it in its entirety.

When subjects reach the first proposition, after completing 21 very similar race contests, one sees a peak in latency from both information conditions. Propositions sound very different because of this large paragraph of text. They also take much longer to play than the individual candidates in a race. The newness and length of the first proposition both contribute to the spike in time seen at race 22. Directed subjects have been told how to vote in the propositions, so can utilize the barge-through on the audio to go directly to the responses. This is most likely why the time for the directed subjects falls well under the time for the undirected subjects in the majority of the propositions. For undirected subjects, the propositions are a somewhat different experience. The propositions responses alone (“Yes” or “No”) are uninformative and require

subjects to listen to the entire text of the proposition, which is a challenging piece of text whether presented by audition or text, filled with legal jargon and dealing with specific changes to certain laws. Having to listen to the lengthy audio, understand it, and make an informed decision all increase the amount of time that undirected subjects spend on the propositions.

Audio Speed

A negative correlation between ballot completion time and user-set audio speed (with higher numbers indicating faster speeds) was found $r(18) = -.55$, $p = .01$ (Figure 17). This is the expected direction of this effect, with fast audio speeds correlating with faster overall ballot completion time. The mean voting times based on audio speed can be seen in Table 11. There was a significant difference between groups as determined by a one-way ANOVA ($F(3, 16) = 4.89$, $MSE = 96932.07$, $p = .013$, $\eta^2 = .48$).

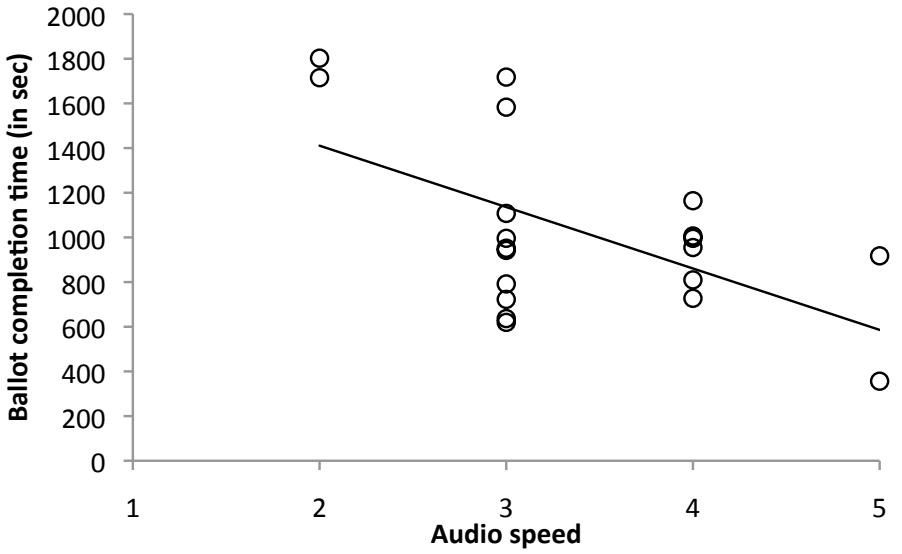

Figure 17. Correlation between ballot completion time and a user-set audio speed which ranged from 1 (slowest) to 5 (fastest).

Table 11

Voting times by subject-selected audio speed

	Voting time in minutes
Speed 2 (100%)	29.3 (*SD*=1.0) n=2
Speed 3 (133%)	16.8 (*SD*=6.3) n=10
Speed 4 (166%)	15.7 (*SD*=2.6) n=6
Speed 5 (200%)	10.6 (*SD*=6.6) n=2

Braille

Self-reported Braille expertise, on a scale of 1-10, correlated significantly with two measures. The correlation between Braille expertise and audio speed was $r(20) = .49$, $p = .03$, with high levels of Braille ability related to the use of faster audio speeds. The correlation between Braille expertise and computer expertise was $r(21) = .58$, $p = .006$. No other correlations in the "technology" category were found, including among computer usage, ATM usage, and smartphone ownership.

Qualitative Results

Subjects' qualitative responses varied greatly, covering topics from positive interface aspects to comparisons with current systems with things they would like to see added or changed. Multiple subject comments focused on the ability to change audio speed using the CHILVote interface. One subject said:

> The one they have currently have in place, I don't know if you can speed up the speech and I thought to myself "My God, I could do this much faster if that damn thing would

> talk faster." Cause I mean it talks…like…this. And you know, we who are proficient in that don't have patient for that. So I'm like, "My God!". I love that you can speed up the speech, that's wonderful.

Another subject said "I liked the fact that you can adjust the speed to a speed you like," and also compared CHILVote to their previous voting experience saying "I didn't like the one that I used because I couldn't adjust the speed, I thought the man was talking too slow and I couldn't speed him up."

In addition to the voice speed, one subject commented on improving the quality of the synthesized voice chosen, saying "You could improve the voice a little bit, it was understandable but it was a little shaky. As far as the voting system, the voting system is beautiful." Another subject said "This audio was the clearest audio I've heard."

Physically, some subjects had a problem with the button size. "The buttons I felt were a little too large, because if you didn't hit it exactly in the middle it wouldn't work. So if the buttons were a little smaller, I think it would take care of that. That's the only thing I didn't like about it." Another subject had a similar suggestion saying "Maybe make the buttons a little bit smaller. They were kind of big." One subject pointed out that the size of CHILVote's setup made it somewhat more transportable and easy to arrange than preexisting DREs, saying "I thought [*CHILVote*] was really easy. I thought the one in place was really easy too. I've never had any difficulties. But it's an awful big piece of equipment and [*CHILVote]* was smaller, I kind of thought that was cool."

There were some suggestions about interface improvement to CHILVote. One subject felt that "It gives the instructions too many times. You should be able to switch them on and off. So if

you already know how to do it, you don't need the instructions anymore." Another subject felt the select/deselect mechanism needed to be clarified more, saying "When you go back, you deselect one. When you go back and select you deselect one. That was the only thing that was sort of unclear to me." A final subject made a suggestion about navigating to an individual contest from the review choices section, saying:

> About the only thing I would have come up with is if you did want to make a change instead of having to hit the select button as it instructed you could just do the left arrow to get to the specific race you wanted to change, and then up or down arrow to the other choice, and then hit your select button from that. That would be the only change I'd recommend.

Many subjects compared using CHILVote to what they had voted on in previous real elections. One woman spoke of her experience using punchcards, and transitioning to using an audio interface on a DRE:

> Yes, when they had the punch cards, it was just horrible. I would get my niece and she would go through it and tell me. She would read it to me and to me she was honest. Sometimes some of the people complain that before they got the voice voting machine that people would vote in the way that they wanted to for them and that discouraged a lot of disabled people from voting. But since they've got the voice we're trying to get more people to vote.

Not all subjects had used accessible voting methods before, but those who had often compared their voting experiences to CHILVote. One woman spoke about privacy concerns she had when using any system in a real election:

> I mean, I worry a little bit about privacy and discrimination. I had trouble with that on the, we actually had the electronic voting machine, that was the first time I'd ever had that, before it had been on paper. It took me a little bit to figure out the system. It's kind of hard because you don't want to ask, I mean, not that you don't want to, but the whole… I want to feel like my vote is private. I don't want anyone else to see what I'm voting for. Especially being a certain supported in a very one-party state.

One subject referred to a previous DRE that they had used, saying "It's pretty tedious. It just doesn't feel good to use it, I don't know, it's ugly," however they felt that CHILVote was "a pretty comprehensive system. I think though that it would be nicer, more convenient, if there was a voter's guide that you could access via the interface." Some subjects spoke about "the wheel" interface, referring to the Hart eSlate which is used in a large part of Texas where many of subjects did their voting. One subject said "Love this machine. The wheel is so awful." and expanded his thoughts "I love this machine. Let's get rid of the wheel. The thing is when you've got an election of 75 [*races*] you feel the pressure of time, your wife's sitting around there, other people waiting in line….[*CHILVote*] is much faster." Another woman spoke of her experiences voting:

> To me, [CHILVote] is better, because you have to punch in a number to vote and y'all do that for a person. So the person has to do that, and I know [my husband] can see okay and he drives sometime still , but he's a little older than me and he finished high school but that's it, and he didn't have standard education, but he had to get somebody to help him vote because the machines intimidate him even though he's visually. So, they're not as good as they could be, the machines they use now, because not everybody understand the

> wheel. They have this wheel on there that you have to put. So that's what was confusing, the wheel. Once you get the thing [voter number] in there, it's pretty self-explanatory, but getting that in there that takes all day if you don't understand the concept of it. I thought well, I majored in this computer stuff, this will be easy, and the first time I went to do it it was not as easy as I thought it would be because of the wheel.

In general the overall feedback from subjects was very positive. One subject said "I hope it gets approved. I love it. It's so easy, I mean, it's so easy there's no reason it shouldn't." Another subject commented "Well I think as far as this machine is concerned, it's very accessible. I can't think of more improvement because after a short explanation, I was able to use it. It's alright." One person mentioned the wide range of users this machine could help, saying "Well, I liked it because it was verbal, it could help anybody pretty much, but it could really help blind people." Finally, another subject summarized her feelings saying "It's all good. You can put that down. It's all good! Put an exclamation point there."

The wide variety of qualitative responses served to highlight some of the more important aspects of the interface design. The overall positive nature of the comments towards the interface in general matches up well with the users' self-reported high satisfaction scores on the SUS. Confusion about how to use the review screen was noted by users, and reflected in the data, as the review screen only served to introduce, not prevent, errors. The positive response to the ability to change audio speed maintains the assertion put forth by Piner and Byrne (2011) that adjustable speed audio is essential for this kind of interface. More broadly, these comments underscore the necessity of an independent and private accessible interface in the domain of voting.

Discussion

Overall, CHILVote performed as hoped and as expected. Error rates and satisfaction scores remained on par with sighted voters using a DRE, and did not decline from the levels achieved by the paper ballot analog, VotePAD. In fact, the complete lack of errors among the 11 subjects in CHILVote's undirected condition is a very encouraging sign that this system does in fact capture voters intent when they are free to choose how they wish to vote (as would be the case in an actual election). Voting time has improved significantly over the amount of time taken by voters using VotePAD, reducing the difference between sighted and blind voters from a five times disparity to only about a two and a half times longer voting experience. As long as speech is used to represent the ballot, some of this time difference will always remain because it is slower to convey spoken words to a listener than it is to convey written words to someone with the capability of reading text. However, this system is maintaining the important variables of a low error rate and high user satisfaction, while making progress in providing a more efficient voting process. Improving voting speed without sacrificing user accuracy or satisfaction means that this interface is a step in the right direction to providing a more equivalent voting experience for the blind population. The integration of accessibility into mainstream technology often provides ideas for general usability improvements, incorporating benefits beyond just allowing a larger portion of the population the ability to access the system.

The body of literature on disabilities is mostly sweeping generalizations and thoughts about ideal implementations. Some checklists and guidelines exist and offer lists of to-dos and not-to-dos, such as the W3C's Web Content Accessibility Guidelines and NIST's Voluntary Voting System Guidelines. But in the disability realm, both data-driven studies and sound theory

are in most cases absent. The lack of relevant literature and theory is one of the challenges faced when designing an accessible system. ACT-R, a cognitive architecture used to simulate human cognition in a wide variety of human-computer interaction tasks, only begins to touch on the auditory realm of human abilities. In a model of basic aircraft maneuvering, ACT-R's audition module "listened" for a beep to indicate when it should begin executing a certain maneuver (Gluck, Ball, Krusmark, Rodgers, and Purtee, 2003). Trafton, Bugajaska, Fransen, and Ratwani (2008) implemented ACT-R's auditory module to simulate conversation in a robot, but only so far as to track the sound and locate the origin of the conversation. These implementations of low level auditory abilities comes nowhere close to providing the structure needed to understand, interpret, and use a speech-based interface as complex as a voting system.

It is understandable why these theories do not exist. In general, the disabled population covers a huge range of physical, visual, auditory, cognitive, and emotional disabilities. In essence, almost anything in the human body or mind can become impaired in one way or another, leading to innumerable difficulties in everyday tasks. Even when this is narrowed down to only visual challenges, the spectrum is incredibly broad. Users with blurred vision, lack of color vision, limited peripheral vision, or light sensitivity could potentially all need very different, individualized solutions in order to be able to effectively interact with a system. The implementation of audio in these situations, where most users have intact hearing, is where system development could really benefit from a general theory of audio interface usability. Minor, physical concerns, like the maximum comfortable volume to present to users are addressed in the Voluntary Voting System Guidelines (United States Election Assistance Commission, 2009). It would be ideal to have a larger body of literature that combines the

psychophysical data regarding human audition with behavioral tasks to better inform the design of auditory systems.

There are some lessons from the CHILVote design that can be generalized across systems. Voting systems share a lot of commonalities with other computer systems, especially "walk up and use" systems designed for novice or infrequent users. These interfaces must provide some of all or the same types of elements that CHILVote does: easily understood instructions, an ability to navigate a complicated list, or the ability to change options and make selections. The goal of almost any system is to convey a user's intent efficiently, effectively, and to their satisfaction. Because of these commonalities, there are some design implications that were realized during the accessibility testing phase beyond the principles that guided the system design (Piner & Byrne, 2011). These include the importance of landmarks and an indication that modes should be used sparingly and only with rigorous user testing.

Landmarks, be they auditory or visual, are important in tedious or long tasks, such as voting. Auditory landmarks were designed into the CHILVote interface and there was anecdotal evidence in the form of subject feedback that suggests users recognized and utilized landmarks when provided. Landmarks are important for lengthy tasks. People may need to know how to best distribute their time over a set number of items, and landmarks and progress indicators help people make those kinds of decisions.

CHILVote, like many interfaces, employed the use of modes, which allowed the users to complete two similar, but separate, tasks (inputting their selections and reviewing those selections). The problem with modes is that they often can't be easily identified. In this system, subjects used the same input device and heard many of the same pieces of feedback (such as

identical error messages, navigation instructions, landmarks, etc.). Although it may be ideal to try to eliminate modes altogether, this is sometimes not possible. In situations that require modes, it is of utmost importance to differentiate between them in a way that is obvious to the user (but to keep as much of the functionality interchangeable across modes). There are many very salient visual cues that can help remind people of a changed state, but auditory interfaces are more limited in this regard. A recommendation would be to use a different voice for each mode. Ideally there would be only two modes, which could be easily differentiated by using a male voice for one and a female voice for another. Modality changes, however, should avoid forcing users to relearn a system. CHILVote kept the functionality of the buttons the same across the two modes, so that the user's learned understanding of the system's layout and navigation transferred and did not have to be relearned.

The technological knowledge needed to interact with different voting systems varies greatly. VotePAD, although generally considered an analog to the paper ballot, did require a certain amount of technology, albeit antiquated, to use. Voters had to understand how a cassette tape player worked, as well as a pause and play button. CHILVote, being implemented on a computer, naturally requires more technical savvy in its implementation of arrow buttons, menu structures, and "pop-up" warning messages.

Several of the survey questions (such as level of vision and Braille ability) can be utilized in novel ways to see if there is an impact of the subject's technological exposure on his ability to utilize a computer interface when voting. Use of screen readers and synthesized text-to-speech was not directly asked about, but it can be inferred by the level of vision. Subjects who are completely blind, or only have light perception, would not be able to use large font sizes or

magnification in order to receive information about the world. Presumably, this group would be more experienced with TTS (text-to-speech) applications than the subjects still retaining some useable forms of vision. However, the only significant correlations among measures of technological comfort and expertise were found among Braille readers, who both rated themselves as having higher levels of expertise and also tended to use faster audio speeds. These findings in themselves are unsurprising, as Braille reading, computer usage, and use of rapid TTS are all related measures of blind technology expertise.

The subject pool for this experiment was specifically drawn from individuals who are either independent travelers or have a support structure that allows them to travel to conferences. People who are interested and invested in this cause enough to participate in a group such as the National Federation of the Blind tend to be the people who are most well versed with the options and technology that are on the leading edge, and through events such as these conferences are also the subjects most likely to have been exposed to them in the first place. This group also places a large amount of importance on Braille reading skills, and that presumably influences its members (NFB Braille Initiative, 2013). If a large range of blind individuals from the community had been assessed, it is quite likely one would see a larger differentiation in the use and exposure to assistive technology, as well as an impact of that knowledge and flexibility on the use of a novel interface.

The blindfolded subjects that utilized CHILVote were all university undergraduates. Although they were intended to represent a group of "newly blind" subjects, their demographic as young technologically-immersed students and their view of this experience as only a psychology experiment may not make them the best analog. Their intentions were clearly to

complete the task of voting as quickly and efficiently as possible, without any of the real vested interest in participating in the electoral process as was present among the blind voters. Being modern university students required them to have a fairly high level of technological comfort and ability. While their experience and expertise may not be identical to those who are well versed in using accessible technology, this level of ability may well have contributed to their fast times and low error rates. Blindfolded subjects all came with a preexisting understanding of how computer systems are normally laid out, how menus work, how arrow keys work, etc. and this may have given them an advantage when navigating the interface.

In future work, it would be important to recruit subjects that better represent "newly blind" users rather than using university undergrads. This would ideally include older individuals who may now be dealing with the effects of a degenerative visual impairment. Additionally, it is important to measure the performance of subjects with lack of experience not just using accessible technology, but technology in general, as CHILVote tends to be organized in the same way one would expect most computer programs to be and behaves appropriately.

Multiple disabilities, as well as the wide continuum of visual disabilities, needs to be addressed by altering some versions of CHILVote for use in a real election. Physical, auditory, and cognitive disabilities lie far outside the range of this study. However, individuals with these disabilities make up a portion of the voting population and HAVA requires that polling places address all these situations. It is also important to address the needs of voters with multiple disabilities. There exists a large diversity among disabilities, and the number of individuals with any one combination of functional limitations is much smaller than each of the broad sub-categories. Solutions targeted to address the needs and abilities of a single, specific disability

may not be useful to this wider audience. According to the National Healthy Interview Survey (1983-1985, in LaPlante, 1988), 74% of people who are blind report other impairments. This calls to light the importance of systems that provide multi-modality interactions. As Vanderheiden (1990) points out, "When products, environments or systems are made more accessible to persons with limitations, they are usually easier for more able-bodied persons to use. Some of the potential benefits include lower fatigue, increased speed and lower error rates." Multi-modality audio and visual systems may improve the voting experience beyond visual impairment and impact individuals with other factors like aging, cognitive impairment or language-based disorders. The current study may inform design aspects of voting systems, as well as the broader range of interactive technologies, for the general population. A visual component to complement the auditory interface is important to provide dual sources of information to people with co-occurring auditory and visual impairments. The integration of audio into a visual voting machine would allow for any user who felt he could benefit from an additional level of redundancy in obtaining the information to utilize both audio and visual modes, without having to specially request a "disabled" voting machine. This might prove useful for individuals with cognitive disabilities or older users with diminished eyesight who do not realize or do not wish to consider themselves as being legally blind. The Web Content Accessibility Guidelines 2.0 may prove to be particularly useful when designing to provide customizable visual interface options, such as font size, magnification, contrast, and color schemes (W3C, 2008).

As could be seen by both the error results and the user comments, the separate review modality did not adequately perform its task of helping users identify and correct errors. Future

iterations of CHILVote should include a redesigned review section. Several potential solutions exist to mitigate the negative effects of the current review section, but these should each be tested with legally blind users to determine their effectiveness. The current review section implements a sequential design so that subjects have to go through the voted contests in order. A direct navigation system, in which subjects choose only the potentially problematic or important races to review, may be feasible. Caution should be taken as direct navigation makes mental navigation more cognitively complex by providing multiple routes to the same destination. Usability testing should be done to determine which of these navigation types is best applied in an auditory domain.

To maintain a simple sequential navigational model, the review section could exist as essentially a second run through the ballot. New information could be introduced during the review process by stating the candidate that had been selected by the voter during each contest's introductory audio. Should the subject wish to change their selection, the could do so using the same method they did during voting. This review section could potentially mitigate any errors caused by unintentional omission or attempts at "emphasis votes" by adding some kind of "vote for none" option. Explicitly forcing voters to choose an option when they intentionally would like to leave the contest un-voted would prevent omission errors. Re-selecting an already selected candidate would leave the selection unchanged, thus preventing emphasis votes from deselecting an intended choice.

Considerations for improving the review section should take into account efficiency, and endeavor not to add unnecessary time to an already lengthy process. Voters should also be provided with the option to skip the review section entirely if they are confident in the

technology. Voters should be provided with a way to directly cast their vote without a forced review process. It's important to remember than any review mode to be instituted in a universally designed voting system isn't present just to support visually impaired voters, but will likely be experienced by a wide range of individuals. Keeping in mind how a review section would be implemented simultaneously using audio and visual modalities is an important goal when redesigning the review section.

Tactilely, there are several improvements that could be made to CHILVote. The button box was only labeled with shape-based raised markers to indicate the button functions, but a single Braille letter or word to indicate their uses may be helpful for a portion of the target population. All the buttons were round; although their spacial placement made it possible to discern between the individual buttons and functions, this might prove challenging for someone that lacks the ability to feel the raised markers. Because neuropathy, nerve damage that can often cause numbness or reduced sensation in the fingertips, can co-occur with blindness, changing each button's overall shape to make them easier to distinguish may be helpful. The EZ Access keypad is a good example of this implementation (TRACE Center, 2007). CHILVote was restrained by having to use a button box that was commercially available, and while it was certainly viable, as can be seen by the results, it is most likely not the ideal solution for a voting system keypad.

The headphones used with CHILVote were provided by the experimenters and already plugged into a laptop's audio output port. In an actual polling place, the location and labeling of the headphone port would need to be considered in order to comply with the recommendations made by the 2010 ADA Standards for Accessible Design (Department of Justice, 2011). To adjust

the audio volume while voting with CHILVote, subjects had to use the inline volume control provided on the headphone cord. This was to offload some of the functionality of the system so that volume control would not have to be programmed, and to reduce the complexing of the input device, since it was limited to only the 6 buttons provided. However, use of the slide switch audio requires a certain level of manual dexterity that should not be required of all voters. Voters who lack fine motor control or the use of their hands may have difficulty using a physical switch. The VVSG 1.1 3.3.4 d (p. 74) advises against any type of manual controls that require "tight grasping, pinching, or twisting of the wrists." Because of this, a software volume control should also be built into a DRE's interface to accommodate more users. This is also crucial because voters can bring their own headphones with them when voting and some of these may not provide the ability to change volume directly from the hardware. The ability to change the volume using the headphone does provide some benefits, and should probably be retained as a secondary volume control on headphones provided at the polling place. With it, subjects were able to adjust the volume while they were voting, and compensate almost immediately if the environmental noise increased or decreased. With a software-based volume system, a subject would most likely have to interrupt the voting process and navigate a menu to make the changes. This would add unnecessary complexing, time, and a source of interruption to the voting task.

Several interface changes can be recommended after completing this study, that were neglected in the original CHILVote version due to time constraints in obtaining subjects and being able to implement the system. In order to provide contextual help and error recovery, if the voter makes no input to the system, ideally timeout audio will repeat whatever text is currently active, as well as detailed instructions. The length of the timeout should be set to approximately

20 seconds of inactivity after the system finishes speaking. 20 seconds falls within the times recommended by VVSG 1.1 3.2.6 f (p. 62) but provides enough time for a voter to think about his selection without feeling rushed. CHILVote was specifically designed to prevent the "dead air" errors experienced by the author when using certain commercially available system. Any button push at any stage of CHILVote provides some kind of auditory response to the user. However, the button pushes themselves are only acknowledged by the tactile feedback of button box. It might be worthwhile to add a tone to the interface that would play whenever a button was pushed, and precede the speech information given, to allow for a smoother transition between pieces of audio.

There are several voting peculiarities not covered by this system's design that would be necessary to include in an actual election. The ability to write in votes would need to be addressed. Additionally, some states allow voters to cast a straight-party ticket, usually with a single selection. Where in the ballot and what type of audio instructions would precede this option would need to be carefully considered. "K of N" races, in which a voter may select more than one choice for a given office, may cause difficulties with the current implementation of selecting and deselecting votes, since it's clear that that process may have caused some user confusion even in simple "select one" contests.

Security is not addressed when considering CHILVote, since this was specifically a usability study to acquire baseline rates. The use of headphones could be considered a "low-tech" security solution in as far as it keeps a single voter's selections private as long as the visual display is off. Any cryptographic or end-to-end verifiable security solutions implemented in a precinct where CHILVote was used would need to be implemented in an audio interface so that voters had equal access to receipts, keys, checked ballots, etc.

Improvement of the physical button box, review section navigation, and introduction of a visual component to the interface, as well as addressing the wide range of real-world election considerations, are crucial steps to be taken before implementing the next generation of CHILVote. The research with CHILVote can be used as a foundation when moving forward in both general and accessible DRE designs, and will provide the necessary baseline measurements that all future audio DREs should meet or exceed before being utilized in a real election.

References

Asakawa, C., Takagi, H., Ino, S., Ifukube, T. (2003) Maximum listening speeds for the blind, Proc. Conf. of International Community for Auditory Display 2003.

Bailey, B. (2002). User Interface Design Update. Retrieved April 9, 2008 from http://www.keller.com/articles/readingspeed.html

Bank of America. (2003). Independently access your accounts with Bank of America Talking ATMs. Retrieved from http://www.bankofamerica.com/ accessiblebanking/pdf/ talk_atm_broch.pdf

Bederson, B. B., Lee, B., Sherman, R. M., Herrnson, P. S., & Niemi, R. G. (2003). Electronic voting system usability issues. In *Human Factors in Computing Systems: Proceedings of CHI 2003*, (pp. 145–152). New York: ACM.

Brooke, J. (1996) SUS: A "quick and dirty" usability scale. In P. W. Jordan, B. Thomas, B. A. Weerdmeester & A. L. McClelland (eds.) *Usability Evaluation in Industry*. London: Taylor and Francis.

Byrne, M. D., Greene, K. K., & Everett, S. P. (2007). Usability of voting systems: Baseline data for paper, punch cards, and lever machines. In *Human Factors in Computing Systems: Proceedings of CHI 2007*, (pp. 171-180). New York: ACM.

Camilli, M., Dibitonto, M., Vona, A., Medaglia, C. M., & Di Nocera, F. (2010). User centered design approach for interactive kiosks: evaluation and redesign of an automatic teller machine. Proceedings of the 9th ACM SIGCHI Italian Chapter International Conference on Computer-Human Interaction.

Campbell, B. A., & Byrne, M. D. (2009). Now do voters notice review screen anomalies? A look at voting system usability. *Proceedings of the 2009 Electronic Voting Technology Workshop/ Workshop on Trustworthy Elections* (EVT/WOTE '09).

Citizen Advocacy Center. (2004). Electronic Voting Brochure: The Move Towards Electronic Voting. Retrieved November 24, 2010 from http://www.citizenadvocacycenter.org/ Brochures/ElectronicVotingBrochure.pdf

Everett, S. P., Byrne, M. D., & Greene, K. K. (2006). Measuring the usability of paper ballots: Efficiency, effectiveness, and satisfaction. In *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting*. Santa Monica, CA: Human Factors and Ergonomics Society.

Everett, S. P., Greene, K. K., Byrne, M. D., Wallach, D. S., Derr, K., Sandler, D., & Torous, T. (2008). Electronic voting machines versus traditional methods: Improved preference, similar performance. *Human Factors in Computing Systems: Proceedings of CHI 2008* (pp. 883-892). New York: ACM.

Gluck, K. A., Ball, J. T., Krusmark, M. A., Rodgers, S. M., & Purtee, M. D. (2003). A computational process model of basic aircraft maneuvering. In F. Detje, D. Doerner, & H. Schaub (Eds.), In Proceedings of the Fifth International Conference on Cognitive Modeling (pp. 117-122). Bamberg, Germany: Universitats-Verlag Bamberg.

Greene, K. K. (2008). *Usability of New Electronic Voting Systems and Traditional Methods: Comparisons Between Sequential and Direct Access Electronic Voting Interfaces, Paper Ballots, Punch Cards, and Lever Machines*. Master's Thesis, Rice University, Houston, TX.

Greene, K. K., Byrne, M. D., & Everett, S. P. (2006). A comparison of usability between voting methods. In *Proceedings of the 2006 USENIX/ACCURATE Electronic Voting Technology Workshop*. Vancouver, BC.

Hart intercivic. (2010). Security and FAQs. Retrieved December 1, 2010 from http://www.internetvoting.com/pages/214

Hollander Cohen & McBride Marketing Research (2008). Blind Voters Experience Assessment Study Research Summary [PowerPoint slides]. Retrieved from the National Federation of the Blind Voting, Accessibility, and the Law site: http://www.nfb.org/nfb/HAVA_legislation.asp

Johnson, G.I., & Coventry, L. (2001). "You Talking to Me?" Exploring voice in self service user Interfaces. *International Journal of Human-Computer Interaction*, 13(2), 161-186.

Kuell, C. (n.d.). ATM Accessibility. Retrieved from http://www.nfb.org/Images/nfb/Publications/bm/bm99/bm990508.htm

Laskowski, S. J., Autry, M., Cugini, J., Killam, W., & Yen, J. (2004). Improving the usability and accessibility of voting systems and products. NIST Special Publication 500-256.

Manzke, J.M. (1998). Adaptation of a cash dispenser to the needs of blind and visually impaired people. Proceedings of the *Third International ACMConference on Assistive Technologies*, Marina del Ray, CA (pp. 116-123).

Mebane, Jr., W. R. (2004). The wrong man is president! Overvotes in the 2000 presidential election in Florida. *Perspectives on Politics, 2*(3), 525-535.

Mulligan, D. & Hall, J. L. (2004) Preliminary Analysis of E-Voting Problems Highlights Need for Heightened Standards and Testing. National Research Council, Committee on Electronic Voting, National Academies Press.

National Federation of the Blind. (1986). LEGALLY BLIND, legal definition. Retrieved April 9, 2009 from http://www.nfb.org/nfb/Legally_Blind_Definition.asp

National Federation of the Blind Jernigan Institute. (2009). The Braille Literacy Crisis in America. Retrieved January 20, 2011 from http://www.nfb.org/images/nfb/documents/pdf/Final%20Braille%20Literacy%20 Report_ Secure.pdf

National Library Service for the Blind and Physically Handicapped. (2006). NLS Factsheet: About Braille. Retrieved April 9, 2009 from http://www.loc.gov/nls/reference/factsheets/braille.html

National Organization on Disability. (2004). 2004 N.O.D. Annual Report . Retrieved January 20, 2011 from http://www.nod.org/about_us/our_history/annual_reports/2004_annual_report

Nichols, S. M., & Strizek, G. A. (1995). Electronic voting machines and ballot roll-off. *American Politics Quarterly, 23*(3), 300-318.

Piner, G. E. & Byrne, M. D. (2010). Baseline usability data for a non-electronic approach to accessible voting. Proceedings of *the 2010 Electronic Voting Technology Workshop/ Workshop on Trustworthy Elections* (EVT/WOTE '10).

Piner, G. E., & Byrne, M. D. (2011). The experience of accessible voting: Results of a survey among legally-blind users. Proceedings of *The Human Factors and Ergonomics Society 55th Annual Meeting*, Las Vegas, NV pp. 1686-1690.

Resnikoff, S., Pascolini, D., Etya'ale, D., Kocur, I., Pararajasegaram, R., Pokharel, G.P., & Mariotti, S.P. (2004). Global data on visual impairment in the year 2002. *Bulletin of the World Health Organization, 84*(11), 811-890.

Rhode Island Office of the Secretary of State. (n.d.) Guidelines for Braille and Tactile Ballots. Retrieved April 9, 2009 from http://www.sec.state.ri.us/elections/voting/blindordisabledvoters/blindordisabledvoters/BrailleTactileBallotGuidelines.html

Rice University Computer Security Lab. (n.d.) VoteBox: a tamper-evident, verifiable electronic voting system. Retrieved from http://votebox.cs.rice.edu/

Runyan, N. (2007). *Improving access to voting: A report on the technology for accessible voting systems*. Retrieved October 1, 2008 from http://demos.org/pubs/ improving_access.pdf

Stephanidis, C. (2009). Universal Access and Design for All in the Evolving Information Society. In C. Stephanidis (Ed.), *The Universal Access Handbook* (pp. 67-86). Boca Raton: CRC Press.

TCF Financial Corporation. (2012). Accessibility at TCF. Retrieved from http://www.tcfbank.com/PersonalBanking pb_convenience_banking_accessibility_at_tcf.jsp

Trafton, J. G., Bugajska, M. D., Fransen, B. R., & Ratwani, R. M. (2008). Integrating vision and audition within a cognitive architecture to track conversations. Human Robot Interaction 2008 (HRI 2008).

United States Department of Health and Human Services. (1995). National Health Interview Survey on Disability. Hyattsville, MD.

United States Department of Justice. (2011). 2010 ADA Standards for Accessible Design. Retrieved from http://www.ada.gov/2010ADAstandards_index.htm

United States Election Assistance Commission. (2007). Testing and Certification Program Manual. Retrieved January 20, 2011 from http://www.eac.gov/testing_and_certification

United States Election Assistance Commission. (2009). Voluntary Voting System Guidelines Version 1.1. Retrieved from http://www.eac.gov/testing_and_certification/ voluntary_voting_system_guidelines.aspx

United States Government, 47th Congress. (2002). Help America Vote Act of 2002, 42 U.S.C. § 15481(a) Public Law 47-252. Washington, D.C.

United States Government. (1990). Americans with Disabilities Act of 1990, Public Law 101-336. Washington, D. C.

U.S. Census Bureau. (2010). Voting and Registration in the Election of 2008. Retrieved June 21, 2010 from http://www.census.gov/hhes/www/socdemo/voting/index.html

U.S. Census Bureau. (2005). Americans with Disabilities. Retrieved January 20, 2011 from http://www.census.gov/prod/2008pubs/p70-117.pdf

Vanderheiden, G. (2009). Accessible and Usable Design of Information and Communication Technologies. In C. Stephanidis (Ed.), *The Universal Access Handbook* (pp. 67-86). Boca Raton: CRC Press.

Vote-PAD, Inc. (n.d.). Accessible Voting Without Computers. Retrieved October 1, 2008 from http://www.vote-pad.us

W3C. (2008). Web Content Accessibility Guidelines 2.0. Retrieved February 16, 2013 from http://www.w3.org/TR/WCAG

Wand, J. N., Shotts, K. W., Sekhon, J. S., Mebane, W. R., Jr., Herron, M. C., & Brady, J. E. (2001). The butterfly did it: The aberrant vote for Buchanan in Palm Beach County, Florida. *American Political Science Review, 95*(4), 793-810.

Wells Fargo. (n.d.). Talking ATM Overview. Retrieved from https://www.wellsfargo.com/help/locations/talking_atm_overview

Appendix A
Survey Items

1. Please rate your ability to understand this voting system's synthesized voice (1 = voice was impossible to understand, 10 = voice was easy to understand):

   1 2 3 4 5 6 7 8 9 10

2. How easy would you say it is to discriminate between the buttons on the button box and tell which one is up, down, left, right, etc?
   - ___Very Easy
   - ___Easy
   - ___Average
   - ___Difficult
   - ___Very Difficult

Demographics

3. Age:

4. Gender: _____ Male _____ Female

5. What ethnicity do you consider yourself?
   - ___African American
   - ___American Indian
   - ___Asian American
   - ___Caucasian
   - ___Mexican American or Chicano
   - ___Other Hispanic or Latino
   - ___Multiracial
   - ___Other

6. Are you left or right handed? ____ Right ____ Left ____ Ambidextrous

7. Are you a native English speaker? ____ No ____ Yes -- If no, what is your native language?

8. Please indicate 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 of higher

9. Do you have any residual vision? ____ No ____ Yes
    a. If yes, please describe.

10. Are you left or right handed? ____ Right ____ Left ____ Ambidextrous

11. Do you own a smartphone? ____ No ____ Yes

12. Please rate your level of proficiency with reading Braille (1 = never used it, 10 = completely proficient):

    1 2 3 4 5 6 7 8 9 10

Computer Familiarity

13. How many hours per week do you use a computer?
    a. ____ less than 5 hours
    b. ____ between 5 and 20 hours
    c. ____ between 20 and 40 hours
    d. ____ over 40 hours

14. Please rate your level of computer expertise (1 = novice, 10 = expert)

    1 2 3 4 5 6 7 8 9 10

15. How often do you use an ATM (Automated Teller Machine) to get money or complete other transactions at a bank, grocery store, or other location?
    - ____ never
    - ____ very infrequently
    - ____ occasionally (for example 1-4 times a year)
    - ____ often (for example once a month)
    - ____ frequently (for example once a week or more)

Prior Voting Experience

16. How many national-level elections (that is, elections for President or Congress/Senate, typically held every two years; both 2010 and 2012 would count for this) have you voted in?
    a. ___None
    b. ___1-8
    c. ___9-15
    d. ___More than 15

17. How many non-national but governmental elections have you voted in?
    a. ___None
    b. ___1-8
    c. ___9-15
    d. ___More than 15

18. How many other elections of any type (local, school, etc.) have you voted in?
    a. ___None
    b. ___1-8
    c. ___9-15
    d. ___More than 15

19. If you have ever voted in a state other than Texas, please list the state or states where you have voted. _____

20. If you have ever voted in a country other than the United States, please list the country or countries where you have voted. _____

21. Do you typically cast your vote on an absentee ballot? ____ No ____ Yes

22. Do you typically vote a straight-party ticket? ____ No ____ Yes

23. Do you typically cast a vote for **every** office on the ballot? ____ No ____ Yes

24. Have you ever felt worried about figuring out how to use the ballot or technology to cast your vote? ____ No ____ Yes

25. Have you ever felt that time pressure caused you to rush, make a mistake, or leave a choice blank when you would not otherwise have done so? ____ No ____ Yes

26. Is there anything you would like to add? What parts of this voting system did you like, what could be improved or changed, etc?
    _____
    _____

Appendix B
Summary of Modified Ballot

1. President & Vice President
   - Gordon Bearce and Nathan Maclean - National
   - Vernon Stanley Albury and Richard Rigby – Jeffersonian
   - Janette Froman and Chris Aponte - Liberty
2. United States Senator*
   - Corey Dery – Independent
   - Fern Brzezinski - Jeffersonian
   - Cecile Cadieux - National
3. Representative in Congress District 7
   - Pedro Brouse – National
   - Robert Mettler - Jeffersonian
4. Governor (1&2)
   - Rick Stickles – Jeffersonian
   - Glen Travis Lozier – National
   - Maurice Humble - Independent
5. Lieutenant Governor*
   - Cassie Principe - Jeffersonian
   - Shane Terrio - National
6. Attorney General*
   - Rick Organ - Jeffersonian
   - Tim Speight – National
7. Comptroller of Public Accounts
   - Therese Gustin – Independent
   - Greg Converse - Jeffersonian
8. Commissioner of General Land Office*
   - Elise Ellzey - Jeffersonian
   - Sam Saddler - National
9. Commissioner of Agriculture
   - Polly Rylander – National
   - Roberto Aron - Jeffersonian
10. Railroad Commissioner
    - Jillian Balas – National
    - Zachary Minick - Jeffersonian
11. State Senator*
    - Wesley Steven Millette - Jeffersonian
    - Ricardo Nigro – National

12. State Representative District 134*

- Susanne Rael - Jeffersonian
- Petra Bencomo – National

13. Member State Board of Education District 2
    - Peter Varga – National
    - Mark Baber - Jeffersonian
14. Presiding Judge Texas Supreme Court Place 2
    - Tim Grasty - Jeffersonian
15. Presiding Judge Court of Criminal Appeals*
    - Derrick Melgar - Jeffersonian
    - Dan Plouffe – National
16. District Attorney
    - Corey Behnke – National
    - Jennifer A. Lundeed - Jeffersonian
17. County Treasurer
    - Dean Caffee – National
    - Gordon Kallas - Jeffersonian
18. Sherriff (1&2)
    - Jason Valle - Jeffersonian
    - Stanley Saari – National
19. County Tax Assessor
    - Howard Grady – National
    - Randy H. Clemons - Jeffersonian
20. Justice of the Peace*
    - Clyde Gayton Jr. - Jeffersonian
    - Deborah Kamps – National
21. County Judge (1&2)
    - Lewis Shine - Jeffersonian
    - Dan Atchley – National

22. Proposition 1 _____ Yes _____ No

23. Proposition 2 _____ Yes _____ No

24. Proposition 3 _____ Yes _____ No

25. Proposition 4 _____ Yes _____ No

26. Proposition 5 _____ Yes _____ No

27. Proposition 6 _____ Yes _____ No

* Contests indicate the candidate order was rearranged for this study

Appendix C
Literary passages used to measure wpm

Comma Gets a Cure
A Diagnostic Passage for Accent Study (Draft September 7,2000)
By Jill McCullough & Barbara Somerville
Edited by Douglas N. Honorof

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Well, here's a story for you: Sarah Perry was a veterinary nurse who had been working daily at an old zoo in a deserted district of the territory, so she was very happy to start a new job at a superb private practice in north square near the Duke Street Tower. That area was much nearer for her and more to her liking. Even so, on her first morning, she felt stressed. She ate a bowl of porridge, checked herself in the mirror and washed her face in a hurry. Then she put on a plain yellow dress and a fleece jacket, picked up her kit and headed for work. When she got there, there was a woman with a goose waiting for her. The woman gave Sarah an official letter from the vet. The letter implied that the animal could be suffering from a rare form of foot and mouth disease, which was surprising, because normally you would only expect to see it in a dog or a goat. Sarah was sentimental, so this made her feel sorry for the beautiful bird.

Before long, that itchy goose began to strut around the office like a lunatic, which made an unsanitary mess. The goose's owner, Mary Harrison, kept calling, "Comma, Comma," which Sarah thought was an odd choice for a name. Comma was strong and huge, so it would take some force to trap her, but Sarah had a different idea. First she tried gently stroking the goose's lower back with her palm, then singing a tune to her. Finally, she administered ether. Her efforts were not futile. In no time, the goose began to tire, so Sarah was able to hold onto Comma and give her a relaxing bath.

Once Sarah had managed to bathe the goose, she wiped her off with a cloth and laid her on her right side. Then Sarah confirmed the vet’s diagnosis. Almost immediately, she remembered an effective treatment that required her to measure out a lot of medicine. Sarah warned that this course of treatment might be expensive—either five or six times the cost of penicillin. I can’t imagine paying so much, but Mrs. Harrison—a millionaire lawyer—thought it was a fair price for a cure.

The Rainbow Passage

From Fairbanks, G. (1960). Voice and articulation drillbook, 2nd edn. New York: Harper & Row. pp124-139.

When the sunlight strikes raindrops in the air, they act as a prism and form a rainbow. Therainbow is a division of white light into many beautiful colors. These take the shape of a long round arch, with its path high above, and its two ends apparently beyond the horizon. There is , according to legend, a boiling pot of gold at one end. People look, but no one ever finds it. When a man looks for something beyond his reach, his friends say he is looking for the pot of gold at the end of the rainbow. Throughout the centuries people have explained the rainbow in various ways. Some have accepted it as a miracle without physical explanation. To the Hebrews it was a token that there would be no more universal floods. The Greeks used to imagine that it was asign from the gods to foretell war or heavy rain. The Norsemen considered the rainbow as a bridge over which the gods passed from earth to their home in the sky. Others have tried to explain the phenomenon physically. Aristotle thought that the rainbow was caused by reflection of the sun's rays by the rain. Since then physicists have found that it is not reflection, but refraction by theraindrops which causes the rainbows. Many complicated ideas about therainbow have been formed. The difference in the rainbow depends considerably upon the size of the drops, and the width of the colored band increases as the size of the drops increases. The actual primary rainbow observed is said to be the effect of super-imposition of a number of bows. If the red of the second bow falls upon the green of the first, the result is to give a bow with an abnormally wide yellow band, since red and green light when mixed form yellow. This is a very common type of bow, one showing mainly red and yellow, with little or no green or blue.

Arthur the Rat

Once upon a time there was a rat who couldn't make up his mind. Whenever the other rats asked him if he would like to come out hunting with them, he would answer in a hoarse voice, "I don't know." And when they said, "Would you rather stay inside?" he wouldn't say yes, or no either. He'd always shirk making a choice.

One fine day his aunt Josephine said to him, "Now look here! No one will ever care for you if you carry on like this. You have no more mind of your own than a greasy old blade of grass!" The young rat coughed and looked wise, as usual, but said nothing.

"Don't you think so?" said his aunt stamping with her foot, for she couldn't bear to see the young rat so coldblooded.

"I don't know," was all he ever answered, and then he'd walk off to think for an hour or more, whether he would stay in his hole in the ground or go out into the loft.

One night the rats heard a loud noise in the loft. It was a very dreary old place. The roof let the rain come washing in, the beams and rafters had all rotted through, so that the whole thing was quite unsafe.

At last one of the joists gave way, and the beams fell with one edge on the floor. The walls shook, and the cupola fell off, and all the rats' hair stood on end with fear and horror.

"This won't do," said their leader. "We can't stay cooped up here any longer." So they sent out scouts to search for a new home.

A little later on that evening the scouts came back and said they had found an old-fashioned horse-barn where there would be room and board for all of them.

The leader gave the order at once, "Company fall in!" and the rats crawled out of their holes right away and stood on the floor in a long line.

Just then the old rat caught sight of young Arthur - that was the name of the shirker. He wasn't in the line, and he wasn't exactly outside it - he stood just by it.

"Come on, get in line!" growled the old rat coarsely. "Of course you're coming too?"

"I don't know," said Arthur calmly.

"Why, the idea of it! You don't think it's safe here any more, do you?"

"I'm not certain," said Arthur undaunted. "The roof may not fall down yet."

"Well," said the old rat, "we can't wait for you to join us." Then he turned to the others and shouted, "Right about face! March!" and the long line marched out of the barn while the young rat watched them.

"I think I'll go tomorrow," he said to himself, "but then again, perhaps I won't - it's so nice and snug here. I guess I'll go back to my hole under the log for a while just to make up my mind."

But during the night there was a big crash. Down came beams, rafters, joists - the whole business.

Next morning - it was a foggy day - some men came to look over the damage. It seemed odd that the old building was not haunted by rats. But at last one of them happened to move a board, and he caught sight of a young rat, quite dead, half in and half out of his hole.

Thus the shirker got his due, and there was no mourning for him.