

Auditing Technology for Electronic Voting Machines

by
Sharon B. Cohen

Submitted to the Department of Electrical Engineering and Computer Science
in Partial Fulfillment of the Requirements for the Degrees of
Bachelor of Science in Computer Science and Engineering
and Master of Engineering in Electrical Engineering and Computer Science
at the Massachusetts Institute of Technology

May 19, 2005

Copyright 2005 Sharon B. Cohen. All rights reserved.

The author hereby grants to M.I.T. permission to reproduce and
distribute publicly paper and electronic copies of this thesis
and to grant others the right to do so.

Author _____
Department of Electrical Engineering and Computer Science
May 19, 2005

Certified by _____
Ted Selker
Thesis Supervisor

Accepted by _____
Arthur C. Smith
Chairman, Department Committee on Graduate Theses

Auditing Technology for Electronic Voting Machines

by

Sharon B. Cohen

Submitted to the
Department of Electrical Engineering and Computer Science

May 19, 2005

In Partial Fulfillment of the Requirements for the Degree of
Bachelor of Science in Computer Science and Engineering
and Master of Engineering in Electrical Engineering and Computer Science

ABSTRACT

Direct Recording Electronic (DRE) voting machine security has been a significant topic of contention ever since Diebold voting machine code turned up on a public internet site in 2003 and computer scientists at Johns Hopkins University declared the machine “unsuitable for use in a general election.” Since then, many people from computer scientists to politicians have begun to insist that DREs be equipped with a paper trail. A paper trail provides a paper printout for the voter to approve at the end of each voting session. Although there have been strong political efforts to place paper trails on DRE machines, there have not been any scientific studies to indicate that paper trails are effective audits. This work describes a user study done to compare paper trails to audio audits, a new proposal for DRE auditing. Participants in the study completed four elections on a voting machine with a paper trail and four elections on a machine with an audio trail. There were purposeful mistakes inserted into the audits on some of the machines. Results from the study indicated that participants were able to find almost 10 times as many errors in the audio audit than they were able to find in the paper trail. Voters’ attitudes towards the paper audit were extremely apathetic, and voters did not spend much time reviewing their paper record. When asked which type of audit voters would prefer for their own county elections, almost all voters preferred the VVPAT. These results indicate that newer alternative audit technology holds great promise in delivering a safe and accurate audit and further that paper trails have some significant design obstacles that need to be overcome before they will be effective audits.

Thesis Supervisor: Ted Selker

Title: Associate Professor, Program in Media Arts and Sciences

Table of Contents

I. Introduction	4
II. Background: Electronic Voting and Audit Trails	6
III. Voter Verified Paper Audit Trail	9
IV. Voter Verified Audio Audit Transcript Trail	14
V. What Makes a Good Audit System	17
VI. User Study Protocol	21
VI – 1. Subjects – Potential Voters	22
VI – 2. Equipment	23
VI – 3. VVPAT Implementation	26
VI – 4. VVAATT Implementation	27
VI - 5. Experiment Protocol	29
VI - 6. Creating a Voting Experience	31
VI - 7. Errors in the Audit Trail	32
VI - 8. Error Condition Variables	35
VI - 9. Elections, Error Placements, and Voting Agendas	36
VI – 10. Response to Voters who Reported Errors	38
VI – 11. Subject Voting Assignments	39
VII. Experiment Results	40
VII – 1. Usability	40
VII – 2. Effectiveness	44
VII – 3. Time Spent Voting	48
VII – 4. Attitudes and Responses to the Paper Trail	51
VII – 5. Attitudes and Responses to the Audio Trail	53
VII – 6. Experiment Subject Audit Preferences	55
VII – 7. Results Overview	56
VIII – Hypothesis Explanations of Experiment Results	57
VIII – 1. Differences in Number of Errors Found	57
VIII – 2. Differences in Types of Errors Found	58
VIII – 3. Differences in Attitudes Towards Each System	59
VIII. Conclusions	61
Reference	63
Appendix: Experiment Materials	64
Appendix A: Experiment Script - Used to prep subjects before they began voting	64
Appendix B: Experiment Elections	65
Appendix C: Experiment Voting Agendas	83
Appendix D: Subject Assignments – Voting Machine order and Error Order	87
Appendix E: Experiment Surveys	88

I. Introduction

Voting is one of the most important responsibilities provided to us by the United States Constitution. Every American citizen above the age of 18 is afforded this right. Although currently the right to vote is restricted only on the basis of citizenship, it was not always so; many people spent their entire lives working to gain this right. While the success of previous generations struggles has quelled the controversy of who can vote, the presidential election of 2000 and the Florida hanging chad problem has opened a new era of election controversy.

Every aspect of the voting process has been subjected to significant scrutiny. Scientists, politicians and even regular citizens have begun to re-evaluate the entire voting process, from voter registration and election officials, to polling locations, absentee voting, and finally voting technology, the equipment we use to collect and count the votes. This evaluation has brought many changes and recommendations to our voting process. Older technologies, including lever and punch card machines have been invalidated as proper voting devices, while newer electronic technologies have been hailed as the way of the future that will make voting an even more democratic process as disabled and impaired voters are able to vote independently.

While direct recording electronic (DRE) voting machines hold a significant amount of promise in bringing an independent vote to millions of people who never had that opportunity previously, there have also been some serious concerns raised recently over the security of these machines. Modern computer technology has brought many conveniences and comforts to our lives. Our world today is vastly different from just a few years ago. Computers run many critical systems from banking to flight control, however, many people still view computers as a black box. There is very little

understand or oversight of what happens inside the computer. Given this black box viewpoint, people have been questioning whether it is wise to allow DRE machines to count our votes. Since the opportunity for a recount is limited with DRE technology, audit trails have become a source of controversy. An audit trail is a separate technology that may be added to a voting machine and will result in an independent record and count, or at least ability to re-count, the votes.

Currently, the most popular implemented and certified audit mechanism is the paper trail. To create a paper trail audit a small printer must be attached to each voting machine. After the voter finishes making their selections on the DRE, a printout appears of the vote which the voter then approves. While there are a few other available audit technologies, for the most part, the audit trail debate has centered on printer trails. The debate has become highly political. Citizen groups have been formed specifically to force counties to add printers to their DRE machines. Lawsuits were filed prior to the November 2004 elections asking that election officials be forced to provide paper voting options to voters. Now there are laws being enacted that will require printer trails to be added to electronic voting machines.

While the calls for printer trails have gotten louder and more political, very few people have taken the time to step back and question how effective printer trails are at providing a secure audit of an election. Ted Selker, of the MIT Media lab has proposed a new idea for an audio audit. His proposal for a Voter Verified Audio Audit Transcript Trail (VVAATT) would work similar to the printer trail except that the audit created would be in an audio form instead of paper.

My thesis project has been an investigation of voting audit technology through both qualitative comparisons and through an extensive user study comparing VVAATT

to the paper trail. The user study measured general satisfaction and usability criteria associated with each system and also measured voters' ability to find errors in the audit trails, a fundamental characteristic of how well the system can serve as an audit.

II. Background: Electronic Voting and Audit Trails

Although the publicity and controversy surrounding DRE voting machines increased significantly following the 2000 presidential election, DRE machines were being developed and used long beforehand. The first DRE machines were actually deployed in the 1970's and strongly resembled lever machines; the levers were replaced by buttons. The use of DREs grew very slowly before the 2000 election. In 1980, less than one percent of registered voters were voting on DRE machines. Over the next fourteen years, from 1980 to 1994, the use of DREs grew to five percent of registered voters. DRE market growth was clearly taking off as their market share doubled from about five percent of voters to ten percent in the next four years, 1994 to 1998. Below, in Figure 1 is a graph showing the market share of various voting technologies between 1980 and 2004. The influence of the 2000 presidential election is fairly easy to spot in the graph. Between 2000 and 2002, the use of DREs nearly doubled from thirteen percent to twenty-three percent. [1]

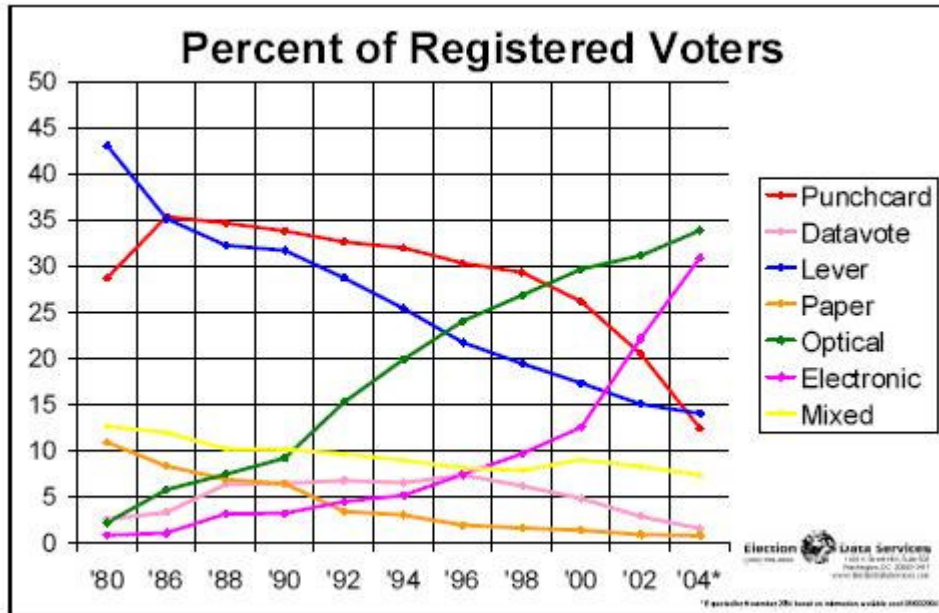


Figure 1: Graph showing the percentage of registered voters using various kinds of voting technology. [1]

At the same time that DREs were gaining market share, the market share of lever and punchcard machines was significantly decreasing. The Help America Vote Act (HAVA) [2] of 2002 set specific technology and accessibility requirements for voting machines. HAVA specifically de-certified punchcard and lever machines for failing to provide a reliable voting system and because both systems are inaccessible to people with impairments or disabilities. All states were mandated to replace punchcard and lever voting machines in time for the November 2004 election and funds were provided to facilitate such replacements. [2]

In January 2003, the controversy over the security of voting machines erupted with the discovery of Diebold voting machine source code on an unsecured internet site. The fact that the source code was unsecured was contentious enough, however, the real problems started for DRE machines with the release of Dr. Avi Ruben’s report on the

code[3]. Ruben and other researchers at Johns Hopkins University analyzed the Diebold source code and published a report on the security vulnerabilities of voting machines. This report forced many people to rethink their trust in voting machines and even prompted election officials in Maryland to conduct a separate review of their Diebold machines. [4] Ruben's report declared the Diebold machine "unsuitable for use in a general election" and further declared that "any paperless electronic voting system might suffer similar flaws, despite any "certification" it could have otherwise received." [3] As voting machines have been put under more and more scrutiny, many more people have begun to insist that a paper trail is necessary for all DRE voting machines. Quite a few political action groups have been founded with the goal of forcing all DRE machines to be equipped with printer trails. The most vocal of these groups is the Verified Voting Foundation.

Prior to the November 2004 election, there were lawsuits filed in several states which attempted to force the states to give voters an option of voting on paper if they did not wish to use DRE machines. A group of seven people in Maryland sued the election commission in an attempt to force the state to provide paper alternatives to the newly purchased Diebold DRE machines. [5] A group in Florida sued the state alleging that the lack of paper printout on their DRE machines violated their right to a manual recount. [6] Ultimately both groups lost their cases and the elections were conducted with the DRE machines.

Even with the November 2004 election over, the political maneuvering has not stopped. Now there are laws being proposed and enacted which will require DRE machines to be equipped with printer trails before they can be used in elections. This type of legislation has already been enacted in many states and is pending in many more.

(Legislation has been enacted in 17 states including Nevada and California, and is currently proposed in 19 more.) [7]

III. Voter Verified Paper Audit Trail

The concept of a voter verified paper audit trail (VVPAT) predates the current controversy over DRE security. Rebecca Mercuri first introduced the VVPAT in March 1992 in her paper “Physical Verifiability of Computer Systems.” [8] The idea behind the VVPAT is quite simple.

1. The voter uses the DRE to record their choices.
2. When they are finished recording their choices, they press a button on the DRE and a printout appears behind a glass panel.
3. The voter reads over the printout in order to verify that their selections have been properly recorded on the paper.
4. If the voter accepts the printout then the paper is deposited in a secured ballot box. Otherwise, if the voter rejects the printout, they begin voting again. Rejected paper ballots are marked to indicate that they were rejected and are not deposited in the ballot box.

When Mercuri first proposed this system, no DRE supplier had implemented it. More than 10 years after the initial proposal, Avi Rubin’s report and increasing security concerns prompted commercial vendors to implement the VVPAT system. Currently almost all commercial DRE vendors promote some kind of VVPAT implementation. While a majority of states using DRE machines currently do not use a paper trail, that trend may be changing. In September 2004, the state of Nevada became the first state to

run an election with a paper trail. Implementing and running an election with the VVPAT places new responsibilities on every person involved in the voting process; voters, poll workers and election officials.

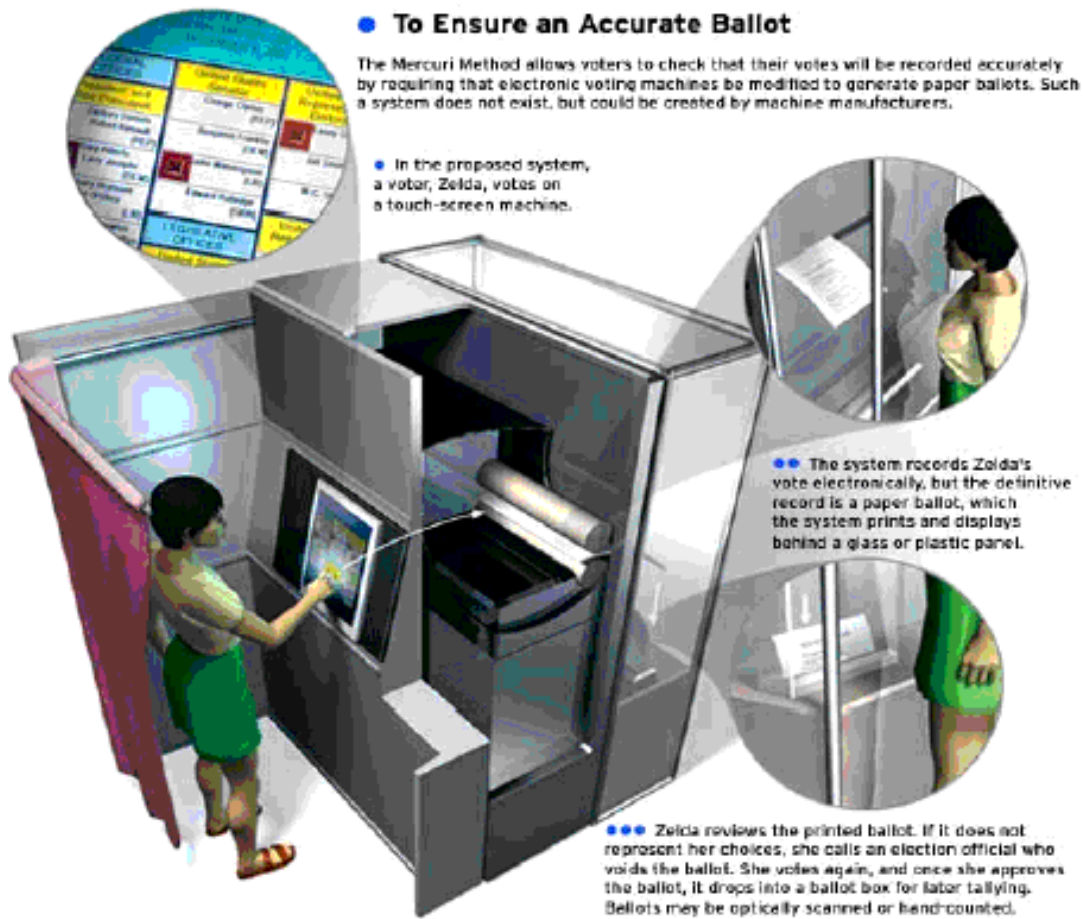


Figure 2: VVPAT illustration, originally published in IEEE [9]

Voters are responsible for checking the correctness of their paper ballot. In order for VVPAT to serve as an effective and trustworthy audit mechanism, the voter must verify their paper ballot. Mercuri herself emphasizes the difference between a voter **verified** audit trail and a voter **verifiable** audit trail. [8] Merely adding the capability for

a voter to verify their vote is not sufficient for an audit trail. The voter must actually take action and certify that the printout is correct.

Running an election with VVPAT places additional responsibilities on already overburdened poll workers. In addition to setting up and maintaining the DRE machines, poll workers must also set up and maintain the printers. New responsibilities for poll workers and election officials include:

- Setting up the printers
- Fixing the printers in the event of a paper jam or other technical difficulty (lack of ink, unclear printing, etc.)
- Handle the concerns of voters who say the printout does not match their choices.
- Safely transport the paper printouts to the central election headquarters.
- Safely store the paper printouts for as long as election law requires

These new responsibilities place additional demands on the poll workers and require an even more technical skill set than has been required in the past. In addition, states are challenged to properly train poll workers in their new roles.

Performing an audit of the election using the paper receipts brings in another group of people and requires different responsibilities. People performing an audit with the paper receipts must be able to accurately read and record the voter's choices. The new tally must then be accurately counted and compared with the tally that the DRE machines gave. Although Mercuri has suggested that it would be possible to design a computer system to read and tally the paper records, to date there is no such system.

While the VVPAT provides a good starting point for an audit trail, it faces some significant obstacles. Two of the main obstacles that challenge the successful implementation of a VVPAT are the requirements placed on voters to actually verify

their selection and the ability of poll workers and election officials to keep the paper receipts secure before, during, and after the elections.

One of the key principles that the VVPAT relies on is the idea that voters actually check their paper ballots before submitting them. However, a recent observation of an election using a VVPAT calls that concept into question. Ted Selker recently published a paper, “Process can Improve Electronic Voting: A Case Study of an Election” [11], about the primary election he observed in Reno, Nevada September 7th, 2004. This election was run with Sequoia DRE machines which used a VVPAT. Several of his interactions with voters and poll workers indicated that many voters did not actually verify their paper receipt. Some notable examples include:

- “Before leaving, I asked one of the exiting first voters, “Did you notice a second display?” trying to get him to tell me about the paper trail behind the glass. “No.....” the man replied, “I just voted and reviewed my selections on the screen.” [11]

- “However, in the course of the day, I saw no more than 3 people spend even five seconds viewing the printout.” [11]

- “Many voters were disappointed that they did not get to keep their paper receipt.

However, a poll worker noted, “People aren’t looking at the paper.” [11]

If voters do not actually take the time to verify their paper receipts, then VVPAT cannot serve as a secure audit trail. While many computer scientists feel strongly that an audit trail is necessary for the security of their vote, many voters do not understand this and may not recognize how the VVPAT actually helps secure their vote.

Another major challenge in implementing a VVPAT election is the ability to keep the paper trail secure before, during and after the election. There is a long history of

elections being rigged though ballot stuffing, ballot theft and general mishandling. Elections officials must be careful to implement policies and procedures which insure that VVPAT printers and paper depositories are treated with the same care and respect as a ballot box. During Selker's experience in Nevada, he observed a situation in which one of the VVPAT printers had jammed and a poll worker was attempting to fix it. Though the poll worker did not have ill intentions, and did not intentionally jeopardize the security of the paper trail, in the course of fixing the jam she had to open the printer, cut out some of the receipts, reload the paper and stuff it all back in the box.



Figure 3: Poll Worker attempting to fix a jammed VVPAT printer. [11]

In this situation, the poll worker could have easily placed extra ballots in the box or taken some that were already there. Clearly, this would not be acceptable treatment for a normal ballot box; it should not have been acceptable treatment for the paper receipts either.

Though these are two main challenges to VVPAT elections there are others as well. Other challenges include the cost of the printers (of the currently available systems, each printer costs about \$1000), the disenfranchisement of blind and low vision voters, the questionable ability of voters to accurately check their receipts, and the extra time required of the voters.

IV. Voter Verified Audio Audit Transcript Trail

The voter verified audio audit transcript trail (VVAATT) is a new idea for a cheaper and potentially more effective election audit tool. Selker introduced VVAATT in his article “The Voter Verified Audio Audit Transcript Trail” [12] as well as his Scientific American article, “Fixing the Vote.” [13] VVAATT is similar to the VVPAT in many ways but has some critical differences. The procedure for a voter is as follows:

1. The voter steps into the voting booth and puts on the provided headphones.
2. The voter begins voting as normal.
3. Each time the voter makes a selection, he hears a confirmation in the headphones.

For example, when the voter selects candidate A, the DRE will say “selected candidate A”. This audio confirmation will be heard for every important action that the voter takes including, selecting a candidate, unselecting a candidate, advancing races, and submitting the ballot.

4. The DRE audio output is also passed to the VVAATT recording unit which records the voting session on some physical medium such as an audio cassette.
5. At the end of the session the voter submits their ballot and leaves the voting booth.

One of the most important differences between VVAATT and VVPAT is the immediate verification that occurs with the VVAATT system, as opposed to the delayed verification that the voter does at the end of a VVPAT voting session. As the voter presses candidate A, he verifies that the audit trail records candidate A. There is no time delay between the voter's selection and the verification of that selection. The immediate verification will also help decrease accidental mistakes such as pressing an incorrect candidate. (The same number of accidental mistakes will be made, however, it may be easier for the voter to notice the mistakes when they hear the audio verification for the incorrect candidate.)

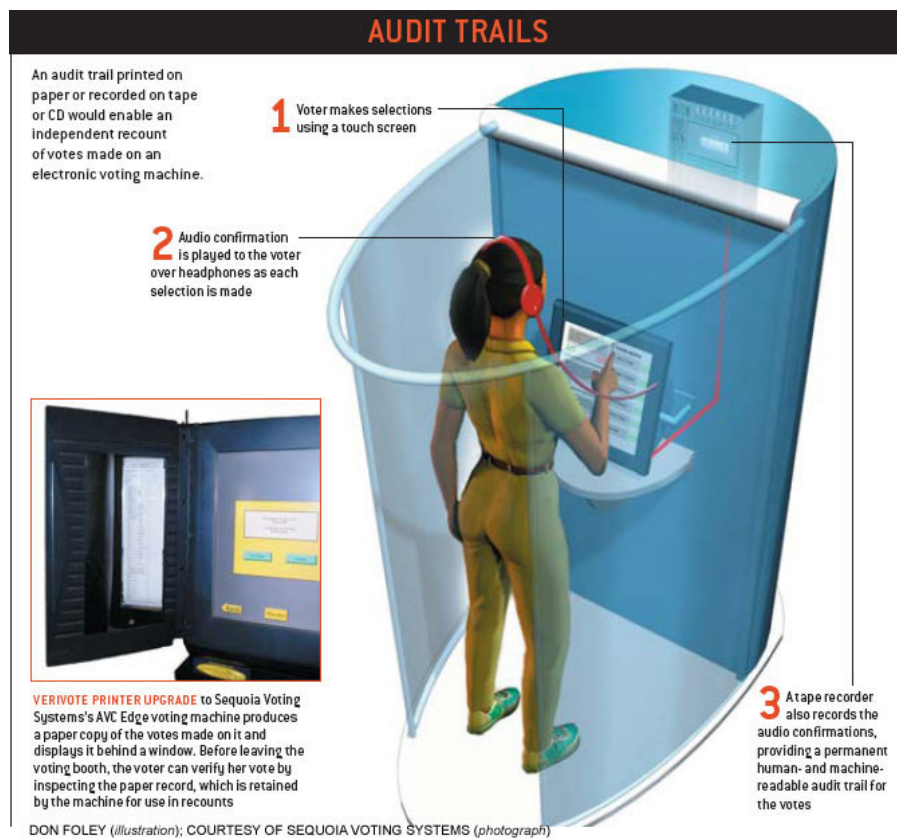


Figure 4: Illustration of VVAATT, originally published in Scientific American [13]

Implementing an election with a VVAATT places slightly different stresses on the election system than the VVPAT does. One of the first areas of concern for election officials, is the question of if their DRE voting machines can actually support the VVAATT system. No DRE machine as it is currently built can automatically support VVAATT (except machines which are enabled for visually impaired voters.) However, with only slight modifications, any DRE could support the system. The DRE machines must support simultaneous visual and audio output. Although VVAATT would work seamlessly with a visually impaired audio ballot, it would be impractical and unnecessary to force all voters to vote in this manner. The audio output needed for the VVAATT system is significantly different and simplified from the audio of a visually impaired ballot. Audio is only required at the major interaction points the voter has with the machine. These include: selecting a candidate, deselecting a candidate, advancing races, and submitting the ballot.

VVAATT places only minimal requirements on voters. The main requirement is simply that voters wear the headphones. Without instruction or prompting, it is unlikely that many voters would wear the headphones, however, a few simple steps could drastically reduce this problem. Simply placing informative posters around the polling locations reminding voters to wear their headphones would likely provide enough encouragement, however, poll workers could also be enlisted to encourage voters to wear the headphones. With enough encouragement and voter education, voters would have no trouble understanding how wearing the headphones is in their best interests.

The additional poll worker responsibilities with the VVAATT system are similar to those of VVPAT system. Poll workers are responsible for setting up and maintaining the audio VVAATT units, however, since VVAATT is much less expensive than

VVPAT, malfunctioning VVAATT units could be replaced by entirely new ones instead of having the poll worker try to fix the broken one. Poll workers would still need to set up the tape recorders and maintain them throughout election day, however, the process would be easier to handle because of the simpler audio output attachments. Anyone who has ever used a pair of headphones could easily manage to plug in and start the VVAATT. Storing and transporting the audio tapes would be much easier than storing the paper receipts because there would be fewer audio tapes than paper receipts and in addition, tapes are a much more durable medium than paper.

Auditing the VVAATT “by hand” would be a tedious process, workers would have to listen to each vote. As much as a minute or more per vote could be expected. There are however, many very reasonable possibilities for creating a software system to perform the tallying automatically.

There are several challenges that the VVAATT will have to overcome in order to be a fully successful audit trail. Some major challenges include making the system as general as possible so that it can properly interact with multiple DRE systems, implementing the system without disenfranchising deaf voters, reducing the cost and amount of time needed to perform a hand audit, and convincing voters and experts that a good audit system does not have to be paper and does not have to be physically visible.

V. What Makes a Good Audit System

Before it is possible to talk about comparing two different audit systems, one must decide on what basis to compare them, or more generally, what makes a good audit system. Some important characteristics of audit systems have already been alluded to in

the previous descriptions of the VVAATT and VVPAT audits. When judging an audit system, all the people involved in the voting process need to be considered.

At the top of the list of people to consider, is the voter. Voters are the people who will be using and interacting with the system with the highest degree of frequency. If the audit system fails to meet the voter's needs, then it can not be considered an acceptable system. Conveniently, the voter's needs are actually easiest to articulate. The voter wants to accurately and completely place their vote. They want this process to be as efficient as possible. In addition, voters want elections to be held with the highest integrity possible. Audit systems should only increase the integrity of the election.

The amount of time a voter takes to place their vote is an important consideration for both voters and election officials. The harder it is and longer it takes voters to place their vote, the less satisfied voters will be with the process. It is also generally true that the more complicated the voting process becomes, the more problems that will arise and the less accurate voters will be. If it takes voters a long time to cast their ballot, long lines could result at polling places. Long lines are at best a minor inconvenience, but in the worst case, voters may decide not to wait around to cast their vote. Long lines were a major problem during the November 2004 election. In Ohio, some people reported having waited more than seven hours before they were able to vote. [14] These circumstances were mostly the result of having too few voting machines in the polling sites, however, similar problems could arise if voters were taking too long on the equipment.

In addition to time constraints, voters must be able to properly use any audit system in order for it to be valuable. Some audit systems do not involve the voter at all. This is a great advantage because it means the usability of the system depends only on the

usability of the DRE. (The usability of the DRE is a major concern which should not be overlooked, however, this concern is present in all elections, whether there is an audit system or not.) Many audit systems do require the involvement of the voter, and often the voter's involvement is required to maintain the security of the system. If a voter has some responsibility in the proper functioning of the audit system, those responsibilities must be simple enough for all voters to perform reliably and further voters must be motivated to actually perform them. Audit systems must be useable for all voters; if necessary, accommodations must be made so that handicapped or otherwise impaired voters can reliably use the systems.

Poll workers want to interact with the audit systems as little as possible. In the ideal case, a poll worker would never interact with the audit system. Poll workers are already overburdened with many responsibilities. Given that not interacting with the audit system, may not be a feasible goal, the next best situation is for poll workers to interact with the audit system exactly twice, once at the beginning of the day to start the system, and once at the end of the day to shut it down and prepare it to be transported to election headquarters. Both setting up and shutting down the audit system should be as simple as possible. Poll workers are paid employees; however, no assumptions can be made about their skill level. There are no official requirements in order to be a poll worker and the training they receive is very minimal. If possible, no technical background should be assumed. In addition to setting up and shutting down the audit system, poll workers are the ones who will be on-site and will be the first to respond if any of the audit units malfunction or break down. It is in the election's best interests if the system is simple enough for the poll workers to fix minor problems immediately. Shutting down a voting station while waiting for a technician to arrive on site could cause

significant delays, especially during the peak voting times. Finally, poll workers must be able to handle voter questions and concerns. While simple voter questions about how to use the audit system correctly are to be expected and should not be taxing for any poll worker, of more serious concern is voters who claim that the audit trail is not accurately reflecting their selections.

The objective of any audit system is to accurately reflect the selections that a voter makes on the DRE. Any report to the contrary needs to be taken seriously. Poll workers need procedures that will allow them to address voters concerns in a professional manner while not violating the privacy of the voter's vote, something they are legally entitled to. For the moment, it is safe to assume that any report of an inaccurate audit is either a mistake or the act of a malicious voter who intends to derail the election by forcing a machine out of service or invalidating the election results. For the voters who are simply mistaken in their report, it should be sufficient for the poll worker to instruct the voter on the proper use of the system and how to make a change to their selections. For a voter who insists that the machine is changing their vote, if possible, the poll worker should confirm the voter's claims, again without violating the voter's privacy. If the poll worker can not confirm the claim without violating the voter's privacy then, there should be clear procedures in place for when and how to take a machine out of service, however, an election official should probably be involved that decision.

For election officials, one of their main concerns is money. Election officials are concerned with the initial cost of the audit equipment, any continuing costs that result from using the system, and the cost to perform an audit. The initial costs cover only the equipment that is needed. The continuing costs of the audit system are the costs incurred by using the audit system during each election. These continuing costs can include any

fresh supplies that must be purchased as well as the costs of transporting and storing the material produced by the audit. Finally, election officials must be concerned with the costs of auditing the election using the system. Although it is unlikely that an entire election would ever be audited if there were no indication of fraud or other problems, even auditing a small percentage of the votes could incur significant costs. If the audit can be automated with special hardware or software, the costs of those systems will be important. If the audit can not be automatically counted and must be done by hand, then elections officials must consider how long it takes to perform an audit and how many people will be needed to perform the job.

Given the different needs of voters, poll workers and election officials, it is challenging for audit systems to completely fulfill everyone's needs. Choices must be made and there are tradeoffs to every design. The user study described below measures only how well the audit systems serve voters needs.

VI. User Study Protocol

To measure how well the VVAATT and VVPAT met voter's needs, 36 potential voters were asked to participate in a user study. They voted on two different voting systems, one with a VVAATT audit and one with a VVPAT audit. The study was designed to focus on voters three main needs:

1. usability – How easily can voters use the system? Do they need instructions?
What is the general experience of using the audit system?
2. effectiveness – How well does the system serve as an audit? Are voters able to spot mistakes in the audit?
3. time – How long does it take for voters to use the system?

Usability was measured qualitatively through observation as well as through surveys completed after the voters finished using each system. Effectiveness was measured by purposefully inserting mistakes into the audit trail. Observations as well as survey questions helped determine how many errors voters had discovered. Timing data was collected by measuring how long voters took on each of the elections they completed. The protocol for this study was approved by the MIT Committee on the Use of Humans as Experimental Subjects,

VI – 1. Subjects – Potential Voters

The thirty-six subjects who participated in the study were recruited from the MIT community. They were all eligible voters, above the age of eighteen. While the majority of subjects were US citizens, not all subjects were. This decision was justified because being a US citizen does not confer any special knowledge or abilities regarding the usability of audit mechanisms. (All participants were fluent in English and had no trouble reading the voting interface or the surveys.)

The poll of subjects, was mostly young and highly technical. Almost half the subjects, forty-seven percent, were between ages eighteen and twenty-two and exactly seventy-five percent were between eighteen and thirty. Seventy-eight percent of participants reported having used a computer for more than twenty hours in the week preceding their participation in the experiment. Only one subject in the study did not own a computer and over sixty-three percent of participants owned two or more computers. Ninety-seven percent listed an education level of some college experience or higher.

The participants were mostly novice voters. Six subjects, seventeen percent, reported never having voted before and twenty-one subjects, fifty-eight percent reported having voted between one and five times previously. (Seventy-five percent had voted fewer than five times.) As a group, all the popular voting systems were represented in previous voting experience. The most popular voting equipment used by subjects was the optical scan ballot. Almost a third of participants reported having voted on an optical scan ballot. Only two subjects reported having voted on a DRE. Eleven participants reported having voted through an absentee ballot.

With such a young and highly technical subject pool one would expect that these participants might be better able to use the audit mechanisms than a more representative voting population would. Participants in study would be better at following instructions and carefully checking their ballots. In addition, some participants may have been familiar with the DRE security controversy and paper trail questions. (When the Diebold voting code first appeared on the internet, the story was being discussed around MIT and a few students even posted parts of the code on their own websites until MIT asked them to take it down.)

VI – 2. Equipment

Although there were originally thoughts of using a commercial voting machine in the experiment, the changes needed in the audit trails as well as the control needed over the election races made this impractical. Instead, we implemented VVAATT and VVPAT on an experimental voting system.

The voting system used was the Low Error Voting Interface, LEVI. LEVI is a voting interface that has been designed and tested through the CalTech MIT Voting

Technology Project. One of the main advantages of using the LEVI system was the ability to control how the audit systems worked and the ability to easily create elections. Another significant advantage of the LEVI system, was that none of the subjects had previous experience with the interface so all subjects started off with the same background level.

Previous experimentation had shown that the LEVI ballot enabled voters to be more accurate and less error prone as compared to a simulated commercial voting interface. A previous user study comparing the LEVI ballot to a commercial ballot found that among the users who did make errors, about half as many errors were made on the LEVI ballot as compared to the commercial ballot. Voters averaged 1.8 errors on LEVI and 3.1 errors on the commercial system. [15]

LEVI provides additional forms of feedback that are not available on many commercial systems. Some additional feedback includes side navigation tabs on the screen that allow the voter to easily see which races they have made selections in and which they haven't. Below, in figure 5, are two screen shots of the LEVI interface. The image on the left shows the interface when the voter is making selections in the "3rd District Court of Appeals" race. The green side tabs indicate races that the voter has already made selections in. These green tabs also list the candidates that the voter selected, even when the race is not visible on the screen. The grey tabs are races the voter has not yet made a selection in. When a race allows the voter to choose more than one candidate, the tab turns green incrementally. For a two selection race, once the voter has made one selection, the tab will be half green, once there is a second selection, the tab will become fully green.

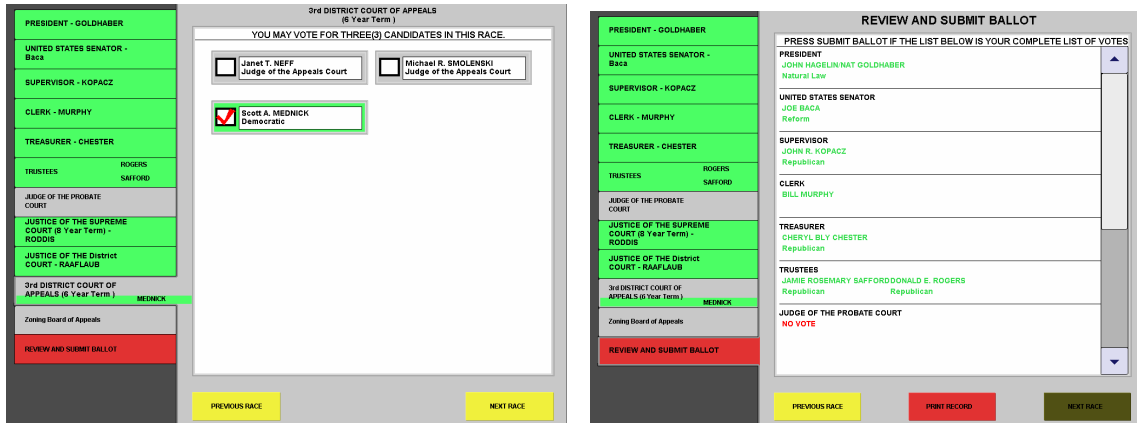


Figure 5: Screen shots of LEVI voting interface.

The image on the right in figure 5 shows the LEVI review screen. The review screen gives a clearly delineated list of all races and uses color to help emphasize the races that a voter has either skipped or undervoted. (An undervote is when a voter makes fewer selections than they are allowed, for example selecting only one candidate in a two selection race.) Touching any of the races on the review screen will bring the voter back to that race and allow them to change their vote. These additional forms of feedback are very effective in reducing accuracy mistakes and undervotes. Many times during the experiment, we observed subjects going back to previous races to fix errors that they observed on the side tabs or through the review screen.

Though LEVI was a starting point for our experiment, we still needed to add some external hardware and a few software changes as well in order to obtain the entire voting system, audit included. Both voting systems started off with a fifteen inch diagonal touch screen.

VI – 3. VVPAT Implementation

To implement the VVPAT audit, we purchased a standard receipt printer and created a unit to house the printer and protect the paper trail that was produced. The VVPAT printer was a Samsung model SRP-270 dot matrix printer. Although each voting manufacturer makes their own unique VVPAT printer the one characteristic common to almost all of them is that the paper trail produced is protected in some manner so that the voter can not touch or disturb the paper. A window is provided over the paper so the voter can see their choices once they are printed. In order to create a more authentic election, a plastic housing unit for the receipt printer protected the paper trail and ensured that voters could not touch or modify the paper. As you can see in the image below, the experimental housing unit is similar to the commercial one and achieves the same results.

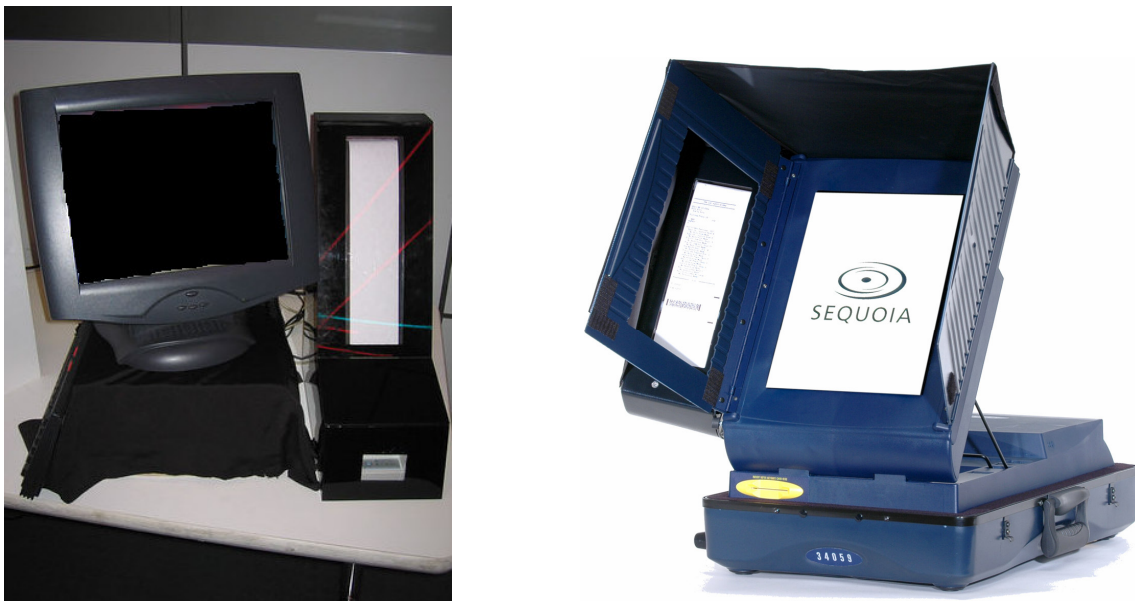


Figure 6: Experimental VVPAT voting unit is seen on the left and Sequoia’s AVC Edge[®] with VeriVote Printer is seen on the right. The printer in the Sequoia unit is behind the panel on the left. [16]

Small software modifications had to be made in order to accommodate the VVPAT audit. In the standard LEVI interface, the review screen is the last step in the voting process; the “Submit Ballot” button simply submitted the ballot and ended the program. However, when using the VVPAT system, instead of submitting the ballot from the review screen, the voter has to first print their ballot. The “Submit Ballot” button on the review screen was changed to read “Print Record” and a new screen was added to the end of the voting process. When using the VVPAT audit, once the record is printed, the voter has two options, they can accept the printed record and cast their ballot, or they can go back and make changes to their vote. The final selection screen added to the LEVI interface was based on the screen shot found in the Clark County, Nevada, instructions for voters guide. [17] The final selection screen as well as the Nevada reference are shown in the images below.

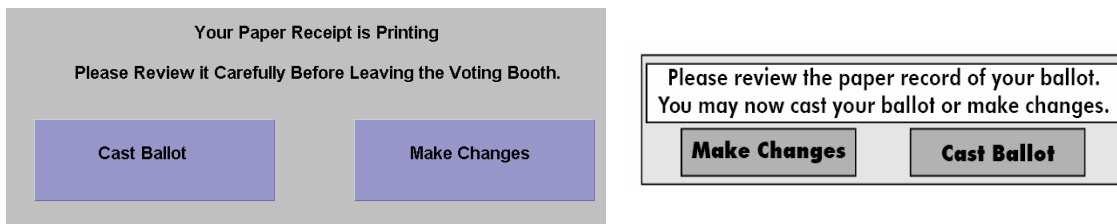


Figure 7: Final selection screen in experimental VVPAT setup (on left) and Nevada instructions to voters (on right).

VI – 4. VVAATT Implementation

VVAATT has not been widely implemented by many commercial voting vendors so the experimental system we built is based our own decisions about how to produce the most secure audit system while providing voters with the best experience possible. For

the audio recording device, a tape recorder was used. There were two reasons for this. First, tape recorders are easy to operate and are readily available. Second, with a tape recorder, the voter is able to look at the recorder, see the wheels spinning and visually verify that the tape is recording. Further, tape recorders do not contain a computer. In order not to waste tape, the recorder used a voice activated recording mode. This mode records to the tape only when audio is detected. For the most part, this worked well, however, there was a problem with background noise. Because the tape recorder did not always detect audio through the microphone input, which was connected to the computer, it tried to pick up input from its internal microphone which resulted in background noise. Using a tape recorder without an internal microphone would have reduced this problem.

In order to protect the tape from being tampered with by voters, a protective box was constructed that allowed the audio wires to be connected properly while still blocking off access to the tape recorder. The top of the protective box is see-through plexiglass so that the voter can see that the tape recorder is recording while the audio is playing. One inadvertent result of the protective box was that the volume control was inaccessible. This problem was solved by providing headphones with volume control on the cord. The image below shows the tape recorder in the protective box.



Figure 8: VVAATT audio recorder in protective box.

The only software changes needed for VVAATT was audio capability at the key interaction points. To add this capability, we used a java api that supported Microsoft Wave files and then created individual files for all the candidates, races and actions such as “voted”, “unvoted”, and “changed a vote”. The sound files were created using the AT&T Natural Voices Text to Speech engine. We decided to use a speech generating tool in order to avoid problems of biased voicing and uneven tone. Though a few different engines were considered, we felt the AT&T option was the best. Most of the names were no trouble to produce and only a few required rewriting with additional sound cues. Questions were included in the surveys to try to determine if using a computer generated voice was a good decision.

VI - 5. Experiment Protocol

During the experiment, subjects voted on both the VVAATT and VVPAT systems. Each subject completed four elections on each system. One election was a normal election and contained no mistakes in the audit trail. The other three elections each contained a single error in the audit trail. (See section VI - 7 for a description of the errors.) Both the order of voting systems that subjects used and the order of the errors they received were randomized. In between the different voting systems, subjects were given a short story to read that was unrelated to voting and served as a small distraction task. After having voted on both systems, subjects were given four final surveys to complete. The detailed experiment procedure follows.

1. Subjects arrived at the MIT Media Lab. Before starting the experiment, subjects signed consent forms and filled out a brief pre-survey. (All surveys can be found in Appendix E.)
2. Subjects were prepped for the experiment with a short experiment script. The exact script can be found in Appendix A, however, the script gave the following information:
 - The basic structure of how the experiment would procedure, voting four elections each on two different voting machines.
 - Informed the subject that both machines were touch screen and gave basic instructions on how to best use the machines.
 - Informed the subject that each voting booth contained instructions, they could look over if necessary.
 - Explained that their task was to accurately follow a voting agenda, a card with candidates listed for each race.
 - Informed the subject that the role of the person running the experiment was that of a poll worker and if they had any problems or questions as they preceded they could ask for help.
 - Answered any questions the subject may have had before voting.
3. Subjects voted all four elections on the first voting system.
4. Subjects completed a short distraction task, reading a short story unrelated to voting. (This task lasted approximately one to two minutes.) The intention of this task was to try to get participants minds off the voting task that they had just completed and back to a similar state of mind as when the first started. The

distraction task helped to reduce order differences that might otherwise be present in the data.

5. Subjects voted all four elections on the second voting system.
6. Subjects completed four surveys. The first survey asked questions about the printed instructions in the voting booths, and the visual LEVI interface. The second survey asked questions specific to the first voting system the subject voted on. The third survey asked questions specific to the second system the subject voted on. The fourth and final survey asked some comparison questions about the two systems.
7. Subjects were asked if they had any final comments the surveys did not cover.
8. Subjects were thanked for their time and compensated \$10.

VI - 6. Creating a Voting Experience

Throughout the experiment, a strong effort was made to simulate a realistic voting experience. This was accomplished both through the language and terminology used as well as through the physical environment.

Throughout the experiment as many voting terms were used as possible. Computers were referred to as voting machines. Subjects were directed to voting booths and experiment observers were the poll workers.

While there were some limitations to the changes we could make to the physical environment, as much as possible a realistic polling station was created. The experiment was conducted in the basement atrium of the Media Lab. This space is a large open public space that is easily accessible. It was chosen for its similarity to many polling locations. In addition to conducting the experiment in a location similar to a real polling

location, two voting booths were created to give the voter a sense of privacy. Both voting booths included instructions on how to properly use the voting systems.

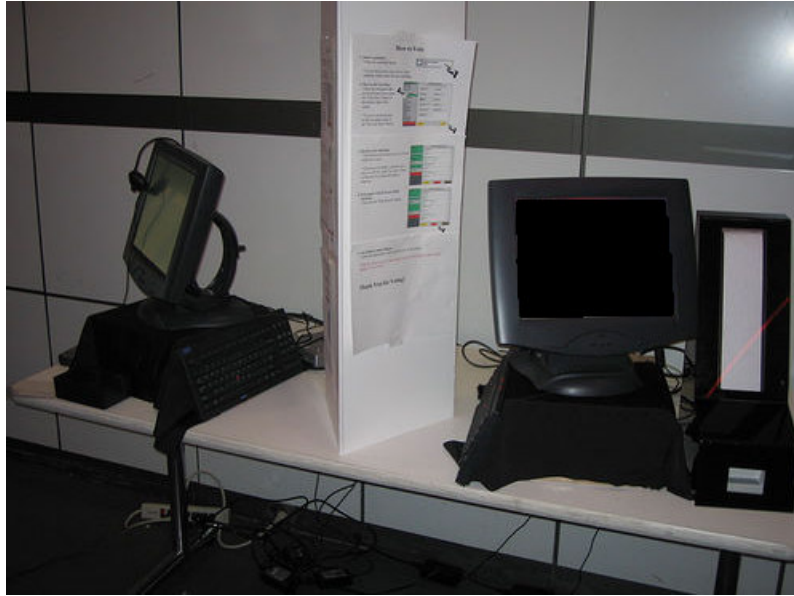


Figure 9: Voting booths set up with a separating divider.

VI - 7. Errors in the Audit Trail

The purpose of inserting errors into the audit trail was to determine how well voters were able to use the audit trail to insure that their votes were accurately recorded, however, errors were not simply random. The errors placed in the audit trail represented realistic changes that someone with malicious intentions might use to either affect the outcome of an election or cast significant doubt on the election results. In the end, there were three error conditions:

- Error Condition 1: changing a vote to a different candidate
- Error Condition 2: removing a vote from a candidate
- Error Condition 3: removing a race from the audit

Also briefly considered was an error condition where a candidate the voter did not select was given a vote in the audit trail, however, it was unclear how this kind of error would be translated in the audio audit and we needed to reasonably limit the size of our experiment. Significant effort was invested to make sure that the error conditions translated symmetrically in both the audio and the paper trails. It is important to note that for all error conditions, the errors only appeared in the audit trails, either the audio feedback or the printed record. The visual interface that the subject was viewing always reflected the actual choices that had been made.

The first error condition was a simple change of candidates. In this error condition, when the voter selected candidate A, candidate B would appear in the audit trail. In the printed record this meant that candidate B was printed instead of candidate A. In the audio, the voter heard, “voted for candidate B” instead of “voted for candidate A” even though they just pressed the selection button for candidate A.

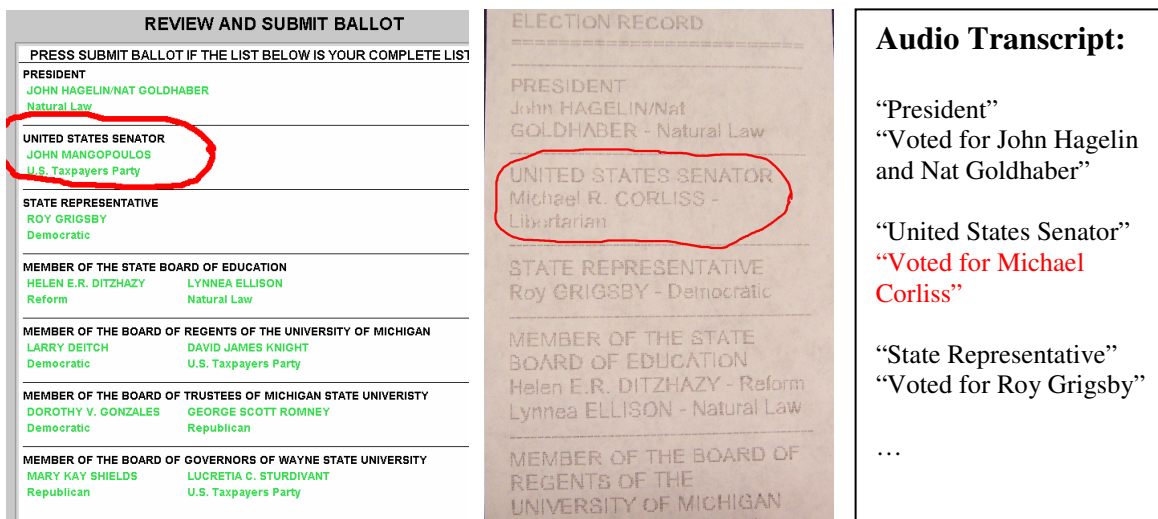


Figure 10: Error Condition 1, from left to right, screen shot from LEVI, paper record, audio transcript.

The second error condition was a missing candidate. In this situation, a candidate that the voter cast a vote for did not appear in the audit record. For example, if the voter cast a vote for candidate A in the President race then in the audit record, the President race would indicate that the voter had not cast any vote in that race. In the audio audit we translated this situation into the candidate name not actually playing. When the voter selected candidate A in the President race, they would hear “vote for” without any name being played.

REVIEW AND SUBMIT BALLOT	
PRESS SUBMIT BALLOT IF THE LIST BELOW IS YOUR COMPLETE L	
Park Commissioners	
THOMAS BENIGNO Republican	LINCOLN PICKARD Libertarian
Gas and Electric Commissioner	
NO VOTE	
Road Superintendent	
TOM LANTOS Libertarian	
Public Utilities Commission	
WILMA CHAN Democratic	JAY LANG Libertarian
Register of Deeds	
CHRISTINE KEEDY Democratic	
Electoral Board Members	
KEN BADE Republican	TONI L. CASEY Democratic
CHRIS LARKIN Republican	
Sheriff	
LINDA SHAW Democratic	

Road Superintendent
Tom Lantos - Libertarian

Public Utilities Commission
Wilma Chan - Democratic
Jay Lang - Libertarian

Register of Deeds
Christine Keedy - Democratic

Electoral Board Members
Ken Bade - Republican
Chris Larkin - Republican

Sheriff
Linda Shaw - Democratic

END OF ELECTION RECORD

Audio Transcript:

...

“Register of Deeds”
“Voted for Christine Keedy”

“Electoral Board Members”
“Voted for Ken Bade”
“Voted for Chris Larkin”
“Voted for “

“Sheriff”

...

Figure 11: Error condition 2, LEVI interface, paper ballot, audio transcript.

The final error condition was a race that was missing entirely. In this error condition, a race that appeared on the screen and that the subject placed votes in did not appear in the audit trail. For the paper records, the race was simply left off the record. In the audio audit, no audio plays while the voter is voting the race. The race title does not

play, and no audio is heard when the voter selects candidates. The audio resumes as normal as soon as the voter moves out of the error race.

REVIEW AND SUBMIT BALLOT

PRESS SUBMIT BALLOT IF THE LIST BELOW IS YOUR COMPLETE L

MEMBER OF THE BOARD OF REGENTS OF THE UNIVERSITY OF MICHIGAN
 REBECCA MCGOWAN Democratic JOE SANGER U.S. Taxpayers Party

JUSTICE OF THE SUPREME COURT
 JERRY J. KAUFMAN

MEMBER OF THE BOARD OF GOVERNORS OF WAYNE STATE UNIVERSITY
 DOROTHY V. GONZALES Democratic PAUL NAVE Democratic

COUNTY CLERK
 BADI BADIOZAMANI Independent

MEMBER OF THE STATE BOARD OF EDUCATION
 LAWRENCE C. PATRICK Republican CLARA C. PILCHAK U.S. Taxpayers Party

PROSECUTING ATTORNEY
 EDWARD R. REED Republican

REGISTER OF DEEDS
 MICHAEL CHELI Independent

STATE REPRESENTATIVE
 DIANE BARNES - Libertarian

MEMBER OF THE BOARD OF REGENTS OF THE UNIVERSITY OF MICHIGAN
 REBECCA MCGOWAN - Democratic
 JOE SANGER - U.S. Taxpayers Party

JUSTICE OF THE SUPREME COURT
 JERRY J. KAUFMAN -

MEMBER OF THE BOARD OF GOVERNORS OF WAYNE STATE UNIVERSITY
 DOROTHY V. GONZALES - Democratic
 PAUL NAVE - Democratic

MEMBER OF THE STATE BOARD OF EDUCATION
 LAWRENCE C. PATRICK - Republican
 CLARA C. PILCHAK - U.S. Taxpayers Party

Audio Transcript:

...

“Member of the Board of Governors of Wayne State University”

“Voted for Dorothy Gonzales”

“Voted for Paul Nave”

[Silence]

“Member of the State Board of Education”

“Voted for Lawrence Patrick”

Figure 12: Error Condition 3, LEVI Interface, paper record, audio transcript.

VI - 8. Error Condition Variables

In addition to the three error conditions, there were two important variables that were considered in the experiment. These included what kind of race the error occurred in, a single selection race or a multiple selection race, and how far down the ballot the error occurred, if the error was in the top, middle or bottom of the ballot.

The first variable, what kind of race the error occurred in was spread among the different error types, without really trying to obtain comparison data. Error condition one, the changed name, was always placed in a single selection race. The missing candidate, error condition two, was always in a multiple selection race. The missing race error, error condition three, was placed in both single selection and multiple selection races.

The error placement within the ballot variable was controlled within each error condition. For each error condition there were three different elections. One election contained the error in the top of the ballot, one contained the error in the middle of the ballot and one contained the error in the bottom of the ballot.

VI - 9. Elections, Error Placements, and Voting Agendas

Participants in the experiment each voted four elections on each voting system. While each of the four elections was unique, the composition of the elections was similar. Some of the races overlapped and some of the candidate names were used in more than one election. The number of single selection and multiple selection races was fairly evenly distributed among the elections. The table below shows the number of multiple selection races that each election contained. All the elections had eleven races. The full content of the elections can be found in Appendix B.

	Single selection races	Double selection races	Triple selection races
Election 1	7	4	0
Election 2	8	3	0
Election 3	8	2	1
Election 4	7	3	1

Table 1: Distribution of race types among the four elections.

When placing the error conditions, one election was assigned to each error condition and one election was used for the null condition. Election 1 was used with the first error condition, Election 2 was used with the third error condition, Election 3 was the null error condition and Election 4 was the second error condition. For each election

except Election 3 there were three conditions for the placement of the error. Given that each election had eleven races, an error placed in the top of the ballot was in the first two races, races 1 and 2, an error in the middle of the ballot was in races 5, 6, or 7, and the error placed in the bottom of the ballot was in the last two races, races 10 and 11. The table below shows the exact placement of all errors.

	Error Condition 1	Error Condition 2	Error Condition 3
Race 1			TOP
Race 2	TOP	TOP	
Race 3			
Race 4			
Race 5		MIDDLE	
Race 6	MIDDLE		MIDDLE
Race 7			
Race 8			
Race 9			
Race 10		BOTTOM	
Race 11	BOTTOM		BOTTOM

Table 2: Distribution of errors in the ballots.

Each election had only a single voting agenda, the “cheat-sheet” given to voters that instructed them how to vote each election. On each voting agenda, all the races in that particular election were listed and the subject was either specifically instructed on who to vote for, told to vote for anyone of their choosing, or told to skip the race. While the majority of races specifically told the subject who to vote for, some races gave the subject a choice of who to select and some races instructed the voter to skip the race. It was important to include some races where the voter did not place a vote so they could

see how a race that they had skipped would appear in the audit trail. Appendix C contains all the voting agendas used during the study.

Although voters were asked to use the voting agendas while they were voting, voters were not able to use the voting agendas to check their printed record. This decision was validated by the fact that even in a highly salient race such as the president, there was no difference in the number of errors found relative to the other races that weren't as easy to remember.¹

VI – 10. Response to Voters who Reported Errors

When voters in the study reported errors to the poll worker, the response was uniform in addressing the voters concern while still encouraging them to continue voting. When voters reported errors to the poll worker, the poll worker would first try to briefly get the voter to explain the exact nature of the error. Some voters offered this explanation without prompting while other voters were asked “What is the problem?” or “For which candidate is this a problem?” Getting the voter to explain the error was a way of double checking that they were reporting the error that was intended to be present and not some other problem. After the voter explained the specific error, the poll worker told the voter that they would “take note of the problem” and voters were then encouraged to continue voting. Although in a real election, continuing to vote given a problem in the audit trail would not be an appropriate response, in this election voters were asked to continue in order to collect uniform and complete voting data from all subjects.

¹ An error of type 3, missing race, was placed in the President race.

VI – 11. Subject Voting Assignments

Given all the different variables present in the experiment care was taken to properly randomize subjects in the voting pool. Half the subjects voted on the VVPAT system first and half the subjects voted on the VVAATT system first. All subjects completed the same four elections on both systems. The four elections consisted of one election of each of the error conditions and one null election. In addition, for each subject, one election contained the error in the top of the ballot, one contained the error in the middle of the ballot, and one contained the error at the bottom of the ballot.

The order of the errors that subjects saw was also carefully randomized. In an effort to simplify the error randomizing, we randomized only the order of the three actual errors and then considered the placement of the null condition afterwards. This simplified randomization because we consolidated the placement of the null condition down to three placements instead of all four. (The second and third election positions were equivalent as they both represented a “middle” placement of the null condition.) A latin square design was used to obtain the three error condition orderings:

- Error condition 1, Error condition 2, Error condition 3
- Error condition 2, Error condition 3, Error condition 1
- Error condition 3, Error condition 1, Error condition 2

Twelve subjects voted each of the three orderings. Within the twelve subjects for each ordering, four voted with the null error condition placed as the first race, four voted with the null error condition in the middle (two as race 2 and two as race 3) and four voted with the null error condition as the last race. In addition, within each error condition, twelve subjects voted with the error in the top of the ballot, twelve subjects voted with the error in the middle and twelve subjects voted with the error at the end of the ballot.

Details of which subjects voted on which machine first and with what error order can be found in Appendix D.

VII. Experiment Results

Given that this experiment was designed to measure the usability, effectiveness and the time required to vote for each audit system, it would have been ideal all our results and observations fit neatly into one of these categories. Instead, two additional result categories have been added. From observation and some survey data, many interesting results regarding subjects' attitudes towards both the paper trail and audio trail were found which did not quite fit in any of the three original categories. The results presented below clearly show that both the VVAATT and VVPAT audit systems have strong values as well as weak ones.

VII – 1. Usability

From a usability perspective, both systems fared very well. The vast majority of subjects had no trouble using the voting system and audit trails. There were only a few recurring usability problems observed in the VVAATT system and the VVPAT system.

While post survey data indicated that about sixty-four percent of participants did read the printed voting instructions that were present in the voting booth, it is unclear that all of these participants read the instructions before starting to vote. From observations taken during the study, only noted three subjects (8.3 %) were noted as having looked at the instructions prior to starting to vote. There is no way to be sure that we did not miss some people looking at the instructions or simply not write it down, however, it is unlikely that all of the people who indicated that they read the instructions, actually read

them before starting to vote. Many subjects were observed looking at the instructions while their paper ballots were printing which could account for the high response rate. Especially with a participant group so heavily immersed in technology, it is not unsurprising that many people jumped into voting without having read the instructions. Systems that are depend on people reading instructions are doomed to failure.

In the VVPAT voting system, the one systematic usability problem observed was that many people got to the review screen, reviewed their votes and then didn't know what to do. A few people specifically made comments indicating that they were looking for a "submit ballot" button while some subjects simply weren't certain that they had to print their ballot. Verbal comments made when subjects encountered this problem included "How do I submit?" and "I don't see submit ballot." This problem was observed with seven subjects, almost twenty percent. For six of these subjects, VVPAT was the first system they voted on. Their confusion can not be attributed to the fact that they had seen a "Submit ballot" button in the VVAATT system.

Results from post survey data support the observations that subjects had few problems using the VVPAT system. Only one subject disagreed with the statement that "It was easy to create my printed record." All subject responses averaged out to 4.19 (using 5 as strongly agree, 4 agree, 3 neutral, 2, disagree, 1 strongly disagree), fairly strongly in the agree side. Subjects also indicated that it was easy to accept or reject their paper ballot although subjects were slightly more neutral on this statement with responses averaging out to 3.77. When asked if it was easy to read their printed record, 25 subjects agreed that it was easy while 4 disagreed and 7 remained neutral. Post survey results indicated that the font size was ok for most people. The average of responses was 3.77 and only 3 people disagreed that the font size was large enough. Participants were mostly

evenly split when asked if they thought it would be easier to read the paper ballot if they could have held it themselves. Eleven people disagreed that it would have been easier, 10 people were neutral and 15 people thought it would have been easier to hold the ballot themselves. (This is however, a hard question for people to judge, because they are making a guess about what a behavior would be like, not evaluating something they had just done.) Overall, most subjects enjoyed voting on the VVPAT system and found it easy to vote on this system. Only one person disagreed with the statement “I enjoyed voting on this system” and the average was solidly in the agree range at 3.91. Almost all subjects agreed that it was easy to vote on the VVPAT system. Only one subject was neutral on this statement and the average was 4.17.

Subjects had a similarly positive experience with VVAATT system. There were very few systematic usability problems observed and post survey results indicated a positive experience for most voters. One systematic problem observed on the VVAATT system that was not seen as much with the VVPAT system was problems with the touch screen. Although it was thought that the screens were basically the same in the two systems, there were clearly some differences and the screen used with the VVAATT was not as sensitive as the screen used with the VVPAT system. Many people had to make several attempts to get their touch to register. Unfortunately, people’s normal reaction to touch the screen for a longer period of time worked against them as shorter and harder taps seemed to work best on the screen, not longer taps. While this problem was not related to the VVAATT system and could have easily been corrected with another touch screen, one usability problem that was related to the VVAATT implementation was that subjects occasionally failed to notice that their selection had actually registered. The underlying problem here was that in the VVAATT implementation, the audio feedback

played before the visual interface updated and the visual interface was not updated until after the audio finished playing. A few times, we noticed that subjects would make a candidate selection, look for the visual interface to update and see that it hadn't so they would press their selection again, however, this had the effect of removing their vote, because the first press had also registered. This caused voters to become lost and confused as to what was happening in the interface. Most voters who encountered this problem, quickly realized what was going on and were able to adjust by moving slower in the interface. Only in two cases did we intervene for a voter who was continuing to get lost. After advising these voters to move slower in the interface and wait until the visual had updated they had no trouble using the interface. Better integration of the audio feedback into the visual interface could have avoided these problems.

Responses to the survey questions for the VVAATT system were generally positive and indicated that subjects did not encounter many usability problems. Most subjects indicated that it was easy to understand the audio feedback. Six subjects disagreed that it was easy and only one was neutral on this topic. The average of the responses was 3.83, fairly strongly in the agree side. Participants were slightly critical of the voice in the audio feedback. Responses to the statement "the audio feedback was pleasant to listen to" averaged to only 3.16 and responses to the statement "the audio feedback was too robotic for my tastes" averaged to 3.22. While this is not a strong indication it does still show that there are some tradeoffs to using computer generated speech. Participants mildly agreed that the audio verification helped them confirm their selections, average response 3.78. Subjects agreed that when they heard mistakes in the audio they noticed the mistake immediately, average response 4.0. Overall subjects agreed that they enjoyed voting on the VVAATT system and that it was easy to vote on

this system, though their responses were not quite as strong as in the VVPAT system. The responses averaged to 3.42 for the question of if they enjoyed voting on the audio system and 3.72 for the statement that it was easy to vote on the audio system.

VII – 2. Effectiveness

When measuring effectiveness of the voting systems we looked at how subjects reacted to the mistakes in the audit trail. Subjects' reactions were broken down into two important measures. The most important measure was how many errors subjects reported to the "poll worker" or experiment observer. However, there were also cases when participants were observed finding an error that they did not report to the poll worker. Although in a real election it would do no good for a subject to find an error and not report it to a poll worker, these were noteworthy situations in this study since with more voter education discovered errors could become reported errors. An error that is never found can never be reported.

The results strongly indicate that subjects have an easier time identifying and reporting errors in the VVAATT system than in the VVPAT system. Almost ten times as many errors were discovered in the VVAATT system than in the VVPAT. Using the VVAATT system, twenty-two subjects discovered twenty-six errors and reported fifteen of them. Using the VVPAT system, two subjects discovered three errors, none of which were reported to the poll worker. The fifteen errors reported in the VVAATT system were reported by twelve voters. The graph below represents this data.

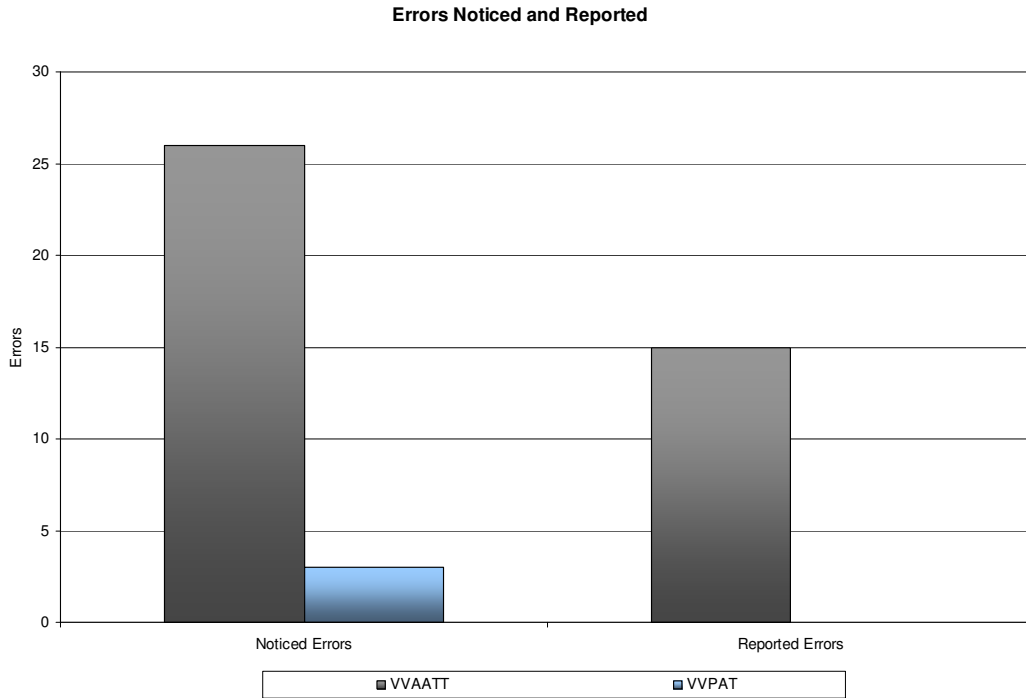


Figure 13: Errors noticed and reported in each voting system.

The numbers in the above graph are based solely on observations. The number of reported errors was easy to measure. A reported error was defined as an error that the subject encountered and reported to the poll worker. The subject had to tell the poll worker about the error prior to submitting the ballot. (Telling the poll worker there was a problem after having submitted a ballot will not help protect the security of the voter's vote.) In some cases, a change in behavior clearly indicated that a subject had noticed an error even if they did not report it. While sometimes the behavior change was subtle, a shake of the head, an especially long pause or simply a strange look in their face, in most cases, the behavior change was more obvious. Some voters started selecting and unselecting the same candidate, or moving back and forth between races. While the number of reported errors is an accurate representation of what happened in the

experiment, the number of noticed errors, at least for the VVAATT system, under-represents the true number of noticed errors.

While many people strongly reacted to the errors in the audit trail, other people's reaction was much more subtle and could not be visually verified. To try to get a measure of how many people this affected, post survey questions asked subjects if they had noticed any mistakes in the audit trail. The question asked subjects to either agree, disagree or indicate that they were not sure in response to the statement "There were some mistakes in the {printed record/audio verification}." (Asked as two separate questions.) Results from this question indicated significant differences in the two audit mechanisms. While twenty-nine subjects agreed with this statement for the VVAATT system, only three subjects agreed with the statement for the VVPAT system. For the VVAATT system, this indicates that at least seven subjects noticed an error that was not visually identified. This would indicate at least seven additional errors that were noticed, however, it is quite likely that the additional noticed errors is more than seven because some subjects may have noticed more than one error. While one additional person indicated that there were errors in the paper trail than was counted in the observations, it is not clear how to interpret this data point. The two other subjects who were observed finding an error in the paper trail pressed the "Make Changes" button on the final review screen indicating that they had noticed the error. Pressing the make changes button was not counted as reporting the error because nothing was said to the poll worker. (See section VII - 4 for more discussion on this topic.)

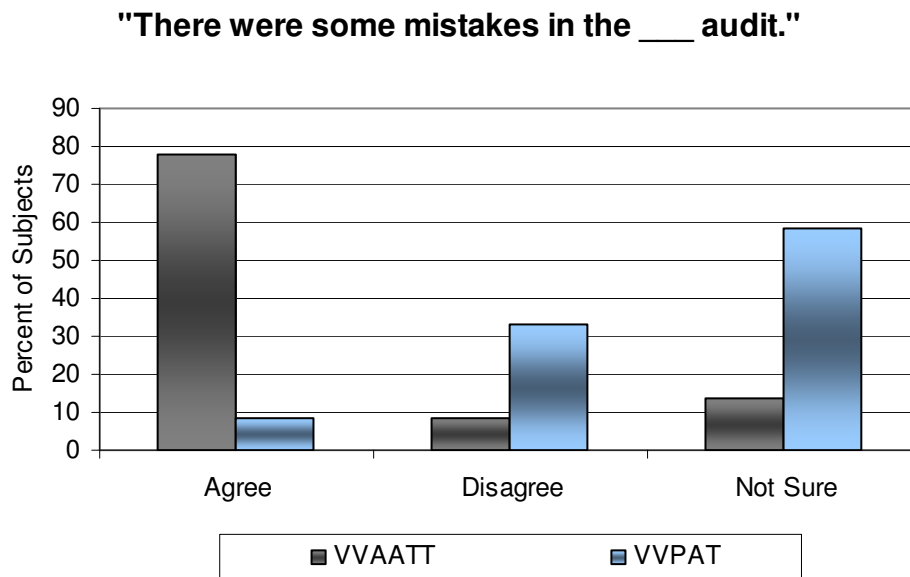


Figure 14: Responses to post survey question asking subjects if they noticed mistakes in the audit trails.

One additional interesting view of the error data is how many errors of each type were caught. In the VVAATT system, subjects were much more likely to find errors of type 1, a changed name, than they were to find the other two errors with missing information. However, in the VVPAT system, subjects were more likely to find errors of type 2 and 3, missing information. Using the VVAATT system, subjects found eighteen errors from error condition 1, the changed name, however, subjects only found three errors of the missing name condition and only five errors of the missing race condition. These differences in values are statistically significant. A single factor ANOVA test on these three values yields a p value of 1.9×10^{-5} . Of the three errors found in the VVPAT system, one was of a missing name and two were of missing races. While this data is not statistically significant, ANOVA p value of 0.36, it does reveal an interesting trend. It

seems likely that the only reason the VVPAT data is not statistically significant is because there are not enough data points.

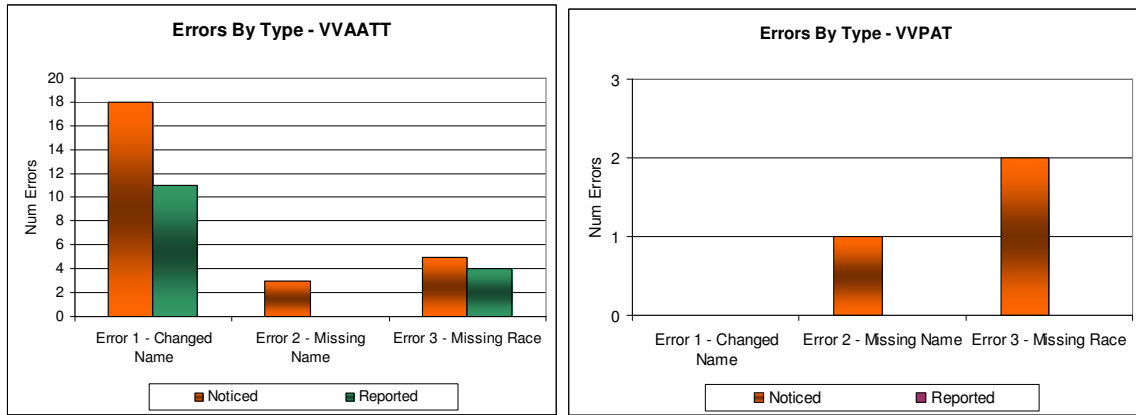


Figure 15: Noticed and reported errors broken down by type. The left graph is VVAATT errors, the right is VVPAT errors.

VII – 3. Time Spent Voting

Subjects spent slightly longer voting on the VVAATT system than they did voting on the VVPAT system. Subjects averaged 136 seconds per election on the VVAATT system and 122 seconds per election on the VVAATT system. This is about ten percent slower. A paired sample t-test indicated that the difference in means was statistically significant ($p = 0.0104$). Although the average amount of time spent voting on the two systems is similar, the standard deviation of times on the VVAATT system is larger than the standard deviation on the VVPAT system. The standard deviation of values in the VVAATT system was 55.67 seconds while the standard deviation of values in the VVPAT system was only 38.08 seconds. The graph below shows a box and whisker representation of the time data. The median values in each group are almost exactly the

same, 120 seconds; however, the quartiles in the VVAATT data have a much larger range. One of the outliers in the print data falls well within the VVAATT fourth quartile.

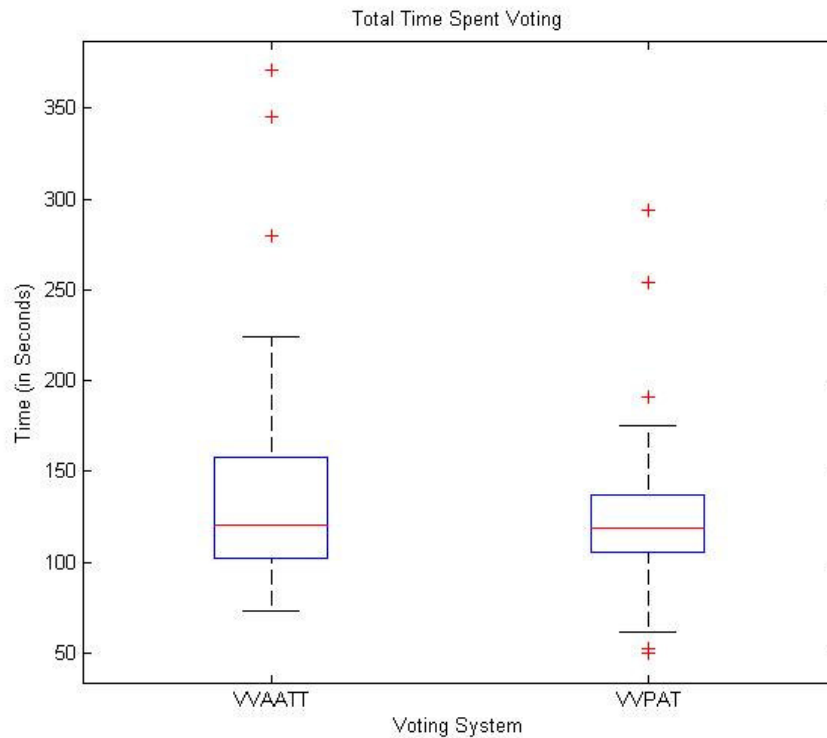


Figure 15: Box and whisker graph of times spent voting.

While the time data collected is important and valuable, we do not want to overuse this information. Broad and far reaching conclusions based on this data are inappropriate because the time data that collected is extremely implementation dependent. A different implementation of the voting system would have resulted in significantly different times. Previous user studies have shown that the LEVI interface is slightly slower than some of the commercial voting interfaces. [15] A different visual interface would have yielded different times. In the VVAATT system, faster times would have resulted with different audio files, faster speaking voice, fewer words, etc. In

the VVPAT system, a faster printer would have resulted in faster times. One last complication when trying to make conclusions from the time data is that the data includes the races where voters discovered mistakes in the audit trail. While in some cases, the voter was only distracted for a short amount of time, less than five seconds, in other cases voting was interrupted for longer periods of time, thirty to sixty seconds.

One strong time related finding found in the data was that many subjects perceived the audio system as slower. This sentiment was much stronger than the actual data indicated. When directly comparing the time spent voting on each election, in forty-five percent of the elections, subjects actually took more time to vote on the print system than the audio system. However, even with this mostly balanced data, the majority of subjects felt that voting on the VVAATT system was slower than voting on the VVPAT system. In a post survey question, subjects were asked if they felt the audio slowed them down. Only two people disagreed with the statement that the audio slowed them down and only two people remained neutral. The average response for this question was strongly in the agree field at 4.28. Twelve subjects wrote additional comments down indicating that they felt that the audio process was too slow. In most cases the sentiment was that the slowness was frustrating, however, in three cases subjects indicated that the slowness was potentially helpful. One subject wrote that “the audio system was very slow. The lag caused a little frustration.” Of the three subjects who commented that the slower voting pace could be an advantage, only one gave a reason that “it forces voter to verify selections.”

There are two factors that could have led subjects to feel so strongly that the audio system was slower; one is that the visual interface in the audio system felt less responsive to voters, the other is that the time spent voting on the audio system was more active than

the time on the print system. Because the visual interface in the VVAATT system did not update until the audio finished playing, the interface felt much less responsive to participants and could have left participants with the sense of slowness. In addition, the time spent voting on the audio system fully represents time that the subject was actively voting while the time in the paper system includes time that the subject was waiting for the paper to finish printing. In the VVPAT system, subjects spent as much as 30 seconds waiting for their paper record to print. It was easy for voters to mentally “check out” when they printed their paper record and not realize they were still voting.

VII – 4. Attitudes and Responses to the Paper Trail

Observations from the study indicated that many subjects did not carefully review the paper record of their votes prior to casting their ballot. The lack of errors found in the paper trail is a direct result of this observation. The majority of the subjects did not spend more than a few seconds reviewing their paper record. Some voters reviewed the ballot as it was printing, however, many subjects completely ignored the ballot while it was printing. Several subjects used the time while the ballot was printing to look at the voting instructions which were inside the voting booth.

Several subjects made a selection to cast their ballot before the record finished printing. This meant that the ballot was still printing when the voter made a selection in the race. Fourteen subjects, thirty-nine percent of participants, cast at least one ballot in this manner. Five subjects submitted all four of their ballots before printing had completed and one additional subject submitted the first record before it had finished printing. (The interface had a short delay that prevented subjects from immediately making a selection after they started printing their ballot, it did not fully prevent the voter

from making a selection while printing was still in progress.) While commercial voting systems may not allow voters to cast a ballot before it is fully printed, this behavior is illustrative of voters' attitudes towards the paper trail. Many voters do not believe that it is necessary to check the paper record and will not invest the time to check it. Six participants wrote comments on their post surveys that very clearly illustrated this attitude:

- “Absolutely no need for paper receipt. Electronic vote was fine. Paper receipt is a waste of time and paper.”
- “I checked the review on the screen and didn't check what was printed. I never saw a printer that printed a different candidate name than it was sent.”
- “I'm not sure if it's necessary to have the voter review the paper record.”

One other behavior observed was that for all of the VVPAT errors that were found, the subjects first reaction was to press the “Make Changes” button on the DRE. Without being able to see that the selection on the screen did not match the selection on the printout, the voters assumed that the mistake was theirs' and not the fault of the machine. Because the experiment VVPAT implementation did not allow voters to make changes to their ballot after printing a record, we were unable to observe how voters would react if they continued to observe the same error.

One final attitude that we tried to gauge was how subjects felt about the relative confidence of the paper record compared to the electronic record. Before asking subjects this question, they were informed that the purpose of VVPAT was to “to have a paper record of each vote made during an election to serve as an audit form.” Subjects were further informed that in a real election a small percentage of paper records would be checked and compared with the electronic records. With this information, subjects were

asked to respond to the statement “In a real election, I would place greater trust in the paper records than the electronic records.” Responses to this question overwhelmingly favored the paper records. Only five subjects disagreed with the statement, eleven remained neutral and twenty agreed with the statement. (Of these twenty, seven indicated that they strongly agreed with the statement.) Subjects were also asked if they would feel confident in the results of an election if their county used a voting system with a paper record. Almost all responses to this question were positive. Only six subjects remained neutral while twenty-four agreed and six strongly agreed.

VII – 5. Attitudes and Responses to the Audio Trail

While it was harder for subjects to ignore the audio feedback, then it was for them to ignore the paper trail, there were still interesting results observed of users’ attitudes towards the audio feedback. Having observed so many people clearly notice an error in the audio trail and yet fail to report it to the poll worker, we wanted to try to figure out why. After the subjects had completed their surveys, we asked subject why they had not reported the error to the poll worker. In a majority of cases, subjects indicated that while they had noticed and been confused by the errors, they had assumed that it was a minor bug in the interface and not a noteworthy event. In a real election, it is possible that voters would not wave off obvious mistakes; however, this kind of attitude is just as dangerous as voter’s lackadaisical attitude towards the paper trail.

Subjects generally did not pay much attention to the VVAATT tape recorder. While many subjects did notice it and a few were curious enough to read the short descriptive poster that was included in the voting booth, post survey results indicate that the majority of subjects did not pay attention to it while they were voting. In the post

survey, subjects were asked to agree, disagree or indicate that they were not sure in response to the statement that “everything they heard in the headphones was recorded on the tape.” Only nine subjects agreed that everything was recorded. The majority of the subjects, twenty-five subjects, were not sure if everything they heard was recorded and two subjects disagreed. Subjects actually would not have been able to hear any audio if the tape had not been recording, however, this was a hard concept for people to understand. When asked if they would feel comfortable with the audio recording during a real election subjects were evenly split. Fourteen subjects said they would not be comfortable with the recording, fifteen said they would feel comfortable and seven remained neutral.

Finally, through post survey questions, subjects were asked about their attitudes toward the relative trust they would place in the audio record as compared to electronic records. The same as with the question that subjects answered regarding the paper trail, subjects were informed that the purpose of VVAATT was to “create an audio record of each vote that would serve as an audit.” Subjects were also told that in a real election a small percentage of the audio records would be audited and compared with the electronic records. When asked to respond to the statement “In a real election, I would place greater trust in the audio records than the electronic records” the majority of responses tended towards disagreement. Eight subjects agreed with the statement, eight remained neutral, eighteen disagreed, and two strongly disagreed. When asked if they would feel confident in the results of a county election that used a VVAATT system, subjects were exactly evenly split. Eleven subjects indicated that they would not feel confident in the results; eleven subjects indicated that they would feel confident in the results and fourteen remained neutral.

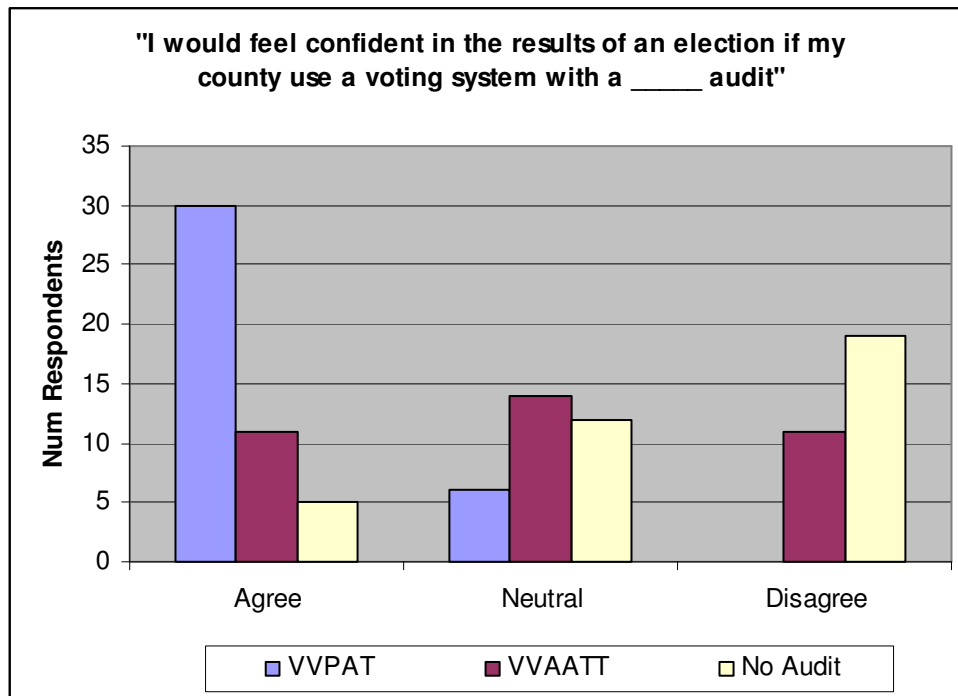


Figure 16: Responses indicating how subjects would feel about the results of an election given three different auditing mechanisms.

VII – 6. Experiment Subject Audit Preferences

After completing surveys asking about their experience with each individual audit system, subjects completed one final survey which asked them to compare their experiences on the VVAATT and VVPAT systems. When asked which system they preferred voting on and which system they found easier to vote on, participants had a slight preference for the VVPAT system, however, when asked which system they would feel most comfortable with for their own county elections, participants overwhelmingly selected VVPAT system.

	VVPAT	VVAATT	No Preference
“I preferred voting on the _____ system”	21 subjects	12 subjects	3 subjects
“I found it easier to vote on the _____ system.”	15 subjects	13 subjects	8 subjects
“I would feel most confident in the results of an election when my county used a voting system with a _____ audit system.”	31 subjects	3 subjects	2 subjects (one subject indicated no preference between the two audit systems and one subject indicated no preference if there was an audit or not.)

Table 3: Results from comparison survey questions.

VII – 7. Results Overview

The strongest results that came out of this study were:

- Both VVAATT and VVPAT were easy for subjects to use. Very few systematic usability problems were seen in either system.
- Participants found many more errors in the VVAATT audit trail than they did in the VVPAT paper records. Seventy seven percent of subjects agreed that there were errors in the VVAATT audit trail compared to only eight percent who agreed that there were errors in the VVPAT paper records.
- Voting on VVAATT took slightly longer than voting on VVPAT and many participants perceived a strong time difference.
- Participants strongly preferred VVPAT to VVAATT when asked which audit system they would recommend to their county.

VIII – Hypothesis Explanations of Experiment Results

While some of the study results were fairly balanced and not out of the ordinary, there were a few results which were particularly unbalanced and surprising. These results included the differences in the number of errors found in each voting system, the differences in the types of errors found with each system and the differences in voters' attitudes towards each system. For these results, some hypothesis explanations are provided below.

VIII – 1. Differences in Number of Errors Found

Subjects in this study found many more errors in the VVAATT audit than in the VVPAT audit. There are a few potential explanations for this significant difference:

- VVAATT provides immediate feedback to the voter. The voter does not have to rely on their memory in order to check the audit.
- VVAATT provides auditory feedback which does not take away the voters' attention. The multimodal feedback allows the voter to focus on both the audio and the visual at the same time.
- VVAATT is integrated into the voting process. It is not a separate step.
- Checking the paper record in the VVPAT system is seen as an extra step. Voters may view this step as optional or unnecessary.

The fact that the VVAATT audit is contemporaneous with the changes the voter is making in the visual interface makes it much easier for voters to verify the audit. There is no delay between the time that the voter makes a selection and the time that they verify the audit. In the VVPAT system, there is a significant delay between the time that a voter selects a candidate and the time that they verify the selection in the paper trail. This time

delay may cause voters to forget who they voted for in a particular race.² Another explanation for the higher number of errors caught in the VVAATT system is that the feedback is in audio form. Providing feedback in a form that is different from the visual feedback the DRE is providing allows the voter to focus on both the DRE and the audit at the same time. One final explanation is that VVAATT is fully integrated in the voting process, while VVPAT is an extra step in the voting process. When voters are listening to the audio feedback they are directly involved in the voting process, however, when voters review their paper record, they have already reviewed their selections on the DRE screen. Voters may have the sense that after they have reviewed their selections on the DRE, the voting process is finished. This would cause them to ignore or only glance over the paper record.

VIII – 2. Differences in Types of Errors Found

Voters in our study identified mostly incorrect names when using the VVAATT system, however, they identified only missing names and races in the VVPAT system. One possible reason why subjects were able to identify so many more errors of a changed name, in the VVAATT system, is that when they hear the changed name, it is in direct conflict with what they are expecting to hear. When audio is simply missing, the voter may not realize that it was missing because there is not as much conflict with their thought process. In the case of a missing name, the audio that the voter expects to hear begins to play and only a short part is missing. This missing audio segment may be too short a gap for the voter to realize that there was a problem before moving on to the next

² Work is currently being done by some voting manufacturers to create contemporaneous VVPAT systems though they are not widely implemented yet.

race or candidate. In the case of a missing race, the audio for the entire race is missing. The audio that the voter is expecting does not play at all; this longer piece of missing audio alerts voters to the problem.

With the VVPAT system, it may be easier for voters to identify missing information because as voters are scanning through the paper record, they may skim over the specific names, however, they will still be looking for information to appear. Missing information stands out more than incorrect information because when one skims over incorrect information it can be misinterpreted as the correct information. However, if nothing is there to take the place of the missing data then its absence is easier to notice.

VIII – 3. Differences in Attitudes towards Each System

Subjects general attitudes towards VVAATT and VVPAT vastly favored VVPAT over VVAATT. Subjects indicated a mild preference for the VVPAT in choosing the system they felt was easier to vote on. There was a stronger preference for VVPAT when asked which system voters preferred voting on. However, VVPAT won by a landslide when voters were asked which system would make them feel most confident in election results.

The first two results of voters' preferred system and perceived easier system are not surprising. Many subjects may have preferred voting on the VVPAT system, because they felt the process was faster and more efficient. With so many participants having indicated that the slowness of the audio was frustrating to them, it is expected that these subjects as well as others would have preferred the paper version which did not have these problems. With a better VVAATT implementation, the results from this question might have been more balanced between the two systems. Given that participants were

pretty evenly split on the question of which voting system was easier, a better VVAATT system might begin to skew the results of this question towards the VVAATT system.

The trend in the final attitude question asking which system voters would make voters feel most confident in the election results is a landslide for the VVPAT system. It is unlikely that a better VVAATT implementation would significantly change the results. There is no way to know for certain why the results are so skewed in this case, however, there are a few ideas that may be part of the explanation.

- Lack of familiarity with audio records.
- Incorrect perception of audio trails as flawed based on experience in the study.
- Preference towards system which less intrusive.
- Bias towards well known, non prototype system.

First, there are no common precedents for keeping important records in an audio format. The only audio records that people are familiar with are voice mail archives and music and radio archives, however, all these records fit seamlessly into an audio form. It would actually seem strange to try to keep music archives in a paper format. Lack of familiarity with the archive format may have discouraged participants from relying on this medium. Another possible explanation is that when voters responded to this question, they were not aware that the errors they heard in the audio trail were intentional and part of our study. Participants might have assumed that the audio trail always would contain errors and bugs and thus be unable to serve as a good audit. Voters may also have chosen the audit trail which “inconvenienced them less.” Many voters were able to simply ignore the paper trail by not actually confirming their votes, however, all voters had to interact with the audio trail which was an inconvenience. Finally, especially voters in this user population may have had prior knowledge of the paper trail system. Paper trails have

received a lot of publicity and may be more familiar to voters. Audio audits, however, have not received much publicity and are in more of a prototype stage than the paper trails. This lack of publicity and prototype status may also have discouraged people from choosing the VVAATT.

VIII. Conclusions

The user study presented here is a starting point for a significant investigation into auditing mechanisms. It is not the end of the discussion. Many more questions remain to be asked and many redesigns of the auditing equipment remain to be done. It would be premature to take the results of this study and say definitively that VVAATT is the audit mechanism we should use with our DRE voting machines. It is similarly premature to conclude that VVPAT should never be used. It would be safe to conclude that the current implementation of VVPAT does not sufficiently allow voters to find errors in the audit.

One strong message that was revealed in this study is that audit mechanisms need to be carefully designed and tested. Designers and manufacturers of audit systems need to consider everyone involved in the voting process, the voter, the poll workers and election officials. Each of these populations has different needs which can occasionally conflict. Choices need to be made to accommodate each stakeholder. For any audit system that is going to affect the voter, serious consideration and study of the usability of the system should be done. The usability of the audit mechanisms is equally important as the usability of the DRE. It is highly unlikely that an audit mechanism that is not tested will be successful.

Another message to be taken from this work is that audit mechanisms are still premature right now. Very few voting manufacturers were thinking about auditing

before 2003 when many security concerns began arising. The systems that we have right now, VVPAT and VVAATT, have not gone through enough design iterations to be considered a “final product.” With a few more design iterations, many of the usability problems that were observed could be significantly reduced. In addition, audit technologies as a group are relatively young. There are many companies working to develop new kinds of audits. Some of these companies are working on cryptographic protocols, some are working on audits that record what appears on the DRE screens and other techniques as well. With so many new audit technologies being developed and so many of these technologies only in their early versions of design, creating legislation that mandates any specific kind of technology will be counterproductive. Our legal process tends to be slow-moving and difficult to change. If a state enacts legislation requiring that DREs be equipped with paper trails now but down the line we discover that some other kind of audit technology is better or more accessible, will the state be able to react in time? Even worse, if many states begin enacting legislation requiring a specific audit technology, will development of better technologies be stifled? In such a developing space, making specific decisions about which technologies to use could inappropriately guide development of newer systems. Now is a time to experiment and innovate, not legislate.

Reference

1. K. Brace. "Overview of Voting Equipment Usage in United States, Direct Recording Electronic (DRE) Voting," Election Data Services, 2004.
2. United States. Help America Vote Act of 2002. Congressional Record. Washington: GPO, October 2002.
3. T. Kohno, A. Stubblefield, A. Ruben, D. Wallach. "Analysis of an Electronic Voting System," IEEE Symposium on Security and Privacy 2004. IEEE Computer Society Press, May 2004.
4. Schulte, Brigid. "Jolted Over Electronic Voting" Washington Post on the Web August 11, 2003. Metro. May 16, 2005
<<http://www.washingtonpost.com/ac2/wpdyn?pagename=article&node=&contentId=A42085-2003Aug10¬Found=true>>
5. "TrueVoteMD - Campaign for Verifiable Voting." TrueVoteMD. May 16, 2005
<<http://www.truevotemd.org/>>.
6. "Lawsuit Filed Over Black-Box Voting." Online posting. March 09, 2004. Pacific Views. May 16, 2005. <<http://www.pacificviews.org/archives/000749.html>>.
7. "VerifiedVoting.org." Verified Voting. May 18, 2005. Verified Voting. May 18, 2005 <<http://verifiedvoting.org>>.
8. R. Mercuri. "*Physical Verifiability of Computer Systems*," 5th International Computer Virus and Security Conference, March, 1992.
9. R. Mercuri. "A Better Ballot Box?," IEEE Spectrum, vol 39, October 2002.
10. R. Mercuri. "Electronic Voting," URL
<http://www.notablessoftware.com/evote.html> (visited 2004, December 6).
11. T. Selker. (October 2004). "Process can Improve Electronic voting: A Case Study of an Election." [WWW Document] URL
http://www.vote.caltech.edu/Reports/vtp_wp17.pdf, (visited 2004, December 6).
12. T. Selker. (September 2004). "The Voter Verified Audio Audit Transcript Trail (VVAATT)" [WWW Document] URL
http://www.vote.caltech.edu/Reports/vtp_wp18.pdf, (visited 2004, December 6).
13. T. Selker. "Fixing the Vote," Scientific American, October 2004.
14. Associated Press. "Lines As Long As Ohio Is Close." CBS News Online November 2, 2004. . May 16, 2005
<<http://www.cbsnews.com/stories/2004/11/02/politics/main653166.shtml>>.
15. T. Selker, M. Hockenberry, J. Goler, S. Sullivan. "Orienting Graphical User Interfaces Reduce Errors: The Low Error Voting Interface" [WWW Document] URL
<http://www.vote.caltech.edu/media/documents/OrientingInterfacesLEVI.pdf>, (visited May 18, 2005).
16. "Sequoia AVC Edge With VeriVote Printer." Sequoia Voting Systems. . Sequoia Voting Systems. May 16, 2005
<<http://www.sequoiavote.com/photo.php?photo=SequoiaEdgeWithVeriVotePrinter.jpg&title=Sequoia%20AVC%20Edge%20With%20VeriVote%20Printer>>.
17. "Voting Machines and Instructions." Clark County Election Department Home Page. . Clark Count Department of Elections. May 16, 2005
<http://www.co.clark.nv.us/election/2004/PRIM/VoteIns_EngSP.pdf>.

Appendix: Experiment Materials

In the appendices that follow are all the materials that were used to conduct the user study presented in this thesis.

Appendix A: Experiment Script - Used to prep subjects before they began voting

Let me explain what we're going to be doing here today.

We're going to ask you to complete eight different elections (or sequences of votes). Because this is a simulated voting situation, we're going to tell you who to vote for. This [*show subject palm card*] is a palm card. It lists each race and gives instructions for who you will select in each race.

You should think of your goal as trying your best to accurately vote for the people listed in your voting agenda.

The experiment is going to proceed in the following way. After I finish explaining the instructions to you I am going to give you your palm card voting agenda and direct you to our voting machine. The machine is a touch screen interface. That means that for you to interact with it you should tap the screen firmly with the flat part of your finger [*demonstrate this to the subject*].

During the experiment you will vote on 2 different voting systems. In each voting booth there are instructions specific to each system. Feel free to view this material before you begin voting. For the purpose of these elections, I am the poll worker. If you encounter any problems or have any questions as you go along, please feel free to inform me so I may assist you.

Do you have any questions at this time? [*pause to answer questions subjects may have*]

Appendix B: Experiment Elections

Election 1 – Error Condition 1 – Top of Ballot Error

PRESIDENT - 1

George BUSH/Dick CHENEY - Republican
Al GORE/ Joe LIEBERMAN - Democratic
John HAGELIN/Nat GOLDHABER - Natural Law
Howard PHILLIPS/J. Curtis FRAZIER - U.S. Taxpayers Party
Ralph NADER/Winona LaDuke - Green Party

UNITED STATES SENATOR - 1 - Michael R. Corliss

Spence ABRAHAM - Republican
Debbie STABENOW - Democratic
Mark A. FORTON - Reform
Michael R. CORLISS - Libertarian
William QUARTON - Natural Law
John MANGOPOULOS - U.S. Taxpayers Party
Matthew R. ABEL - Green Party

STATE REPRESENTATIVE - 1

Steve VEAR - Republican
Roy GRIGSBY - Democratic

MEMBER OF THE STATE BOARD OF EDUCATION - 2

Terri Lynn LAND - Republican
Lawrence C. PATRICK - Republican
John AUSTIN - Democratic
Kathleen STRAUS - Democratic
Helen E.R. DITZHAZY - Reform
Mary Ann LESSNER - Reform
Diane BARNES - Libertarian
Lynnea ELLISON - Natural Law
Gail QUARTON - Natural Law
Clara C. PILCHAK - U.S. Taxpayers Party
Max RIEKSE - U.S. Taxpayers Party

**MEMBER OF THE BOARD OF REGENTS OF THE UNIVERSITY OF MICHIGAN -
2**

Wendy ANDERSON - Republican
Susy AVERY - Republican
Larry DEITCH - Democratic
Rebecca McGOWAN - Democratic
Nick WAUN - Reform
Tim MAULL - Libertarian
Marvin SUROWITZ - Libertarian

Lisa Anne PUCCIO - Natural Law
David James KNIGHT - U.S. Taxpayers Party
Joe SANGER - U.S. Taxpayers Party
Scott S. TRUDEAU - Green Party

MEMBER OF THE BOARD OF TRUSTEES OF MICHIGAN STATE UNIVERISTY -
2

Connie BINSFELD - Republican
George Scott ROMNEY - Republican
Dorothy V. GONZALES - Democratic
Cal RAPSON - Democratic
Michael H. MILLER - Libertarian
Violet STEELE - Libertarian
Robert GALE - U.S. Taxpayers Party

MEMBER OF THE BOARD OF GOVERNORS OF WAYNE STATE UNIVERSITY -
2

Michael KELLY - Republican
Mary Kay SHIELDS - Republican
Paul MASSARON - Democratic
Jackie WASHINGTON - Democratic
Scotty BOMAN - Libertarian
Thomas W. JONES - Libertarian
Frederick KLINE - U.S. Taxpayers Party
Lucretia C. STURDIVANT - U.S. Taxpayers Party
James J. NICITA - Green Party

COUNTY CLERK - 1

Badi BADIOZAMANI - Independent
Judy ELLIOTT - Republican
Diana FOSS - Democratic
Mike SCHMIER - Democratic

COUNTY TREASURER - 1

Sandra S. THATCHER - Republican

DRAIN COMMISSIONER - 1

Todd CARSON - Republican
Rich GOSSE - Republican
Kenneth W. STRONG - Republican

COUNTY SURVEYOR - 1

John W. BEARD - Republican
Joe GUZZARDI - Democratic
Edward R. REED - Republican
Lingel H. WINTERS – Democratic

Election 1 – Error Condition 1 – Error in Middle of Ballot

PRESIDENT - 1

George BUSH/Dick CHENEY - Republican
Al GORE/ Joe LIEBERMAN - Democratic
John HAGELIN/Nat GOLDHABER - Natural Law
Howard PHILLIPS/J. Curtis FRAZIER - U.S. Taxpayers Party
Ralph NADER/Winona LaDuke - Green Party

UNITED STATES SENATOR - 1

Spence ABRAHAM - Republican
Debbie STABENOW - Democratic
Mark A. FORTON - Reform
Michael R. CORLISS - Libertarian
William QUARTON - Natural Law
John MANGOPOULOS - U.S. Taxpayers Party
Matthew R. ABEL - Green Party

STATE REPRESENTATIVE - 1

Steve VEAR - Republican
Roy GRIGSBY - Democratic

MEMBER OF THE STATE BOARD OF EDUCATION - 2

Terri Lynn LAND - Republican
Lawrence C. PATRICK - Republican
John AUSTIN - Democratic
Kathleen STRAUS - Democratic
Helen E.R. DITZHAZY - Reform
Mary Ann LESSNER - Reform
Diane BARNES - Libertarian
Lynnea ELLISON - Natural Law
Gail QUARTON - Natural Law
Clara C. PILCHAK - U.S. Taxpayers Party
Max RIEKSE - U.S. Taxpayers Party

MEMBER OF THE BOARD OF REGENTS OF THE UNIVERSITY OF MICHIGAN -
2

Wendy ANDERSON - Republican
Susy AVERY - Republican
Larry DEITCH - Democratic
Rebecca McGOWAN - Democratic
Nick WAUN - Reform
Tim MAULL - Libertarian
Marvin SUROWITZ - Libertarian
Lisa Anne PUCCIO - Natural Law
David James KNIGHT - U.S. Taxpayers Party

Joe SANGER - U.S. Taxpayers Party
Scott S. TRUDEAU - Green Party

COUNTY CLERK - 1 - Judy ELLIOTT
Badi BADIOZAMANI - Independent
Judy ELLIOTT - Republican
Diana FOSS - Democratic
Mike SCHMIER - Democratic

MEMBER OF THE BOARD OF TRUSTEES OF MICHIGAN STATE UNIVERISTY -
2

Connie BINSFELD - Republican
George Scott ROMNEY - Republican
Dorothy V. GONZALES - Democratic
Cal RAPSON - Democratic
Michael H. MILLER - Libertarian
Violet STEELE - Libertarian
Robert GALE - U.S. Taxpayers Party

MEMBER OF THE BOARD OF GOVERNORS OF WAYNE STATE UNIVERSITY -
2

Michael KELLY - Republican
Mary Kay SHIELDS - Republican
Paul MASSARON - Democratic
Jackie WASHINGTON - Democratic
Scotty BOMAN - Libertarian
Thomas W. JONES - Libertarian
Frederick KLINE - U.S. Taxpayers Party
Lucretia C. STURDIVANT - U.S. Taxpayers Party
James J. NICITA - Green Party

COUNTY TREASURER - 1
Sandra S. THATCHER - Republican

DRAIN COMMISSIONER - 1
Todd CARSON - Republican
Rich GOSSE - Republican
Kenneth W. STRONG - Republican

COUNTY SURVEYOR - 1
John W. BEARD - Republican
Joe GUZZARDI - Democratic
Edward R. REED - Republican
Lingel H. WINTERS – Democratic

Election 1 – Error Condition 1 – Error in Bottom of Ballot

PRESIDENT - 1

George BUSH/Dick CHENEY - Republican
Al GORE/ Joe LIEBERMAN - Democratic
John HAGELIN/Nat GOLDHABER - Natural Law
Howard PHILLIPS/J. Curtis FRAZIER - U.S. Taxpayers Party
Ralph NADER/Winona LaDuke - Green Party

UNITED STATES SENATOR - 1

Spence ABRAHAM - Republican
Debbie STABENOW - Democratic
Mark A. FORTON - Reform
Michael R. CORLISS - Libertarian
William QUARTON - Natural Law
John MANGOPOULOS - U.S. Taxpayers Party
Matthew R. ABEL - Green Party

STATE REPRESENTATIVE - 1

Steve VEAR - Republican
Roy GRIGSBY - Democratic

MEMBER OF THE STATE BOARD OF EDUCATION - 2

Terri Lynn LAND - Republican
Lawrence C. PATRICK - Republican
John AUSTIN - Democratic
Kathleen STRAUS - Democratic
Helen E.R. DITZHAZY - Reform
Mary Ann LESSNER - Reform
Diane BARNES - Libertarian
Lynnea ELLISON - Natural Law
Gail QUARTON - Natural Law
Clara C. PILCHAK - U.S. Taxpayers Party
Max RIEKSE - U.S. Taxpayers Party

MEMBER OF THE BOARD OF REGENTS OF THE UNIVERSITY OF MICHIGAN -
2

Wendy ANDERSON - Republican
Susy AVERY - Republican
Larry DEITCH - Democratic
Rebecca McGOWAN - Democratic
Nick WAUN - Reform
Tim MAULL - Libertarian
Marvin SUROWITZ - Libertarian
Lisa Anne PUCCIO - Natural Law
David James KNIGHT - U.S. Taxpayers Party
Joe SANGER - U.S. Taxpayers Party
Scott S. TRUDEAU - Green Party

COUNTY CLERK - 1
Badi BADIOZAMANI - Independent
Judy ELLIOTT - Republican
Diana FOSS - Democratic
Mike SCHMIER - Democratic

MEMBER OF THE BOARD OF TRUSTEES OF MICHIGAN STATE UNIVERISTY -
2
Connie BINSFELD - Republican
George Scott ROMNEY - Republican
Dorothy V. GONZALES - Democratic
Cal RAPSON - Democratic
Michael H. MILLER - Libertarian
Violet STEELE - Libertarian
Robert GALE - U.S. Taxpayers Party

MEMBER OF THE BOARD OF GOVERNORS OF WAYNE STATE UNIVERSITY -
2
Michael KELLY - Republican
Mary Kay SHIELDS - Republican
Paul MASSARON - Democratic
Jackie WASHINGTON - Democratic
Scotty BOMAN - Libertarian
Thomas W. JONES - Libertarian
Frederick KLINE - U.S. Taxpayers Party
Lucretia C. STURDIVANT - U.S. Taxpayers Party
James J. NICITA - Green Party

COUNTY TREASURER - 1
Sandra S. THATCHER - Republican

DRAIN COMMISSIONER - 1
Todd CARSON - Republican
Rich GOSSE - Republican
Kenneth W. STRONG - Republican

COUNTY SURVEYOR - 1 - Joe GUZZARDI
John W. BEARD - Republican
Joe GUZZARDI - Democratic
Edward R. REED - Republican
Lingel H. WINTERS – Democratic

Election 2 – Error Condition 3 – Error in Top of Ballot

PRESIDENT - 1 - skip

George BUSH/Dick CHENEY - Republican
Al GORE/ Joe LIEBERMAN - Democratic
John HAGELIN/Nat GOLDHABER - Natural Law
Howard PHILLIPS/J. Curtis FRAZIER - U.S. Taxpayers Party
Ralph NADER/Winona LaDuke - Green Party

STATE REPRESENTATIVE - 1

Steve VEAR - Republican
Roy GRIGSBY - Democratic
Helen E.R. DITZHAZY - Reform
Mary Ann LESSNER - Reform
Diane BARNES - Libertarian

MEMBER OF THE BOARD OF REGENTS OF THE UNIVERSITY OF MICHIGAN -

2

Wendy ANDERSON - Republican
Susy AVERY - Republican
Rebecca McGOWAN - Democratic
Nick WAUN - Reform
Tim MAULL - Libertarian
Marvin SUROWITZ - Libertarian
Lisa Anne PUCCIO - Natural Law
David James KNIGHT - U.S. Taxpayers Party
Joe SANGER - U.S. Taxpayers Party
Scott S. TRUDEAU - Green Party

JUSTICE OF THE SUPREME COURT - 1

Robert YOUNG - Justice of the Supreme Court
E.Thomas FITZGERALD -
Jerry J. KAUFMAN -

MEMBER OF THE BOARD OF GOVERNORS OF WAYNE STATE UNIVERSITY -

2

Connie BINSFELD - Republican
George Scott ROMNEY - Republican
Dorothy V. GONZALES - Democratic
Cal RAPSON - Democratic
Sara Ann HANLON - Independent
Paul NAVE - Democratic
Michael H. MILLER - Libertarian
Violet STEELE - Libertarian
Robert GALE - U.S. Taxpayers Party

COUNTY CLERK - 1

Badi BADIOZAMANI - Independent
Mike SCHMIER - Democratic

MEMBER OF THE STATE BOARD OF EDUCATION - 2

Terri Lynn LAND - Republican
Lawrence C. PATRICK - Republican
John AUSTIN - Democratic
Kathleen STRAUS - Democratic
Lynnea ELLISON - Natural Law
Gail QUARTON - Natural Law
Clara C. PILCHAK - U.S. Taxpayers Party
Max RIEKSE - U.S. Taxpayers Party

PROSECUTING ATTORNEY - 1

John W. BEARD - Republican
Joe GUZZARDI - Democratic
Edward R. REED - Republican
Lingel H. WINTERS - Democratic

REGISTER OF DEEDS - 1

Michael CHELI - Independent
Linda Lee MORRISON - Republican
Patricia G. TILLEY - Independent

COUNTY TREASURER - 1

Sandra S. THATCHER - Republican

COUNTY SURVEYOR - 1

Bob LYNN EDWARDS - Democratic
Kirk KASHIAN - Republican
Judy ELLIOTT - Republican
Diana FOSS - Democratic

Election 2 – Error Condition 3 – Error in Middle of Ballot

PRESIDENT - 1

George BUSH/Dick CHENEY - Republican
Al GORE/ Joe LIEBERMAN - Democratic
John HAGELIN/Nat GOLDHABER - Natural Law
Howard PHILLIPS/J. Curtis FRAZIER - U.S. Taxpayers Party
Ralph NADER/Winona LaDuke - Green Party

STATE REPRESENTATIVE - 1

Steve VEAR - Republican
Roy GRIGSBY - Democratic
Helen E.R. DITZHAZY - Reform
Mary Ann LESSNER - Reform
Diane BARNES - Libertarian

MEMBER OF THE BOARD OF REGENTS OF THE UNIVERSITY OF MICHIGAN -
2

Wendy ANDERSON - Republican
Susy AVERY - Republican
Rebecca McGOWAN - Democratic
Nick WAUN - Reform
Tim MAULL - Libertarian
Marvin SUROWITZ - Libertarian
Lisa Anne PUCCIO - Natural Law
David James KNIGHT - U.S. Taxpayers Party
Joe SANGER - U.S. Taxpayers Party
Scott S. TRUDEAU - Green Party

JUSTICE OF THE SUPREME COURT - 1

Robert YOUNG - Justice of the Supreme Court
E.Thomas FITZGERALD -
Jerry J. KAUFMAN -

MEMBER OF THE BOARD OF GOVERNORS OF WAYNE STATE UNIVERSITY -
2

Connie BINSFELD - Republican
George Scott ROMNEY - Republican
Dorothy V. GONZALES - Democratic
Cal RAPSON - Democratic
Sara Ann HANLON - Independent
Paul NAVE - Democratic
Michael H. MILLER - Libertarian
Violet STEELE - Libertarian
Robert GALE - U.S. Taxpayers Party

COUNTY CLERK - 1 - skip

Badi BADIOZAMANI - Independent
Mike SCHMIER - Democratic

MEMBER OF THE STATE BOARD OF EDUCATION - 2

Terri Lynn LAND - Republican
Lawrence C. PATRICK - Republican
John AUSTIN - Democratic
Kathleen STRAUS - Democratic
Lynnea ELLISON - Natural Law
Gail QUARTON - Natural Law
Clara C. PILCHAK - U.S. Taxpayers Party
Max RIEKSE - U.S. Taxpayers Party

PROSECUTING ATTORNEY - 1

John W. BEARD - Republican
Joe GUZZARDI - Democratic

Edward R. REED - Republican
Lingel H. WINTERS - Democratic

REGISTER OF DEEDS - 1
Michael CHELI - Independent
Linda Lee MORRISON - Republican
Patricia G. TILLEY - Independent

COUNTY TREASURER - 1
Sandra S. THATCHER - Republican

COUNTY SURVEYOR - 1
Bob LYNN EDWARDS - Democratic
Kirk KASHIAN - Republican
Judy ELLIOTT - Republican
Diana FOSS – Democratic

Election 2 – Error Condition 3 – Error in Bottom of Ballot

PRESIDENT - 1
George BUSH/Dick CHENEY - Republican
Al GORE/ Joe LIEBERMAN - Democratic
John HAGELIN/Nat GOLDHABER - Natural Law
Howard PHILLIPS/J. Curtis FRAZIER - U.S. Taxpayers Party
Ralph NADER/Winona LaDuke - Green Party

STATE REPRESENTATIVE - 1
Steve VEAR - Republican
Roy GRIGSBY - Democratic
Helen E.R. DITZHAZY - Reform
Mary Ann LESSNER - Reform
Diane BARNES - Libertarian

MEMBER OF THE BOARD OF REGENTS OF THE UNIVERSITY OF MICHIGAN -
2
Wendy ANDERSON - Republican
Susy AVERY - Republican
Rebecca McGOWAN - Democratic
Nick WAUN - Reform
Tim MAULL - Libertarian
Marvin SUROWITZ - Libertarian
Lisa Anne PUCCIO - Natural Law
David James KNIGHT - U.S. Taxpayers Party
Joe SANGER - U.S. Taxpayers Party
Scott S. TRUDEAU - Green Party

JUSTICE OF THE SUPREME COURT - 1

Robert YOUNG - Justice of the Supreme Court

E.Thomas FITZGERALD -

Jerry J. KAUFMAN -

MEMBER OF THE BOARD OF GOVERNORS OF WAYNE STATE UNIVERSITY -

2

Connie BINSFELD - Republican

George Scott ROMNEY - Republican

Dorothy V. GONZALES - Democratic

Cal RAPSON - Democratic

Sara Ann HANLON - Independent

Paul NAVE - Democratic

Michael H. MILLER - Libertarian

Violet STEELE - Libertarian

Robert GALE - U.S. Taxpayers Party

COUNTY CLERK - 1

Badi BADIOZAMANI - Independent

Mike SCHMIER - Democratic

MEMBER OF THE STATE BOARD OF EDUCATION - 2

Terri Lynn LAND - Republican

Lawrence C. PATRICK - Republican

John AUSTIN - Democratic

Kathleen STRAUS - Democratic

Lynnea ELLISON - Natural Law

Gail QUARTON - Natural Law

Clara C. PILCHAK - U.S. Taxpayers Party

Max RIEKSE - U.S. Taxpayers Party

PROSECUTING ATTORNEY - 1

John W. BEARD - Republican

Joe GUZZARDI - Democratic

Edward R. REED - Republican

Lingel H. WINTERS - Democratic

REGISTER OF DEEDS - 1

Michael CHELI - Independent

Linda Lee MORRISON - Republican

Patricia G. TILLEY - Independent

COUNTY TREASURER - 1 - skip

Sandra S. THATCHER - Republican

COUNTY SURVEYOR - 1

Bob LYNN EDWARDS - Democratic

Kirk KASHIAN - Republican
Judy ELLIOTT - Republican
Diana FOSS – Democratic

Election 3 – Null Error Condition

PRESIDENT - 1

George BUSH/Dick CHENEY - Republican
Al GORE/ Joe LIEBERMAN - Democratic
John HAGELIN/Nat GOLDHABER - Natural Law
Howard PHILLIPS/J. Curtis FRAZIER - U.S. Taxpayers Party
Ralph NADER/Winona LaDuke - Green Party

UNITED STATES SENATOR - 1

Joe Baca - Reform
David Cobb - Libertarian
Tim Erickson - Natural Law
Mike Johnson - Republican
Carl Mariz - Democratic
Nicole Parra - U.S. Taxpayers Party
Lois Wolk - Green Party

SUPERVISOR - 1

John R. KOPACZ - Republican
Heather PETERS - Republican

CLERK - 1

Garreth L. BARKER - Republican
Paul L. MALONEY -
Bill MURPHY -

TREASURER - 1

Cheryl BLY CHESTER - Republican

TRUSTEES - 2

Mary G. DANIELS - Republican
Ralph A. HERNANDEZ - Democratic
Jerry KUNZMAN - Independent
Donald E. ROGERS - Republican
Jamie Rosemary SAFFORD - Republican
Paul W. VANN - Republican

JUDGE OF THE PROBATE COURT - 1

Frederick L. WOOD - Judge of the Probate Court
Peggy KNISELY - Republican
Bryan QUINN - Republican

C.T. WEBER - Peace and Freedom

JUSTICE OF THE SUPREME COURT (8 Year Term) - 1

Clifford W. TAYLOR - Justice of the Supreme Court

Marietta Sebree ROBINSON -

Robert W. RODDIS -

JUSTICE OF THE District COURT - 1

Edward McCall THOMAS -

Stephen J. MARKMAN - Justice of the Supreme Court

David H. RAAFLAUB -

3rd DISTRICT COURT OF APPEALS (6 Year Term) - 3

Janet T. NEFF - Judge of the Appeals Court

Michael R. SMOLENSKI - Judge of the Appeals Court

Scott A. MEDNICK - Democratic

Zoning Board of Appeals - 2

Michael KELLY - Republican

Mary Kay SHIELDS - Republican

Paul MASSARON - Democratic

Jackie WASHINGTON - Democratic

Scotty BOMAN - Libertarian

Thomas W. JONES - Libertarian

Frederick KLINE - U.S. Taxpayers Party

Lucretia C. STURDIVANT - U.S. Taxpayers Party

Election 4 – Error Condition 2 – Error in Top of Ballot

President - 1

George BUSH/Dick CHENEY - Republican

Al GORE/ Joe LIEBERMAN - Democratic

John HAGELIN/Nat GOLDHABER - Natural Law

Howard PHILLIPS/J. Curtis FRAZIER - U.S. Taxpayers Party

Ralph NADER/Winona LaDuke - Green Party

United States Senator - 2 - Paul Nave, No Vote

Adam Iris - Republican

GARY LEONARD - Republican

PAUL NAVE - Democratic

GREGORY RUSSELL - Green Party

BILL T. SIMON - Republican

C.T. WEBER - Democratic

Prosecuting Attorney - 1
MIKE MCNEILLY - Republican
HEATHER PETERS - Republican
MARC VALDEZ - Democratic

County Clerk - 1
MAURICE WALKER - Democratic
NED ROSCOE - Republican
DARIN PRICE - Democratic
JONATHAN MILLER - Libertarian

Park Commissioners - 2
Thomas Benigno - Republican
Shirley Coly - Democratic
Jason Gastrich - Republican
Lincoln Pickard - Libertarian

Gas and Electric Commissioner - 1
Joe Coto - Democratic
David Dreier - Republican
Andrew Felder - Republican
Keith Gann - Green Party
Jackie Liu - Republican

Road Superintendent - 1
Patty Brigs - Democratic
Dean Garza - Republican
Tom Lantos - Libertarian

Public Utilities Commission - 2
Richard Ackerman - Democratic
Wilma Chan - Democratic
Bea Foster - Republican
Jay Lang - Libertarian
David Redick -

Register of Deeds - 1
Christine Keedy - Democratic
Herb Peters - Republican
Audra Tuma - Republican
Robert Webber - Libertarian

Electoral Board Members - 3
Ken Bade - Republican
Toni Casey - Democratic
Anna Everett - Republican
Chris Larkin - Republican

Ross Moen - Green Party
Ray Vega - Democratic

Sheriff - 1
Eric Carter - Democratic
Keith Robles - Republican
Linda Shaw - Democratic
Fritz Ward – Republican

Election 4 – Error Condition 2 – Error in Middle of Ballot

President - 1
George BUSH/Dick CHENEY - Republican
Al GORE/ Joe LIEBERMAN - Democratic
John HAGELIN/Nat GOLDHABER - Natural Law
Howard PHILLIPS/J. Curtis FRAZIER - U.S. Taxpayers Party
Ralph NADER/Winona LaDuke - Green Party

United States Senator - 2
Adam Iris - Republican
GARY LEONARD - Republican
PAUL NAVE - Democratic
GREGORY RUSSELL - Green Party
BILL SIMON - Republican
C.T. WEBER - Democratic

Prosecuting Attorney - 1
MIKE MCNEILLY - Republican
HEATHER PETERS - Republican
MARC VALDEZ - Democratic

County Clerk - 1
MAURICE WALKER - Democratic
NED ROSCOE - Republican
DARIN PRICE - Democratic
JONATHAN MILLER - Libertarian

Park Commissioners - 2 - Lincoln Pickard, No Vote
Thomas M. Benigno - Republican
Shirley Coly - Democratic
Jason Gastrich - Republican
Lincoln Pickard - Libertarian

Gas and Electric Commissioner - 1
Joe Coto - Democratic
David Dreier - Republican

Andrew Felder - Republican
Keith Gann - Green Party
Jackie Liu - Republican

Road Superintendent - 1
Patty Brigs - Democratic
Dean Garza - Republican
Tom Lantos - Libertarian

Public Utilities Commission - 2
Richard Ackerman - Democratic
Wilma Chan - Democratic
Bea Foster - Republican
Jay Lang - Libertarian
David Redick -

Register of Deeds - 1
Christine Keedy - Democratic
Herb Peters - Republican
Audra Tuma - Republican
Robert Webber - Libertarian

Electoral Board Members - 3
Ken Bade - Republican
Toni Casey - Democratic
Anna Everett - Republican
Chris Larkin - Republican
Ross Moen - Green Party
Ray Vega - Democratic

Sheriff - 1
Eric Carter - Democratic
Keith Robles - Republican
Linda Shaw - Democratic
Fritz Ward – Republican

Election 4 – Error Condition 2 – Error in Bottom of Ballot

President - 1
George BUSH/Dick CHENEY - Republican
Al GORE/ Joe LIEBERMAN - Democratic
John HAGELIN/Nat GOLDHABER - Natural Law
Howard PHILLIPS/J. Curtis FRAZIER - U.S. Taxpayers Party
Ralph NADER/Winona LaDuke - Green Party

United States Senator - 2

Adam Iris - Republican
GARY LEONARD - Republican
PAUL NAVE - Democratic
GREGORY RUSSELL - Green Party
BILL SIMON - Republican
C.T. WEBER - Democratic

Prosecuting Attorney - 1
MIKE MCNEILLY - Republican
HEATHER PETERS - Republican
MARC VALDEZ - Democratic

County Clerk - 1
MAURICE WALKER - Democratic
NED ROSCOE - Republican
DARIN PRICE - Democratic
JONATHAN MILLER - Libertarian

Park Commissioners - 2
Thomas Benigno - Republican
Shirley Coly - Democratic
Jason Gastrich - Republican
Lincoln Pickard - Libertarian

Gas and Electric Commissioner - 1
Joe Coto - Democratic
David Dreier - Republican
Andrew Felder - Republican
Keith Gann - Green Party
Jackie Liu - Republican

Road Superintendent - 1
Patty Brigs - Democratic
Dean Garza - Republican
Tom Lantos - Libertarian

Public Utilities Commission - 2
Richard Ackerman - Democratic
Wilma Chan - Democratic
Bea Foster - Republican
Jay Lang - Libertarian
David Redick -

Register of Deeds - 1
Christine Keedy - Democratic
Herb Peters - Republican
Audra Tuma - Republican

Robert Webber - Libertarian

Electoral Board Members - 3 - Ken Bade, Chris Larkin, No Vote

Ken Bade - Republican

Toni L. Casey - Democratic

Anna Everett - Republican

Chris Larkin - Republican

Ross Moen - Green Party

Ray Vega - Democratic

Sheriff - 1

Eric Carter - Democratic

Keith Robles - Republican

Linda Shaw - Democratic

Fritz Ward - Republican

Appendix C: Experiment Election Voting Agendas

Election 1

PRESIDENT

John HAGELIN/Nat GOLDHABER - Natural Law

UNITED STATES SENATOR

John MANGOPOULOS - U.S. Taxpayers Party

STATE REPRESENTATIVE

Roy GRIGSBY - Democratic

MEMBER OF THE STATE BOARD OF EDUCATION

Helen E.R. DITZHAZY - Reform
and a candidate of your choice

MEMBER OF THE BOARD OF REGENTS OF THE UNIVERSITY OF MICHIGAN

Larry DEITCH - Democratic
David James KNIGHT - U.S. Taxpayers Party

COUNTY CLERK

Mike SCHMIER - Democratic

MEMBER OF THE BOARD OF TRUSTEES OF MICHIGAN STATE UNIVERISTY your choice

MEMBER OF THE BOARD OF GOVERNORS OF WAYNE STATE UNIVERSITY

Mary Kay SHIELDS - Republican
Lucretia C. STURDIVANT - U.S. Taxpayers Party

COUNTY TREASURER

Sandra S. THATCHER - Republican

DRAIN COMMISSIONER

Todd CARSON - Republican

COUNTY SURVEYOR

Edward R. REED – Republican

Election 2

PRESIDENTIAL

Ralph NADER/Winona LaDuke - Green Party

STATE REPRESENTATIVE

your choice

MEMBER OF THE BOARD OF REGENTS OF THE UNIVERSITY OF MICHIGAN

Rebecca McGOWAN - Democratic

Joe SANGER - U.S. Taxpayers Party

JUSTICE OF THE SUPREME COURT (Partial Term Ending 1/1/03)

Jerry J. KAUFMAN -

MEMBER OF THE BOARD OF GOVERNORS OF WAYNE STATE UNIVERSITY

Dorothy V. GONZALES - Democratic

and a candidate of your choice

COUNTY CLERK

Badi BADIOZAMANI - Independent

MEMBER OF THE STATE BOARD OF EDUCATION

Lawrence C. PATRICK - Republican

Clara C. PILCHAK - U.S. Taxpayers Party

PROSECUTING ATTORNEY

Edward R. REED - Republican

REGISTER OF DEEDS

your choice

COUNTY TREASURER

skip this race

COUNTY SURVEYOR

Judy ELLIOTT - Republican

Election 3

PRESIDENT

Howard PHILLIPS/J. Curtis FRAZIER - U.S. Taxpayers Party

UNITED STATES SENATOR

David Cobb - Libertarian

SUPERVISOR

Heather PETERS - Republican

CLERK

your choice

TREASURER

Cheryl BLY-CHESTER - Republican

TRUSTEES

Donald E. ROGERS - Republican

Jamie Rosemary SAFFORD - Republican

JUDGE OF THE PROBATE COURT

Bryan QUINN - Republican

JUSTICE OF THE SUPREME COURT (8 Year Term)

Marietta Sebree ROBINSON -

JUSTICE OF THE District COURT

your choice

3rd DISTRICT COURT OF APPEALS (6 Year Term) - 3

Janet T. NEFF - Judge of the Appeals Court

Michael R. SMOLENSKI - Judge of the Appeals Court

Scott A. MEDNICK - Democratic

Zoning Board of Appeals

Paul MASSARON - Democratic

Frederick KLINE - U.S. Taxpayers Party

Election 4

President

Al GORE/ Joe LIEBERMAN - Democratic

United States Senator

PAUL NAVE - Democratic

BILL SIMON - Republican

Prosecuting Attorney

your choice

County Clerk

DARIN PRICE - Democratic

Park Commissioners

Thomas Benigno - Republican

Lincoln Pickard - Libertarian

Gas and Electric Commissioner

skip this race

Road Superintendent

Tom Lantos - Libertarian

Public Utilities Commission

Wilma Chan - Democratic

Jay Lang - Libertarian

Register of Deeds

Christine Keedy - Democratic

Electoral Board Members

Ken Bade - Republican

Toni Casey - Democratic

Chris Larkin - Republican

Sheriff

Linda Shaw - Democratic

Appendix D: Subject Assignments – Voting Machine order and

Error Order

Subject Number	First System	Election 1	Election 2	Election 3	Election 4
1	paper	null	EC1 T	EC2 M	EC3 B
2	audio	null	EC1 T	EC2 M	EC3 B
3	paper	null	EC1 T	EC2 M	EC3 B
4	audio	null	EC1 T	EC2 M	EC3 B
5	paper	EC2 M	EC3 T	EC1 B	null
6	audio	null	EC3 M	EC1 B	EC2 T
7	paper	EC1 B	EC2 M	null	EC3 T
8	paper	EC3 M	EC1 T	EC2 B	null
9	audio	EC1 B	EC2 M	null	EC3 T
10	audio	EC2 B	EC3 M	null	EC1 T
11	audio	EC3 B	null	EC1 M	EC2 T
12	audio	EC2 M	EC3 T	EC1 B	null
13	audio	EC1 M	EC2 T	EC3 B	null
14	audio	null	EC2 B	EC3 T	EC1 M
15	paper	null	EC3 M	EC1 B	EC2 T
16	audio	EC3 M	EC1 T	EC2 B	null
17	audio	EC3 B	EC1 M	null	EC2 T
18	audio	EC2 B	null	EC3 M	EC1 T
19	audio	EC3 M	EC1 T	EC2 B	null
20	audio	EC1 B	null	EC2 M	EC3 T
21	paper	EC1 M	EC2 T	EC3 B	null
22	paper	null	EC3 M	EC1 B	EC2 T
23	paper	null	EC2 B	EC3 T	EC1 M
24	audio	null	EC2 B	EC3 T	EC1 M
25	audio	EC2 M	EC3 T	EC1 B	null
26	paper	EC2 B	EC3 M	null	EC1 T
27	paper	EC3 B	null	EC1 M	EC2 T
28	paper	EC3 M	EC1 T	EC2 B	null
29	paper	EC1 M	EC2 T	EC3 B	null
30	paper	null	EC2 B	EC3 T	EC1 M
31	paper	EC2 M	EC3 T	EC1 B	null
32	audio	EC1 M	EC2 T	EC3 B	null
33	paper	EC2 B	null	EC3 M	EC1 T
34	paper	EC3 B	EC1 M	null	EC2 T
35	paper	EC1 B	null	EC2 M	EC3 T
36	audio	null	EC3 M	EC1 B	EC2 T

Appendix E: Experiment Surveys

[Pre Survey – Given before the subject began voting]

Pre-Survey:

Subject Number: _____

What is your age?

18 – 20 20 – 22 22 – 30 30 – 40 40 – 60 over 60

The voting process is easy

Strongly Agree Agree Neutral Disagree Strongly Disagree

About how many times have you voted in your life?

0 1-5 5-10 10 – 20 more than 20

I have voted with the following voting systems: (circle all that apply)

Absentee ballot optical scanning system
(like a scantron test) DRE (touch screen) Other

How many computers do you own?

0 1 2 3 4 or more

In the last seven days, I have used a computer:

Not at all 1 – 5 hours 5 – 10 hours 10 – 20 hours more than 20 hours

Circle your highest level of Education:

Less than High School
High School Diploma
Some College
College Degree
Masters Degree
Doctoral Degree or Professional Degree

[Post Survey #1 – First survey given after subject finished voting on both machines]
Post Survey #1 **Subject Number:** _____

PRINTED VOTING MATERIALS EVALUATION

I took some time to read the printed instruction material in the voting booth.

Agree Disagree Not Sure

The instructions were easy to follow.

Strongly Agree Agree Neutral Disagree Strongly Disagree

I mostly looked at the pictures on the instructions.

Strongly Agree Agree Neutral Disagree Strongly Disagree

I mostly read the text on the instructions.

Strongly Agree Agree Neutral Disagree Strongly Disagree

I found the text and the pictures to be equally helpful at interpreting the instructions.

Strongly Agree Agree Neutral Disagree Strongly Disagree

Overall, I found the instructions were helpful in completing the voting task.

Strongly Agree Agree Neutral Disagree Strongly Disagree

I read the poster describing the Audio verification tool.

Agree Disagree Not Sure

TOUCH SCREEN INTERFACE EVALUATION

I found the interface to be visually attractive.

Strongly Agree Agree Neutral Disagree Strongly Disagree

It was easy to select candidates.

Strongly Agree Agree Neutral Disagree Strongly Disagree

It was easy to unselect candidates.

Strongly Agree Agree Neutral Disagree Strongly Disagree

It was easy to change my vote.

Strongly Agree Agree Neutral Disagree Strongly Disagree

I used the side navigation tabs.

Agree Disagree Not Sure

I found the review screen to be visually appealing.

Strongly Agree Agree Neutral Disagree Strongly Disagree

The review screen was a useful feature of this interface.

Strongly Agree Agree Neutral Disagree Strongly Disagree

[Post Survey #2 – Evaluation of Printer Trail, given as the second survey if the subject voted first on the VVPAT system. Given as the third survey if the subject voted second on the VVPAT system.]

Post Survey # 2 - PRINTER TRAIL EVALUATION

Subject _____

It was easy to create my printed record.

Strongly Agree Agree Neutral Disagree Strongly Disagree

It was easy to accept/reject my printed record.

Strongly Agree Agree Neutral Disagree Strongly Disagree

The printed record was easy to read

Strongly Agree Agree Neutral Disagree Strongly Disagree

The font size (the size of the text) on the printed record was large enough.

Strongly Agree Agree Neutral Disagree Strongly Disagree
It would have been easier to read the paper record if I could have held it myself.

Strongly Agree Agree Neutral Disagree Strongly Disagree

I can not touch or take home the paper record because: (please fill in your best guess)

The printed records accurately reflected the selections I had made.

Agree Disagree Not Sure

There were some mistakes in the printed record.

Agree Disagree Not Sure

On average, I believe I looked at the paper record for about _____ seconds before pressing the accept/reject button.

0-5 seconds 5–10 seconds 10–15 seconds 15–30 seconds 30+ seconds

Overall, I enjoyed voting on this system. (the paper record system)

Strongly Agree Agree Neutral Disagree Strongly Disagree

Overall, it was easy to vote on this system. (the paper record system)

Strongly Agree Agree Neutral Disagree Strongly Disagree

Any Comments on this system:

[Post Survey #3 – Evaluation of Audio Trail, given as the second survey if the subject voted first on the VVAATT system. Given as the third survey if the subject voted second on the VVAATT system.]

Post Survey - Audio System Evaluation

Subject Number: _____

AUDIO EVALUATION

I found it easy to understand the verbal feedback I received from the voting machine.

Strongly Agree Agree Neutral Disagree Strongly Disagree

The audio verification caused me to take more time when voting.

Strongly Agree Agree Neutral Disagree Strongly Disagree

The audio verification was pleasant to listen to.

Strongly Agree Agree Neutral Disagree Strongly Disagree

The voice of the audio verification was too robotic for my tastes.

Strongly Agree Agree Neutral Disagree Strongly Disagree

The audio verification helped me confirm the selections I made.

Strongly Agree Agree Neutral Disagree Strongly Disagree

The audio verification accurately reflected the selections I made.

Agree Disagree Not Sure

There were some mistakes in the audio verification

Agree Disagree Not Sure

When using the audio verification, I noticed mistakes and errors immediately after they occurred.

Strongly Agree Agree Neutral Disagree Strongly Disagree

Everything that I heard in the headphones was recorded on the audio tape.

Agree Disagree Not Sure

The purpose of tape recording the audio verification is: (please make your best guess)

If I were voting in a real election, I would feel comfortable with the tape recording.

Strongly Agree Agree Neutral Disagree Strongly Disagree

Overall, I enjoyed voting on this system. (the audio verification system)

Strongly Agree Agree Neutral Disagree Strongly Disagree

Overall, it was easy to vote on this system. (the audio verification system)

Strongly Agree Agree Neutral Disagree Strongly Disagree

Any Comments on this system:

[Final Survey – the last survey the subject completed.]

Final Survey

Subject Number: _____

I preferred voting on the _____ system.

Paper record Audio Verification No Preference

I found it easier to vote on the _____ system.

Paper record Audio Verification No Preference

The main objective of the system with the paper record is to have a paper record of each vote made during an election to serve as an audit form. In a real election a small percentage of the paper records would be hand counted and their results verified against the electronic results. In the event of a recount, all the paper records would be hand counted.

In a real election, I would place greater trust in the paper records than the electronic records.

Strongly Agree Agree Neutral Disagree Strongly Disagree

In a real election, I would feel confident of the results of an election if my county used a voting system with a paper record trail.

Strongly Agree Agree Neutral Disagree Strongly Disagree

The main objective of the audio verification system is to create an audio record of each vote that would serve as an audit. In a real election, a small percentage of the audio records would be listened to and counted and the results would be verified against the electronic results. In the event of a recount, all the audio records would be counted.

In a real election, I would place greater trust in the audio records than the electronic records.

Strongly Agree Agree Neutral Disagree Strongly Disagree

In a real election, I would feel confident of the results of an election if my county used a voting system with an audio record trail.

Strongly Agree Agree Neutral Disagree Strongly Disagree

In a real election, I would feel confident of the results of an election if my county did not have any audit mechanism. (The electronic records were the only records of the votes.)

Strongly Agree Agree Neutral Disagree Strongly Disagree

I would feel most confident in the results of an election when my county used a voting system with a _____ audit system.

Paper records Audio records No audit system