Baseline Usability Data for a Non-Electronic Approach to Accessible Voting

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Abstract

The Help America Vote Act mandated that all polling places have an accessible method of voting that provides privacy and independence. Direct Recording Electronic voting machines (DREs) have been assumed to be the solution to providing accessible voting, but there is reason to believe extant systems do not adequately serve this goal (Runyan, 2007). This study is a first step in addressing the lack of existing data on the usability of non-electronic accessible voting methods and examined the usability of Vote-PAD, a tactile paper ballot. In comparison with sighted users voting on an identical paper ballot, blind users took five times longer to vote. Both blind and sighted voters showed similar error rates and types, and reported similarly high satisfaction with the usability of paper ballots. Blindfolded subjects, representative of newly blind individuals, had reliably lower satisfaction using this interface, and took significantly longer than either blind or sighted subjects. This provides a baseline comparison point for future studies of accessibility solutions, including though not limited to DREs.

1. 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. On the surface, DREs 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). One difficulty is the the lack of systematically-collected, publicly-available data on usability of voting systems for different groups.This paper extends the voter usability literature to the specific demographic of blind users. Utilizing a non-DRE voting method (Vote-PAD), we sought to measure and understand voting time, errors, and user satisfaction that result from voting on a tactile ballot. The government mandates equal voting opportunities for all US citizens. Although our results show that error rates and user satisfaction are comparable between blind and sighted individuals, it is unclear whether the drastically longer completion time should be seen as acceptable.

Vote-PAD, the voting method being studied in this paper, is a tactile ballot sleeve voting system. Vote-PAD consists of front and back opaque covers, with an inner transparent sleeve that holds the actual ballot (Figure 1). The ballot is inserted into the transparent sleeve, which has holes that correspond to the size and location of the "bubbles" on the ballot. These holes allow for voters to mark the ballot for the desired candidate with a pen or pencil, while preventing any stray marks. Raised tactile markers inform users of the overall ballot layout. Triangular markers are placed at the top of each column, pointing down, and the bottom of each column, pointing up. Aligned in each column are a series of raised dots, located to the left of each cutout. Audio and Braille instructions interpret the raised dots and let the voter know which holes correspond to specific candidates.

Figure 1. Vote-PAD tactile ballot.

Audio instructions were created with the text-to-speech (TTS) program Natural Reader, using the NeoSpeech voice "Kate" set to speed 2. Audio instructions were provided to subjects on cassette tape. Subjects had full control of the cassette tape player, and were informed of the player's tactile buttons (play, stop, pause, fast forward, and rewind) and the location and operation of the volume control. The play button, which was particularly difficult to find because it was centered in the middle of a section of buttons, was given a triangular tactile marker to help subjects locate it. The audio guide directed voters through the ballot using the raised tactile markers as landmarks. Each contest consisted of the reading of the candidates' names, the spelling of the candidates' last names, and the candidates' political parties. The candidates' names and parties were then quickly repeated, before moving on to the next contest. For example, the audio transcript for voting for the Commissioner of General Land Office was:

> *In the middle column on the front of the ballot, there are 8 contests. The top contest is for Commissioner of General Land Office, a State office. There are two candidates. Vote for only one. The top hole is a vote for: Sam Saddler, S a d d l e r, Republican party. The bottom hole is for Elise Ellzey, E l l z e y, Democratic party. Again. Top hole: Sam Saddler, Republican party. Bottom hole: Elise Ellzey, Democratic party.*

Braille instructions used the same text as the audio instruction transcript, except that the last names were not explicitly spelled out.

Subjects were also presented with the option to review their ballot. A light sensing verification wand provided tactile feedback of how the voter had marked the ballot (Figure 2). The verification wand is designed to vibrate and hum when it senses a mark, and remain still when it does not. Subjects using the audio interface played the second section of the audio tape (a verification section that quickly reviewed each contest and the candidates in that contest once) while touching the verification wand to each marking location to determine the presence or absence of a mark. Subjects using the Braille interface were able to verify their votes immediately after marking each contest, or to re-read the Braille guide and verify all of their votes at once. If the subjects determined that they had made an error or wanted to change their vote, they notified the experimenter who noted the change to their ballot.

Figure 2. Light sensing verification wand.

Previous research on voting has focused mainly on the effect of electoral technology on election outcomes. Nichols and Strizek (2005) addressed this issue with ballot roll off (the tendency for races higher on the ballot to receive more votes than those races located lower on the ballot). Simple changes in voting systems noticeably affected the rate of voter participation in these lower electoral races. The issues raised by the voting problems in the 2000 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 do 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 (Everett, Byrne, & Greene, 2006). 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 a study by the National Organization on Disability, 20% of the US population lives with one or more disabilities, and a fifth of those (more than eight million people) have "been unable to vote in presidential or congressional elections due to barriers at or getting to the polls" (Runyan, 2007). The Help America Vote Act (HAVA) of 2002 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 (Runyan, 2007). These rights extend to two crucial aspects of voting: privacy and independence.

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 (data collected from the National Health Interview Survey on Disability indicate that approximately 1.3 million persons reported legal blindness), this study focuses on measuring accessible and usable voting among legally blind individuals (United States Department of Health and Human Services, 1995). "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: Direct-Recording Electronic voting systems (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 (Benderson, Lee, Sherman, Hermson, & Niemi, 2003). DREs are sometimes considered by election officials a panacea for all existing accessibility, usability, and security problems. However, very little data exists 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 (Byrne, Greene, & Everett, 2007; Greene, Byrne, & Everett, 2006; Everett et al., 2006).

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 (Everett et al., 2008, Byrne et al., 2007; Everett et al., 2006; Greene et al., 2006). Their solution to measuring the "goodness" of voting systems is through the use of the International Organization for Standardization's (ISO) usability metrics: effectiveness, efficiency and satisfaction. 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.

These studies have evaluated the usability of paper ballots, lever machines, and punch cards. 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. However, recent innovations in voting technology have produced tactical 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.

Vote-PAD is classified as an assistive technology. The US technology-related assistance for individuals with disabilities act of 1988 defines an assistive technology as "Any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities.” Other examples of these technologies in use today by the blind population include text-to-speech based screen readers, screen magnifiers, and refreshable Braille displays. The most recent available numbers from the National Health Interview Survey's Disability Supplement are from 1994, which may mean they are woefully outdated in the dynamic world of technology. But as early as 1994, over half a million people reported using an assistive device for a visual impairment.

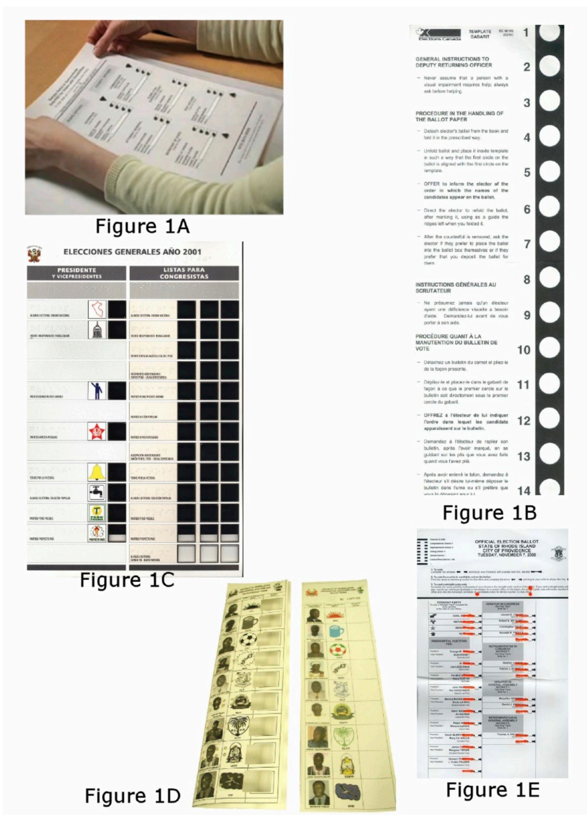

Figure 3. Examples of tactile ballots. (a) Vote-PAD (b) Braille and tactile ballots being used by the state of Rhode Island, (c) Peru (d) Republic of Sierra Leone (e) Canada.

Blind voters’ exposure to assistive technologies may offer an explanation for the drastic differences we see between blind subjects and blindfolded subjects. Just as sighted users are quite skilled and experienced at interacting with paper on a regular basis, so to are blind users experienced with using a wide range of assistive technologies in order to access things in their everyday life. Vote-PAD shares a strong relation with many of these technologies. It utilizes text-to-speech, tactile markers, Braille, and tactile/vibration feedback, all of which are enhancements that are regularly incorporated into assistive technology devices. This level of familiarity and skill could indicate why blind voters had similar, comparable error rates and SUS scores to sighted voters. In addition, the utilization of paper ballots and a verification wand makes it the only voting method that truly allows for accessible verification of the paper record, an action that is necessary to guarantee the reliability and security of an individual’s ballot (Runyan, 2007).

There is a dearth of existing information on the usability of tactile ballots by blind voters, either from laboratory experiments or real-world voter experience. 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). Vote-PAD is one of these traditional systems, and offers multiple interaction modalities (visual, through large print guides, auditory, through audio guides, and tactile, through Braille guides) that can be used separately or combined in whatever manner is needed by the voter. But the National Institute of Standards and Technology (NIST) reminds us that multiple modalities often insufficient; “Once the barriers to access are removed by adding redundancy, a second condition must be satisfied – the product must be usable by these populations” (Laskowski, Autry, Cugini, Killam, & Yen, 2004). This study’s purpose is to compare the usability of a tactile paper ballot by blind voters to the performance of sighted voters on an identical paper ballot.

In addition to both sighted and blind subjects, 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 worse-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). So in another sense these blindfolded college students represent the best-case scenario, because they have no experienced any of the effects of aging and slowing on cognitive performance. They were included in this study to understand and quantify how much their performance and satisfaction would suffer when faced with the challenges of a newly blind individual.

2. Method

2.1. Subjects

The 18 blind subjects for this study were recruited from two sources. Some were affiliated with Rice University, either as students, alumni, or faculty. Others were from the National Federation of the Blind's Texas state convention. Subjects were paid for their time. All subjects were fluent in English and legally blind (with 7 retaining some form of residual vision). Ages ranged from 18-62 years, with a mean age of 35.3 (*SD* = 13.4 years). On average, subjects had voted in 6 national elections (*SD*=5.6), ranging from zero to 20, and had voted in an average of 9.2 non-national elections (*SD*=5.36), ranging from zero to 35. 9 females and 9 males participated.

The 6 blindfolded subjects for this study were Rice University undergraduates, who received credit towards a course requirement. Ages ranged from 18-24 years, with a mean age of 19.8 years (*SD*=2.3). On average, subjects had voted in 1 national elections (*SD*=1.55), ranging from 0 to 4, and had voted in an average of 5 non-national elections (*SD*=7.48), ranging from zero to 20. 3 females and 3 males participated.

The 54 sighted subjects used in this comparison are from data previously collected and published (Everett et al., 2008).

2.2. Design

This experiment was a 3 x 2 x 4 between-subjects design. The 3-level variable was visual condition. Voters were either blind subjects voting on Vote-PAD, blindfolded subjects voting on Vote-PAD, or sighted subjects voting on a standard bubble ballot. The 2-level variable was information condition. Blind voters' information condition was dependent on the voting method they chose. Those voting with audio were in the *directed* condition, and received verbal prompts that told them whom to vote for. Those voting with Braille were in the *undirected* condition, and received a voter's guide that allowed them to make their own selections. All blindfolded voters used the audio interface. Sighted voters were randomly assigned to be in one of the two conditions. The 4-level variable was education, 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 1 shows the frequency for each category; two sighted subjects did not report their level of education.

Table 1. Frequency of each education level

	Sighted	**Blind**	**Blindfolded**
Did not complete high school	7.4% (4)	0% (0)	0% (0)
High school	9.3% (5)	22.2% (4)	0% (0)
Some college	35.2% (19)	33.3% (6)	100% (6)
Bachelor's degree	44.4% (24)	44.4% (8)	0% (0)

As can be seen from Tables 1 and 2, both sighted and blind subjects shared a similar background in both education and voting. Unsurprisingly, the younger, blindfolded subjects had far less experience voting. Table 3 contains information about the educational background of the general population of voters from the 2008 national election (U.S. Census Bureau, 2010).

Table 2. Previous voting experience

	Sighted	Blind	Blindfold
National Elections	6.9	6	1
Other Elections	8.1	9.2	5
Total Elections	15.1	15.2	6

Table 3. Frequency of each education level among the general voting population

	Voters
Did not complete high school	13.4%
High school	31.2%
Some college	28.3%
Bachelor's degree	27.1%

Subjects were self-selected into an information condition based on their ability to read Braille. Those who chose a Braille interface 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 a cassette tape 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 can't read it at all" and 10 representing "I'm an expert." On average, blind subjects rated themselves 7.46 (SD = 2.5). 5 subjects did not respond. Subjects that chose to use the audio interface (12) rated themselves as having a Braille proficiency of 7 (SD= 2.7). Subjects that chose to use the Braille interface (6 subjects) rated themselves more highly proficient Braille readers, with an mean of 9 (SD = 1).

Determining error rates in this study proved to be challenging. Measuring effectiveness in the directed condition was a simple task of comparing the slate (a text version of the verbal prompts that told participants what candidates to vote for) 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 only voted 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, an oral exit interview (simply asking the voters how they voted for each race) was administered to participants in the undirected condition. This allowed experimenters to determine that the votes on the ballot that were consistent with the exit interview correctly represented voter intent. For inconsistent votes, the exit interview was counted as the definitive measure of voter intent.

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 is available in actual elections. 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: undervote errors and intentional undervotes. An undervote error occurs if a voter fails to choose a candidate for a race in which s/he had intended to vote. An intentional undervote 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).

2.3. Materials and Procedure

Subjects who were comfortable with reading Braille and chose to vote with the Braille interface (instead of the audio interface) 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 using the audio interface were given verbal prompts that informed them which candidates to vote for and whether a yes or no vote was desired on the propositions. The experimenter provided these to the subjects. Subjects could pause the audiotape and ask for certain information from the slate whenever they desired it.

There were two versions of the directed condition. In the directed with no roll-off condition, subjects were instructed to vote in all 27 races on the ballot. In the directed with moderate roll-off conditions, subjects were instructed to skip several of the races and propositions. These intentional omissions are more representative of real-world voting patterns, in which people do not vote for every race presented on the ballot.

Both the voter guide and the verbal prompts (synonymous with the slates used in sighted experiments) were identical to those used in previous studies (Byrne et al., 2007; Everett et al., 2006; Greene, 2008; Greene et al., 2006). The only difference was the modality that they were provided in (either tactilely with Braille or orally by the experimenter).

Subjects gave their informed consent and were then read instructions on how to vote using Vote-PAD based on the directions provided in Vote-PAD's Poll Worker Guide (Vote-PAD, n.d.). These instructions differed significantly depending on the type of interface (either audio or Braille) used. Subjects in the directed condition were informed about the audio prompts, 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 experimenter, using a stopwatch. Time started as soon as the participant started reading the Braille instructions or pressed play on the audio instructions, and ended when the participant said they were finished voting. Subjects sat during the entire voting process, and were provided with ample table space to allow them to arrange all parts (ballot, tape player, instructions, voter guide, pen, verification wand, etc.) of the Vote-PAD system in any way they desired.
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, but spacing was altered slightly to accommodate the tactile markers required by Vote-PAD and to make it easier to differentiate between candidates. 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). The ballot's format was adjusted slightly for this study so that the spacing was such that subjects would be able to differentiate races based solely on tactile cues.

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 audio condition, which proceeded in an identical manner to the blind subjects in the audio condition.

Sighted subjects voted on identical bubble ballots, but without any of the Vote-PAD materials. They were given text voter guides or text slates that listed the candidates they were required to vote for, depending on the information condition. They read all directions themselves. These votes were performed in the context of a larger experiment, so some sighted subjects had voted on these ballots one or more times using other voting methods (DREs, lever machines, etc).

After subjects completed voting on and verifying their ballot, 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 questions (such as how many elections have you voted in). A voter guide survey (which differed slightly depending on the information condition) assessed how much a participant used (or would have used) the voter guide. 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).

3. Results

3.1. 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 per-race error rates are displayed in Figure 4. There were significant main effects of both visual condition, $F(2, 57) = 3.56$, $p = .035$ and education, $F(3, 57) = 2.87$, $p = .045$.

However, Subject 10 in the blind condition had errors in 10 out of the 27 races, an individual error rate of 37%. When this subject was excluded from analysis, blind subjects had a per-race error rate of 1.7% (SD = 3.2%), which is far more similar to the sighted subjects. With Subject 10 removed, there was also no statistically-reliable difference between error rates as a function of visual condition, information condition, or education.

Blind subjects choosing their own votes in the undirected condition made more errors (3.7%) than blind subjects in the directed condition (0.7%), although this difference was not statistically significant.

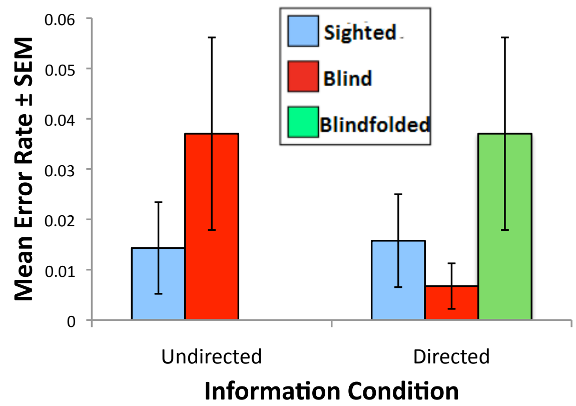

Figure 4. Per-contest error rate vs. visual condition and information condition, with subject 10's data removed.

Both sighted and blind subjects show similar patterns of errors, as seen in Figure 5. (Note that errors were not classified according to such a fine-grained taxonomy by Everett, et al. (2008). The sighted data presented in Figure 5 is from Campbell and Byrne (2009), which used an identical ballot and experimental methodology to what was used in this experiment and the Everett, et al. (2008) paper. Wrong choices were the predominant form of errors (even when Subject 10's errors—all wrong choices—were removed from the analysis). There were no cases of overvotes or extra votes among blind or sighted voters. A few subjects exhibited undervotes and intentional omissions. Blindfolded subjects showed an entirely different pattern. They tended to have overvotes and extra votes, along with a few wrong choice errors. They exhibited no undervote errors. In the blindfolded paradigm, they were given verbal prompts and told whom to vote for, so intentional omissions were not possible.

Intentional omissions are not considered an error, so were not included in the graph. Sighted subjects had an intentional omission rate of 0.4% and blind subjects had an intentional omission rate of 0.6%, which was not significantly different.

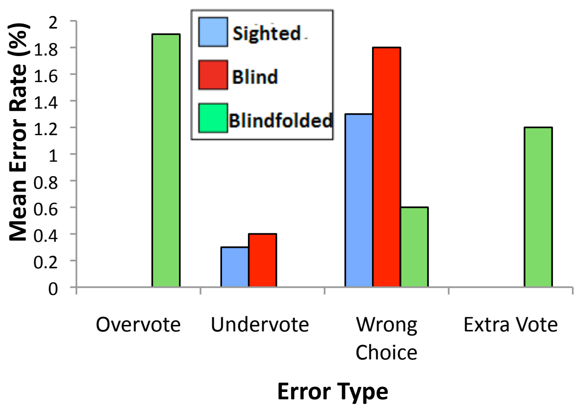

Figure 5. Error rates for different error types by visual condition, with Subject 10's data removed. Inclusion of Subject 10 would increase the blind wrong choice error rate to 3.1%.

The error rates for both the audio and Braille interface of Vote-PAD (both 3.7% when including Subject 10) were not significantly different. Error rates can also be considered on a per-ballot basis. Overall, 14.3% of ballots collected from sighted subjects contained at least one error. 33.3% of ballots collected from blind subjects contained at least one error. 50% of ballots collected from blindfolded subjects contained at least one error. Error rates by ballot were not related to information condition, though effects of both visual condition, $F(2, 57) = 2.57, p = .085$, and education, $F(3, 57) = 2.39, p = .078$, approached significance. Any result that isn't reported was nonsignificant.

3.2. Ballot Completion Time

Overall ballot completion times are presented in Figure 6. Results for ballot completion time as a function of visual condition and information condition are presented in Figure 6. As expected, there was an overall effect of visual condition on ballot completion time, with blind voters having much longer times than sighted voters, $F(2, 62) = 165.24, p < .001$. More specifically, blindfolded subjects took significantly longer than blind subjects, who took significantly longer than sighted subjects. None of the effects of information condition or education were reliable, nor were there any interactions.

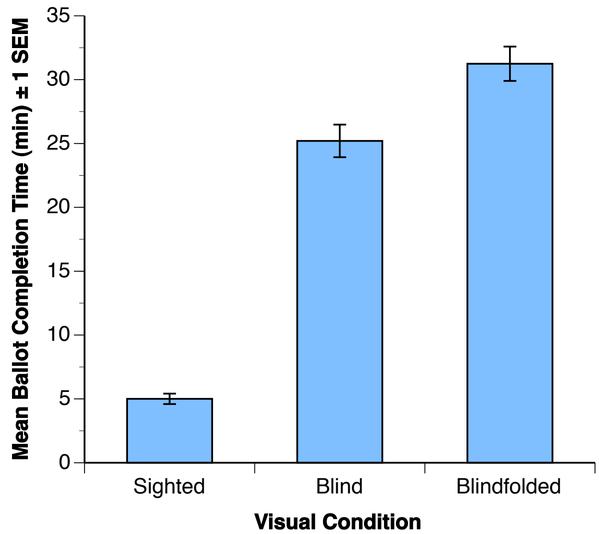

Figure 6. Mean ballot completion time by visual condition.

Both Braille and audio interfaces take similar amounts of time to complete, and were not reliably different (24.5 minutes for Braille vs. 25.5 minutes for audio).

3.3. Subjective Usability

Figure 7 depicts the mean SUS rating as a function of visual condition and information condition. Both sighted and blind voters show a similar high rating, with blindfolded subjects rating the usability as substantially worse. Unsurprisingly, there was a significant effect of visual condition on SUS scores, $F(2, 62) = 9.28, p < .001$. Sighted and blind subjects had similar SUS scores, but blindfolded subjects' ratings were reliably lower. There were no effects of information condition or education.

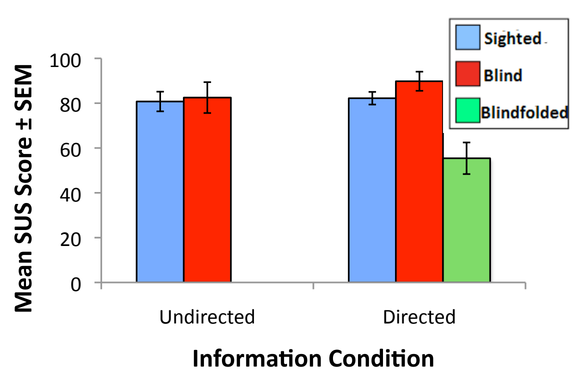

Figure 7. Subjective usability score (SUS) vs. voting method and information condition.

Audio interfaces received a higher subjective rating for usability. Subjects using Braille gave the method an 82.5 SUS rating and subjects using audio gave the method an 89.8 SUS rating. This difference approached significance, $F(1, 13) = 4.43$, $p = .055$.

The perceived usability of voting methods is an important topic, though not just because HAVA has made a requirement that each polling place provide private and secure voting for every voter (United States Government, 2002). It is also a topic that is important to blind individuals. Half of the blind subjects said that when they voted in an election they had been unsure if their vote was cast correctly or would be counted. Several subjects mentioned that they had been unsure if their votes were cast correctly when they were forced used poll workers to make their choices for them. One subject mentioned that she was specifically concerned about the new security issues being introduced by electronic voting, and another subject said "When I voted electronically, I was like did that really go in?" A third subject said with the audio interface on a DRE he could cycle through the races but could not determine what he had selected. Another subject said she was worried about voting integrity after the 2000 election. A final subject said he was worried because "when you're using a machine, it separates you from the ballot, and you don't get a chance to know you submitted it." He mentioned a specific instance when he voted on a DRE but required a poll worker to help him submit his ballot. Upon leaving the polling location, the sheriff who was a candidate on the ballot was aware of what vote the subject had cast. This made an impression on him about the importance of privacy and independence when casting a vote.

Blind subjects had a similar average number of voting experiences to sighted subjects. A further examination of the type of experiences is shown in Table 4. Some subjects had experiences with multiple methods, and several subjects voted before they went blind.

Table 4. Blind subjects' previous voting experience.

Never Voted	2
Paper Ballot w/poll worker or family assistance	7
Punch Card	2
Lever Machine	1
DRE	12
Stopped voting when they lost their vision	2

A substantial finding here is that 2 out of the 18 (11.1%) subjects stopped voting after they lost their vision. It is possible that a usable method that insured privacy and independence would encourage individuals like them to continue voting even after a significant life change such as losing one's vision. According to the U.S. Census Bureau (2010) in 2008's national election, 15 million registered voters did not turn out to vote. 14.9% of these nonvoters reported it was because "they were ill, disabled, or had a family emergency." Of the 30 million unregistered voters, 6% did not register because of permanent illness or disability.

In general, the high mean SUS scores and quotes from subjects indicate blind voters felt that this system provided a necessary and satisfactory service. "I really like the way this ballot is set up, it actually helps blind people vote" and "It's cool, very independent" were two quotes received from our subjects. In comparison with other systems, one user spoke about Vote-PAD: "I find this much nicer than electronic ones. This focuses you on what you're doing. Electronic ones you have to go back and forth." Several felt that this system was an important step forward in assistive technology for people that might not know Braille, or might not be comfortable using it: "I like the orientation cues like 'second from the bottom' were really good, especially for a non-Braille reader, it will help get them back to their place." and "Very intuitive system, people can't stand tapes any more, but a digital system adds a level complexity. And not all people know Braille."

There were some things that multiple subjects wanted to change. A desire to make the system more compact was prevalent ("It would be nice if it were more compact, some way to integrate everything and not spread everything out."). Subjects also came up with a few more features to help people navigate and differentiate between different parts of the ballot ("Very tiny holes, I don't know if someone is elderly or someone with diabetes could vote with this." and "What's hard is finding the hole with the pen and not making other markings. Put a frame around the candidate or separate the circle [referring to the raised marker] from the hole.").

3.4. Ballot Verification

The verification wand was a piece of technology that received a strong, positive response from voters in this study. It elicited comments like "I like the wand a lot" and "I like it, it's very cool" [referring to the verification wand]. Subjects varied greatly in how much and how effectively they used it to verify their ballot. In order for the verification wand to work properly, it must be held straight up and down and lightly touch the paper. Although this was emphasized during the instructional phase, several subjects either held it at an angle (as one would a pen) or failed to touch the paper with it at all, causing the wand to always vibrate and respond as if they were touching a mark. Because users were receiving feedback about a mark that was not actually present, this technique may have contributed to the undervote rate.

Some voters were confident with their abilities to use the system, and used the verification wand sparingly, often only in cases where they were unsure of the mark they made. Failure to verify the entire ballot may have contributed to the wrong choice errors that were found.

Other subjects used the wand only to verify the holes they intended to mark (as opposed to checking to make sure the other holes did not contain stray or erroneous marks). This was fine if they wanted to verify that their mark was dark and complete enough to be read. This method could have caused problems should they have marked an incorrect hole the first time. By only verifying where they thought they should have marked, they could have ended up filling in two holes, leading to overvote errors.

4. Discussion

Although it appears that Vote-PAD and paper ballots have similar user satisfaction ratings and per-contest error rates, blind voters take 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). This study 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.

The lengthy times generated by blind and blindfolded subjects is at some level a necessary function of the technologies used. The audio tape (including both the voting and verification sections) was 28 minutes and 34 seconds long. This can clearly be seen in the time of the blindfolded subjects (who took an average of 31 minutes). All of the blindfolded subjects chose to use the optional, separate verification stage and listen to the repetition of all candidates. They often paused the audiotape to ask for a reminder of the verbal prompts, or to regain their bearings. Blind subjects that chose to use the audio interface tended to multi-task, and verify their selections in-line with the voting task. They rarely paused the tape, and frequently asked for the prompts while the tape was running and introducing the next race.

While the audio length does not directly affect those using the Braille input, there is still a significant time disadvantage for Braille readers. The average reading speed for English prose text in the United State is between 250-300 words per minute (Bailey, 2000). In contrast, the average Braille reading speed is only 125 words per minute (National Library Service for the Blind and Physically Handicapped, 2006). Not only did Braille users have to read the ballot more slowly, but they also had to read and interpret the navigational cues and explanations of page location.

Blind voters' completion time in this experiment, although already five times slower than their sighted counterparts, is in all likelihood an underestimate of the real-world difference. Voting time did not include any of the instructional time during which subjects were taught how to use the ballot, tape player, verification wand, etc. It also did not include any time taken to use the included opaque ballot shield or to privately deposit a vote into the ballot box (this phase of voting was not included in this study). The fact that blind voters are already disadvantaged when it comes to efficiency (because of slower Braille reading speeds, and the length of text-to-speech audio translations), regardless of the interface used, makes it that much more important that the voting system they use be well designed and easy to utilize.

On the other hand, results on errors and satisfaction were encouraging. While with the limited sample size it is impossible to conclude that performance is identical to sighted voters with paper ballots, our results suggest that they are at least similar. This is meaningful, indicating that it is possible to construct voting systems that do not discriminate heavily against visually impaired users on what are probably the two most important metrics for this population.

One potential issue with Vote-PAD is the protection of the voter's privacy. It's important to note that it does contain a privacy shield that covers the ballot while it is being deposited into the ballot box or optical scanner. However there is nothing to insure the blind voter that their ballot is not removed from this shield. It's likely that a DRE provides more assured privacy to the voter.

Care should be taken, however, not to interpret this as an endorsement or recommendation of tactile ballots in general or of Vote-PAD in particular. Different technologies have different strengths and weaknesses for different populations; systems like Vote-PAD do not not necessarily serve all populations (including election administrators) well. Instead, we take this as an object lesson about what is possible and as a benchmark for accessibility; any future system intended to address the needs of the visually impaired should have to show that it can do at least as well as the results we have shown here. That is, now that baseline measures have been obtained for tactile paper ballots, it will be possible in the future to compare other types of accessible voting technologies to determine if they, too, show error rates and subjective satisfaction that is comparable to sighted users voting on paper ballots. Perhaps other technologies can improve upon ballot completion time as well, though we suspect that this is an inherently difficult limitation to overcome. Naturally, the primary voting technology of interest for future research is the DRE. The development and testing of DRE using an auditory interface with blind voters will be essential to understanding the strengths and limitations of the platforms currently deployed in many polling places. Only after comparisons can be made between DREs and other technologies can a viable course of action for providing equal voting rights to the entire population be determined.

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 of these situations. It is important to obtain measures of the accessibility and usability of current voting systems by voters with a wider range of disabilities. 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." The current study may inform design aspects of voting systems, as well as the broader range of interactive technologies, for the general population.

Acknowledgements

This research was supported by the National Science Foundation under grant #CNS-0524211 (the ACCURATE center). The views and conclusions contained herein are those of the authors and should not be interpreted as representing the official policies or endorsements, either expressed or implied, of the NSF, the U.S. Government, or any other organization. We would also like to thank the Texas chapter of the National Federation of the Blind for their participation.

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