Touchscreen Voting Interface Design for Persons with Dexterity Impairments: Insights from Usability Evaluation of Mobile Voting Prototype

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Abstract. To address the need for a universal and accessible voting solution, our research team designed and created a mobile voting user interface prototype for individuals with disabilities using specifications gathered from previous research focused on mobile and/or accessible design. We evaluated the usability of our prototype with individuals with moderate dexterity impairments and with no disabilities, and the majority of participants had a positive reaction and experience using this system. Our study generally confirmed previous research, and we discovered further considerations for mobile voting interface design for users with moderate dexterity impairments, involving buttons that are repeatedly pressed, button placement options, interpretations of inputs or touches, and adjustable support that provides various angle and height options.

Keywords: Accessible voting · Dexterity impairments · Disability · Mobile voting · Universal design · Usability

1 Introduction

In the United States, there are at least 34 million voting-age adults with disabilities [1], and this number is likely to increase with the aging of the population. Approximately 19.9 million people in the U.S. have a dexterity impairment that involves difficulty lifting and grasping (e.g., trouble lifting an object or grasping a pencil) [2]. To address the accessibility of voting in the U.S., the Help America Vote Act of 2002 was passed, requiring polling places to be physically accessible and have at least one accessible voting system to be provided for voters with disabilities [3].

Current stations and systems for voting, however, do not adequately address concerns with accessibility [4, 5], and many individuals with disabilities are unable to vote independently, privately, and/or successfully. For example, after the November 2012 election, 30.1 % of voters with disabilities reported difficulties when voting at a polling place in-person versus 8.4 % of voters without disabilities, and the voter turnout rate for individuals with disabilities was 5.7 % less than those without

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disabilities (i.e., approximately 3 million more persons with disabilities would have voted if these voting rates had been the same) [6].

With the rise of tablet computers and mobile devices, coupled with aging voting machines that will soon need replacing [7], an opportunity to increase the accessibility of voting technology has arisen. For example, mobile usage is becoming widespread as a Pew Research Center Survey found that 42 % of American adults own a tablet computer and 58 % own a smartphone [8].

Mobile voting solutions created with accessibility and universal design in mind provide an opportunity for voters with and without disabilities to use familiar technology, as well as providing a means for those less familiar with the technology or with little technology experience to vote successfully. An accessible mobile voting option at a polling place also addresses the requirement of the U.S. Election Assistance Commission's Voluntary Voting System Guidelines (VVSG) 1.0 that voters with disabilities should be provided with support that is built into voting equipment without requiring the use of personal assistive technology to vote successfully [9]. Prior research has shown that individuals with dexterity or motor impairments have found mobile touchscreen devices to be empowering; however, accessibility issues that limit the extent to which these devices meet the needs of individuals with these types of impairments need to be addressed [10–12].

1.1 Accessible Mobile Voting System User Interface Prototype Design

Our research team designed and created a mobile voting user interface for individuals with disabilities using specifications gathered from previous relevant research, with a primary focus on dexterity and visual impairments [13]. Prior research has examined various touchscreen design elements, but these studies looked at elements in isolation, whereas our touchscreen user interface design incorporated guidance from previous research to create a universal design solution intended to accommodate individuals with limited dexterity, visual impairments, and dyslexia, as well as voters who have limited or no experience with mobile technologies.

When creating the prototype, we referred to research on appropriate button size [14, 15], button spacing [15, 16], and touchscreen gestures and button position [11, 17]. In our mobile voting user interface design, buttons are located near the edges of the screen and the active region of each button is at least 20 mm in length and width (although the visual size may appear smaller), with at least 6.35 mm of spacing between active regions. Where buttons are touching, the minimum button size was increased to provide additional spacing.

All functionality is accessed via tap, which is the preferred and most effective gesture for individuals with motor skill impairments [11]; all other input functions are disabled by default, with the exception of drag, which can only be used in the slider area of the custom scroll bar. Selections are made by touching checkboxes (instead of an entire row) to avoid accidental inputs. Unselected checkboxes are disabled when the maximum number of selections have been made to prevent over-voting.

The size of the ballot text conforms to the National Association for the Visually Handicapped large print standards [18] (modified for bold text using the ratio presented in the Web Content Accessibility Guidelines 2.0 [19]): A minimum of 16 typographic points (5.6 mm or 56px) for normal text and 12.5 typographic points (4.4 mm or 44px) for bold text, as measured by the em-square. In our mobile voting prototype, the size of the bolded contest names and button names is 12.5 typographic points and the size of the body text (i.e., the candidate and party names, etc.) is 16 typographic points. Spacing and separator lines are also included between options for clear layout of lists.

The design is optimized for medium- and large-sized tablets and devices with similar display sizes, as smartphones and small tablets do not provide enough screen area to accommodate a usable and accessible voting system for a wide range of users. The vertical (portrait) device orientation was used for this study, and the screen was locked in this orientation, as changing the display to landscape orientation would have necessitated a redesigned user interface to ensure appropriate usability and accessibility.

2 Methodology

For this first iteration of our accessible mobile voting study, we focused on testing the design with individuals with moderate dexterity impairments and those without disabilities. We analyzed audio and video recordings as well as participant feedback from one-on-one usability evaluation sessions in which participants used the mobile voting prototype on a tablet to cast a sample ballot for a mock election.

2.1 Materials and Procedures

Mobile Testing Configuration. Participants used a Samsung Galaxy Tab 4 with 10.1 inch screen size while seated at an adjustable drafting table with height and angle options (Fig. 1), allowing for customizable angle and position to accommodate individuals whose reach or height differs (including those in wheelchairs of differing heights). The tablet rested on the surface of the table to avoid any strain caused by holding the device, and the table was angled to reduce glare [13]. In addition, the adjustable table was used to provide necessary support for those with dexterity impairments to assist with accuracy of button presses and reduce unintended inputs [20].

During the participant sessions, the tabletop was set at an angle of approximately 26 degrees as the default, with the base of the incline at a height of 71 cm and the peak at a height of 102 cm. The default settings for the table were used for 15 of the 16 participants, and after being asked one participant opted to have the height or angle adjusted. A non-slip matting was also placed on the table to keep the tablet from sliding, and participants could move the position of the tablet within an approximately 40 × 40 cm area that was taped off. Overhead fluorescent lights were turned off, and a lamp with a 60 W lightbulb was placed next to the table, which was adjusted to eliminate glare for each participant.

National Institute of Standards and Technology (NIST) Test Ballot. The NIST Test Ballot [21], which has been used in conformance testing associated with the VVSG 1.0 [9], was used in this study. The ballot uses realistic but fictional names and contests,

Fig. 1. Mobile voting testing configuration

with colors for party names. The ballot used for this study included separate pages for 12 contests (9 single candidate selections, e.g., vote for one; 3 multiple candidate selections, e.g. vote for five), 2 judge retention contests (Yes/No), 4 constitutional amendments (For/Against), and 2 ballot measures (For/Against), as well as View All/Review, Submission, and Confirmation pages. Write-ins are also supported in the prototype; however, it did not include Straight Party voting.

Procedure and Mobile Voting Interface. Participants used the provided tablet to vote the NIST Test Ballot using our mobile voting interface prototype (Fig. 2). Participants were given instructions on which selections to make in each contest, but they were not specifically instructed on how to go about voting using the prototype. An overview of the system was provided in the Help & Options section, which participants could read if they chose to go to this section, and they could view different options that could be adjusted (e.g., font size, contrast, etc.), but these options were not active for this study in order to test the default settings of the system across participants.

During the voting task, participants made selections for twenty contests (as mentioned above). For two of the contests they were asked to complete the write-in option (for one candidate and for two candidates), and at two points in the voting process they were asked to go back and change a previous selection. After completing voting, they then submitted the ballot.

Each contest page had the following button options on the screen: checkboxes for each possible selection on the left side, custom scroll controls along the right side (with options to Screen Up/Screen Down, Scroll Up/Down one item, or use the scroll bar to tap and drag), and navigation and option buttons along the bottom (Prior Contest, Help & Options, View All/Review, and Next Contest).

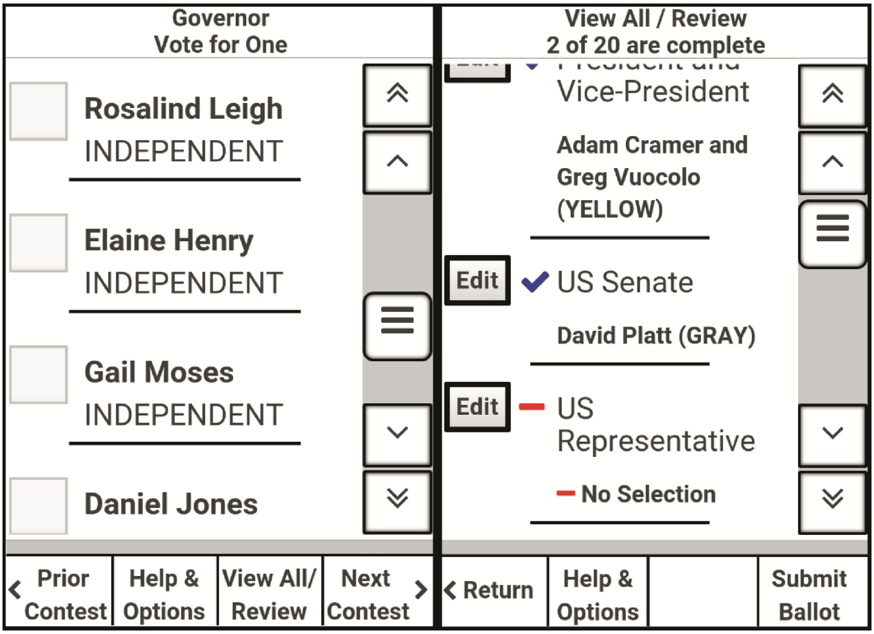

Fig. 2. Example screens of mobile voting prototype: Governor (single candidate) contest screen (left) and View/All Review screen (right).

Key usability measures included voting time, accuracy, and user satisfaction. After completing the ballot, participants were given the System Usability Scale (SUS) questionnaire and rated their level of agreement to ten statements. The SUS is an industry standard used as a quick and reliable tool for measuring usability for a wide range of interfaces, systems, and technologies; the SUS has been proven to be accurate for small sample sizes of 8–14 [22]. Researchers also conducted a brief interview to gather further feedback and satisfaction data.

2.2 Participants

Sixteen participants, including 10 women and 6 men, took part in this study. Half of the participants had moderate dexterity impairments, and half did not have a disability (i.e., control group). Physical limitations for the dexterity group included weakness in arms and hands (which led to fatigue at times), moderate range of motion or control limitations, and/or difficulty walking (use of walkers, crutches, etc.). One participant also mentioned hand/eye coordination and visual tracking issues. Ages for the dexterity group ranged from 18–61, and ages for the control group ranged from 21–63. Six participants from the dexterity group and 4 from the control group were right-handed. All participants were familiar with smartphone or tablet technology and all had experience using the Internet.

Of the 6 participants from the dexterity group who had prior voting experience in a U.S. state or federal election, all had done so via absentee ballot the last time they had voted. For the control group, all 8 participants had voted in a state or federal election, with 2 doing so by absentee ballot, 5 by paper ballot at a polling place, and 1 by electronic ballot at a polling place the last time they had voted.

3 Results

The results of our usability evaluation of the mobile voting interface prototype generally confirmed what has been found in previous research. In addition, we discovered further considerations for interface design for users with moderate dexterity impairments, involving buttons that are repeatedly pressed, button placement options, interpretations of inputs or touches, and adjustable support that provides various angle and height options.

3.1 Overall Findings

Fifteen of the participants across the groups completed the overall voting tasks and submitted a ballot. For one of the dexterity participants, who had less range of motion and control than other participants, her inputs were often not recognized by the touchscreen, but her touches were mostly accurate. Therefore, to gain her feedback on the overall system (if her inputs were being accepted), the facilitator repeated each of her touches.

Across the groups, the majority of participants completed voting and submitted the ballot in approximately 5–15 min. Two of the dexterity participants had longer completion times (between 30–45 min), and they in particular encountered difficulties with unintended inputs and unrecognized touches, and confusion regarding functionality of the scroll options and submitting the ballot. Twelve of the participants had SUS scores in the acceptable range (above 70), while 4 dexterity participants had scores below 70 (Table 1).

Table 1. Results averages for moderate dexterity and control groups

	Dexterity	Control	All
Average time to vote and submit Ballot (mins:secs)	16:16	8:33	12:25
Average system usability score	65.3	88.8	77

The majority of participants had a positive reaction to voting using the mobile voting prototype. When asked whether they would vote with the mobile voting system if it were available in the next election, 13 of the 16 participants answered “yes” (and 3 dexterity answered “no” or “not sure”). Four dexterity participants expressed they have difficulty physically writing and therefore found this system easier to use than an absentee ballot. Ten participants (5 from each group) would prefer to use the mobile voting system from home (or another convenient location) to avoid the pressure and anxiety they feel at a polling place and to allow for as much time as they need.

Although more traditional or native functionality was constrained, the majority expressed that the mobile voting system was easy to use and intuitive (e.g., to figure out after initial confusion about how to scroll using the provided options, and how to choose an option by selecting a checkbox and not by pressing a name). However, some participants wanted an optional, brief overview or tutorial that would explain the functionality and voting process for the interface and the available options that can be adjusted (such as text size and contrast, enabling swiping, location of scroll bar, keyboard options, etc.) at the beginning and throughout the voting process. Additional functionality could also be implemented to anticipate when instructions are needed by users, such as when changing a vote. The overall text size and bolding was useful and accepted, although most control participants desired options to alter the text size at the beginning and during voting to view more options at once on the screen.

The size and placement of the buttons were also well received, along with the simple and clear layout of the ballot and the variety of scrolling options, which allow participants to switch between these options as needed by contest type or rate of reading preference (i.e., most dexterity participants only used the arrow options, but most control participants switched between all of the scrolling options). While using the double arrows (or Page Down) option to scroll, 2 control and 2 dexterity participants (including 1 with visual tracking issues) found it difficult to track how far the double arrows shifted through the options.

Participants appreciated having the list view and Edit options available on the View All/Review page, and after figuring out how to change a vote after a couple presses most also expressed that this feature would help prevent error, and that the ability to edit would be very useful in voting. However, it was unclear to some in each group that the View All/Review screen could be used to navigate the ballot, and that they needed to reach this screen in order to submit their ballot.

3.2 Dexterity-Specific Findings

Repeated-Press Buttons Require Additional Spacing and Support/Reach Considerations. Throughout the voting process, the dexterity participants tended to use the custom scroll buttons (e.g., single or double arrows), and not the scroll bar, to scroll down and up through the selections for each contest. Using these controls required repeated presses for most of the contests. The Next Contest button, which participants had to press each time they finished choosing a selection for a contest, was located directly below the custom scroll options on the right side of the screen. Although the amount of spacing included between these buttons and the placement of the buttons along the edges of the screen was based on previous research, we observed that this spacing proved insufficient, especially for 2 dexterity participants who tended to experience drifting while repeatedly pressing buttons. This proximity of repeated-press buttons led to accidental presses of the Next Contest button when these participants were pressing the options to scroll down, which then required each participant to go back to the previous screen and start scrolling from the top of the list again (i.e., a serious and detrimental consequence, especially for users with dexterity limitations). After completing the ballot, 2 dexterity participants also mentioned wanting a longer scroll bar that extended to the bottom of the screen to help avoid this issue.

In addition, we observed that the placement of the options to scroll down led participants to hover over the screen at times while they pressed these buttons, which then did not allow them to use the support of the table by resting their hand alongside the tablet while pressing a button. Participants who preferred to use their left hand to press buttons also had to move their hand a further distance to reach the custom scroll options and required them to hover over the screen versus those who used their right hand. This hovering, along with the mentioned spacing issues between critical buttons, led to diminished accuracy and accidental inputs for buttons that required repeated presses.

Button Placement Options May be Required to Accommodate Various Hand/Finger Usage. While using the mobile voting prototype, the majority of the participants used a finger on one preferred hand to press buttons on the screen, and at times used both hands (one finger on each) to type the names of write-in candidates using the provided on-screen keyboard. Most used an index finger to touch buttons on the screen, although usage varied more for the dexterity participants (e.g., use of different fingers or a thumb).

During the sessions, it became apparent that hand preference was an important factor for the ease of use of the interface, as those who preferred to use their left hand had to reach across the screen to use the fixed scroll options on the right side, which led to loss of support for their hand and the screen being blocked by their left hand. Seven participants (4 control and 3 dexterity) used their left hand to press buttons and experienced difficulties and accidental inputs at times for buttons they repeatedly pressed. Of these participants, 3 dexterity and 1 control mentioned their desire for an option to choose the location of the scroll bar to facilitate ease of use and accuracy, and also thereby allow for “switching” of hand usage (e.g., 1 dexterity participant switched to using her left hand because her right hand became fatigued). Therefore, although it has been demonstrated that locating buttons along edges of a screen can lead to greater accuracy for users with motor impairments, users should also not be forced to move far from their arm support in order to press a button.

Inputs or Touches may be Misinterpreted by Commercial Touchscreens. Throughout the voting process, we observed how the touchscreen and operating system of the commercial tablet (Samsung Galaxy Tab 4) used to display our interface during the study interpreted the inputs of users. Specifically, the inputs or touches of 4 dexterity participants were not always recognized and/or the system recognized an input as a double press (e.g., selecting and deselecting a checkbox during a single interaction), and these input issues occurred especially for 2 of these participants. For one of these participants, who also has visual tracking issues, the touchscreen system did not accept his inputs at times when he was pressing checkboxes, and especially when using the provided on-screen keyboard. The second participant could reach and touch all the buttons in the interface usually with a high degree of accuracy, but the system accepted almost none of her inputs, most likely because of particularly long dwell times. However, this participant often experienced accepted inputs for buttons that were closer to her (e.g., Next Contest button) versus buttons that required her to reach or hover over the screen with her right hand (e.g., checkboxes) which may have led to her longer dwell times to compensate for support (e.g., pressing down and then pushing off of the screen for buttons that required more reaching).

Adjustable Support is Useful and Essential. Nearly all of the participants expressed that using the tablet on an angled table was useful for viewing ease and for support if needed; however, one dexterity participant would prefer the table itself to be flat for comfortable support with the tablet propped at an angle to facilitate viewing and a mouse available to use for inputs (e.g., to avoid having to hold her hand up and over the tablet). Participants slid or slightly rotated the tablet within the middle of the table as needed for viewing or ease of interaction, and 6 dexterity and 5 control rested their hand(s) on the table at times or throughout the entire voting process. Specifically, 1 dexterity participant mentioned that the angled table would be essential for him to use the tablet because he could rest his hands along the side of the tablet and then move his fingers to press the on-screen buttons (versus needing to hover or reach), although he would also like to have the option to use a mouse for inputs.

One dexterity participant had more limited range of motion and control than the other participants and her inputs were often not accepted when using the mobile voting prototype; she experienced less successful inputs when she was required to reach or hover to press a button (e.g., she had more success for the buttons at the bottom of the screen, such as the Next Contest button, while resting her hand near the bottom of the tablet). As mentioned previously, due to the loss of support when reaching for a button, this participant had particularly long dwell times and seemed to use the tablet as support by pushing off the screen when moving her hand away from the tablet.

4 Discussion

From observing and analyzing the usage of our mobile voting prototype by individuals with moderate dexterity impairments and without impairments, we discovered considerations that are critical for a universally designed voting system.

Specifically for individuals with moderate dexterity impairments, additional spacing is required between repeated-press buttons (versus what has been found in previous research for touchscreen buttons in general) to compensate for drifting and possible support or hovering issues, and to avoid accidental inputs for these types of buttons. A tablet with a larger screen size could help facilitate enhancements that cannot be sufficiently accommodated on a tablet with a 10.1 in. screen size (e.g., extension of the scroll bar and options to the bottom of the screen with the other buttons near the bottom shifted to the left with their current size maintained) in order to avoid unintended inputs for repeated-press buttons.

The placement of the buttons along the edges of the screen was useful for most participants as they could rest their hands on the table for support along the sides and bottom of the tablet as needed. However, usage varied more amongst the dexterity participants for hand and finger usage (e.g., switching between hands or using not only an index finger) and they may have been limited to the use of only one hand. In addition, due to varying ranges of motion, control, and strength, participants may or may not have rested their hand(s) or arm(s) on the table near the tablet (e.g., usage ranges, preference, or comfort differences may have dictated whether they desired to or were able to rest on the table for support versus hovering above the screen). Therefore, further considerations are needed beyond placing buttons along the edges, such as the option to choose the location of repeated-press options (e.g., scroll options) for left hand usage. The option to rotate the ballot may also be necessary as a landscape-oriented ballot could potentially alleviate reach and support issues (e.g., for buttons near the top of the screen).

Additionally, how touchscreen devices interpret the intentions of users with dexterity disabilities requires further investigation, as well as whether additional considerations may be needed to facilitate support and reduce reaching or hovering. Specifically, users with this type of disability have been shown to press touchscreen buttons for a longer duration (dwell time) with more total force for that time (i.e., greater impulse) than users without disabilities [12, 16]. Because of these specific differences, touchscreen devices calibrated to interpret user intentions based on the specific touch characteristics of users without disabilities may have difficulty correctly interpreting the intentions of users with dexterity-related disabilities, as we found in our study. A calibration setup feature may be necessary to assess the touches of a user (e.g., differences in dwell time and force) and adapt the system as necessary [23, 24] to ensure their inputs are recognized throughout the voting process. A landscape-oriented ballot could also potentially reduce reaching or hovering, which could decrease the amount of unrecognized inputs.

Overall, this study demonstrated that flexibility or adjustability is critical for a universal mobile voting system. The default setting for this mobile voting system was usable for the majority of participants, but options for adjustment will facilitate further ease of use, such as the option to choose the location of the scroll bar, to adjust the text size if and when needed, to calibrate the system based on the user's touches, and so on. In addition, a tablet that is not fully attached to a surface also allows a user the option to hold the tablet if desired, or re-position the tablet on the table as needed. An adjustable surface, allowing for varying height and angle options, also is needed to meet the varying needs of users for ease of viewing and support. Additional input devices should also be available (e.g., styluses of varying sizes, mouse options, external keyboard, etc.) and the option to connect personal input or assistive technology to further facilitate ease of use of the digital ballot [25].

5 Conclusion

To further the development of a universally accessible touchscreen voting interface, we used prior research to design and create a mobile voting prototype. We evaluated the usability of our prototype with individuals with moderate dexterity impairments and with no disabilities. Results of our study can inform user interface designers, election officials, voting system manufacturers, and the general public on the specific needs of different user groups, and considerations that are necessary for a universally designed system. Further research is being conducted with low vision and dyslexia participants, and additional research will investigate the ease of use of the audio features of the mobile voting system with relevant disability groups, including blind and aging participants.

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