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## A Web Based Voting Application Study of User Input Devices for Older Adult Voters with Arthritis

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## Executive Summary

The Help America Vote Act (HAVA) legislation was passed by Congress in 2002 in response to the controversy surrounding the Florida butterfly ballot, hanging chads, and other issues in the 2000 U.S. presidential election. As a result, many states changed their procedures and equipment to be more accessible and usable to voters who are hearing or visually impaired or who use a wheelchair. However, there are many hidden disabilities that should also be considered, for example functional limitations such as arthritis, cognitive deficits, or upper mobility impairments. The focus population of this study was those with arthritis. The CDC estimates that 50 million adults in the U.S. have reported being diagnosed with arthritis (MMWR, 2013). Arthritis limits the functional ability of voters that may directly impact their performance in using a voting system. For example, voters with arthritis in the fingers, hands, or wrists may experience difficulty pressing buttons repetitively and therefore find it cumbersome to navigate complex ballots; they may also experience fatigue. By studying how voters with functional limitations such as arthritis interact with voting systems, the accessibility of user input controls can be better understood.

The goal of this research effort was to enable private and independent voting by voters with arthritis. This research study **investigated the usability and accessibility of three different tactile user input devices**: 2-button (advance forward and select), 3-button (advance forward, backward, and select) and 5-button user input devices (advance forward, backward, select, proceed to next contest, and previous contest).

Fifteen older adults with arthritis in the hands, wrists, and/or fingers participated in this study. Each participant sat in front of a computer and used the three input devices to navigate through a web based voting application (Voting App) while their performances were monitored. The Voting App was designed to be modular and adaptable to various testing conditions, and it simulated many of the tasks that users would typically encounter when using a voting system. The Voting App produced an event log that logged the time at which various events occurred, such as selecting a candidate. Eye tracking data were captured to determine where participants were looking. The order in which user input devices were presented to participants was counterbalanced, and after using each input device, participants were asked a series of questions about usability and pain. At the end of the study, participants were asked to rank the overall performance of each of the input devices, and were interviewed about their experience with the three input devices.

Participants were less concerned with how long it took them to vote than with the ease of using and understanding the input devices. There were no significant differences between input devices when considering the time it took participants to: (1) vote in races, (2) complete the write-in candidate, (3) click between selections of on-screen buttons, and (4) find and select the prompted candidate's name on the contest page. Similarly, there were no significant differences between input devices when considering subjective pain ratings, usability ratings, or gaze time on various portions of the display.

Experimenter observations and follow-up interviews revealed probable explanations for the lack of statistically significant results in the objective measures discussed above. Some participants reported a preference for simplicity in the input device; they were confused by additional buttons on the 3-button

and 5-button devices. Many participants used only two buttons on the 3-button device, or used two or three buttons on the 5-button device. Other participants preferred the versatility and efficiency of the 3-button and 5-button device. These differences in preferences precluded a statistically significant preference, over all participants, for any of the three input devices.

The results suggest that the 3-button device is an adequate compromise between simplicity and efficiency. The 5-button device provided more flexibility for some users, but was not well received by other users because of its perceived complexity. The 2-button was preferred by some participants due to its ease of use and simplicity, although it should be noted that there was some frustration when participants would overshoot their targets and would have to cycle through the page content to reach the target. The addition of a tactile back button in the 3-button device, although not often used, can improve efficiency when it is needed.

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## Introduction

In 2002, the Help America Vote Act (HAVA) was passed by Congress in response to the controversy surrounding the 2000 U.S. presidential election. HAVA required that each polling location have at least one voting system that is accessible to individuals with disabilities. The implementation of this has been to ensure that the voting systems are accessible to voters who are hearing or visually impaired, or who use a wheelchair. However, there are many hidden disabilities that to date have not been addressed adequately, such as arthritis.

Lawrence et al (1998) estimate that 59.4 million Americans will be affected by Arthritis by the year 2020. According to the CDC, arthritis is the most common cause of disability among U.S. adults. The CDC analyzed data from the 2010-2012 National Health Interview Survey (NHIS) and found that 52.5 million adults (22.7% of total respondents) self-reported that they had been diagnosed with arthritis; 22.7 million (9.8% of total respondents) reported that arthritis had attributed to the limitations in their daily activities (MMWR 2013). The highest prevalence of arthritis was in those over the age of 45, and these individuals often had comorbidity such as heart disease, diabetes, and fatigue. The older adult population is of particular interest because conditions such as osteoarthritis are often associated with age. In addition, older adults tend to have lower working memory capacity than younger adults (Hambrick & Engle, 2012) and tend to learn new procedures less easily than younger adults (Harada et al., 2010).

Individuals with arthritis have functional limitations that include difficulty reaching, grasping and pushing objects. Alvarez and Hall (2010, as cited in Hall, 2013) found that tasks such as putting a ballot in a ballot box or holding a pen, and other physical tasks associated with a physical ballot can be difficult or impossible for some voters with physical disabilities. Arthritis in the fingers may limit their range of motion in those joints, and result in pain if they have to perform repetitive tasks, such as pressing buttons on a voting system. This could also lead to difficulty sliding the voter card to activate the voting system, because this task requires some degree of precision and dexterity.

Bederson, Lee, Sherman, Herrnson & Niemi (2003, as cited in Hall, 2013) found that hand eye coordination and dexterity issues related to older age could make it more difficult for older adults to operate voting technology. Older adults may have additional complications due to co-morbidity, such as cognitive issues that may require a more simplistic user input device. A simple 2-button input device for a voting system would require the user to learn and remember a very limited number of control-display mappings. Additional buttons may increase versatility and efficiency, but they may also impact learnability and memorability. Therefore, a trade-off could exist between the simplicity of the input device and its efficiency and versatility. The purpose of this research study was to examine trade-offs between simplicity and versatility by examining the usability of three different tactile input devices by older adults (over age 55) with arthritis in their wrists, hands, or fingers. These users with arthritis were expected to prefer the more efficient interfaces, which required fewer button presses.

## Voting Application

GTRI developed a web based voting application test bed, henceforth referred to as the “Voting App”, to be used for testing user interface concepts for a variety of applications and to be used with technologies such as portable computers (Harley et al., 2013). The Voting App is designed to be accessible to individuals with impairments in vision, hearing, upper or lower mobility and cognitive deficits. The Voting App provides designers a means of testing user interface design alternatives with individuals with disabilities. The Voting App captures objective measures of performance, including selection times, ballot duration, sequence of selections, and errors. These objective data, along with subjective usability questionnaires and rating scales, can help designers of voting systems understand how individuals with disabilities interact with their product.

## Eye Tracking

While the Voting App recorded overt user interactions with the system, an eye tracking system was used to track participants’ gazes. This data was expected to provide additional information about the tasks that users were performing, such as visual search and attention to the on-screen navigation controls.

## User Input Devices

Three user input devices were evaluated in this research study; 2-button, 3-button and 5-button devices (Figure 1). The button characteristics are described in previous published paper titled “The evaluation of a web based voting application” (Harley et al., 2013). The three input devices represented a range of minimalism-to-versatility. Minimalistic button designs require more button presses, because users must move the onscreen cursor to their desired option rather than pressing a physical button for that option. Also, the limited directionality of onscreen cursor movement (e.g., “next” only instead of “next” and “back”) can require more button presses to complete a task. The number of required button presses for task completion might substantially impact usability for individuals who experience pain or who have upper mobility impairments.

The 2-button device was minimalistic, and would require users to make more button presses than the two other devices if all devices were used in the ideal manner. It featured a select button and a cursor-forward button. The latter was used to advance the on-screen cursor through the on-screen options. When the desired item was highlighted, the user pressed the select button to actuate it. When the cursor reached the end of the page, the cursor-forward button caused it to wrap back to the top of the page.

The 3-button device included an additional tactile button: a cursor-backward button. Users could complete the ballot with fewer button presses than with the 2-button device if they used the device in the ideal manner. The 3-button device was more versatile than the 2-button device because users could move the cursor to the top of the screen either by using the back button or by moving to the bottom and wrapping back to the top. Use of the back button was more efficient in some cases.

The 5-button device included two additional tactile buttons: a page-backward button and a page-forward button. These served as shortcuts to enable the user to jump to the previous or next page by a single button press, rather than by moving the on-screen cursor to the on-screen “back” and “next”

control buttons. Users could complete the ballot with fewer button presses than with the 2- or 3-button devices if they used the page-backward and page-forward buttons appropriately.

In summary, the additional buttons increased efficiency if used properly. They also increased versatility and complexity by giving users more options for completing a task.



Figure 1. 2-button, 3-button and 5-button input devices.

## Hypotheses

The purpose of this research study was to examine the usability of three different tactile input devices by older adults with arthritis.

**H1.** Subjective user preferences and objective measures of performance were expected to be better for the 5-button device than for the 2-button and 3-button devices. The 5-button device included page-forward and page-backward buttons that were expected to enable users to navigate between pages more quickly and with fewer button presses. Thus, the total voting time was expected to be lower and subjective preference was expected to be higher for the 5-button device. The 2-button device was expected to be the least preferred and slowest. Ratings and times for the 3-button device were expected to be worse than the 5-button device but better than the 2-button device.

**H2.** Participants were expected to report more pain with the 2-button device because it required more button presses.



**H3.** Time to enter a write-in was expected to be significantly slower for the 2-button device than for the 3-button and 5-button devices, because the 2-button device forces users to scroll through all of the on-screen keys, wrapping back to the top of the alphabet to reach preceding letters rather than simply pressing the back button.

**H4.** Participants were expected to look at the on-screen navigation controls (“next” and “back” buttons) less frequently in the 5-button condition, because they could use the tactile buttons on the input device rather than the on-screen buttons.

**H5.** Practice effects were expected to be evident in task completion times and subjective ratings. That is, the order in which the three devices was used was expected to affect task times and ratings, with task times decreasing and ratings increasing as users became more familiar with the system.

## Method

### Participants

Fifteen participants (mean age =  $71.9 \pm 7.1$ , Min = 58, Max = 83; 11 female, 4 male) volunteered for this study. In accordance with inclusion criteria, all participants reported symptoms of arthritis in the wrists, hands, or fingers. Participants were compensated \$30 for their participation in the 1.5 hour experiment. The Georgia Institute of Technology Institutional Review Board approved the study.

### Ballots

Each ballot consisted of 16 items, including 12 races, one Constitutional amendment, one ballot initiative, and two retention questions (e.g., “Shall John Doe be kept as city comptroller?”). These were preceded by instructions and a practice race. The final page of the ballot was a review page that displayed the participant’s selections for all of the races.

Each page of the ballot included four on-screen control buttons and other context-dependent selection options (Figure 2). For the four races with more than eight candidates, the candidates were listed in multiple columns. Prior to each race, participants received an on-screen prompt to vote for a particular candidate in the next race. Users were asked to enter a write-in candidate with an on-screen keyboard in one race. Participants received pop-up warnings immediately if they under-voted or over-voted on any race. The ballot review page also gave a visual indication of under-votes.

Three equivalent ballots were created for use with each of the three input devices. The three ballots were matched with regard to the locations of the correct (prompted) candidates in the races. For example, if ballot A had prompted candidates in list positions 3, 7, and 12, then ballots B and C did also. The locations of the matched races in the ballots were pseudo-randomized across ballots so that participants would not recognize a pattern as they proceeded through the experiment.

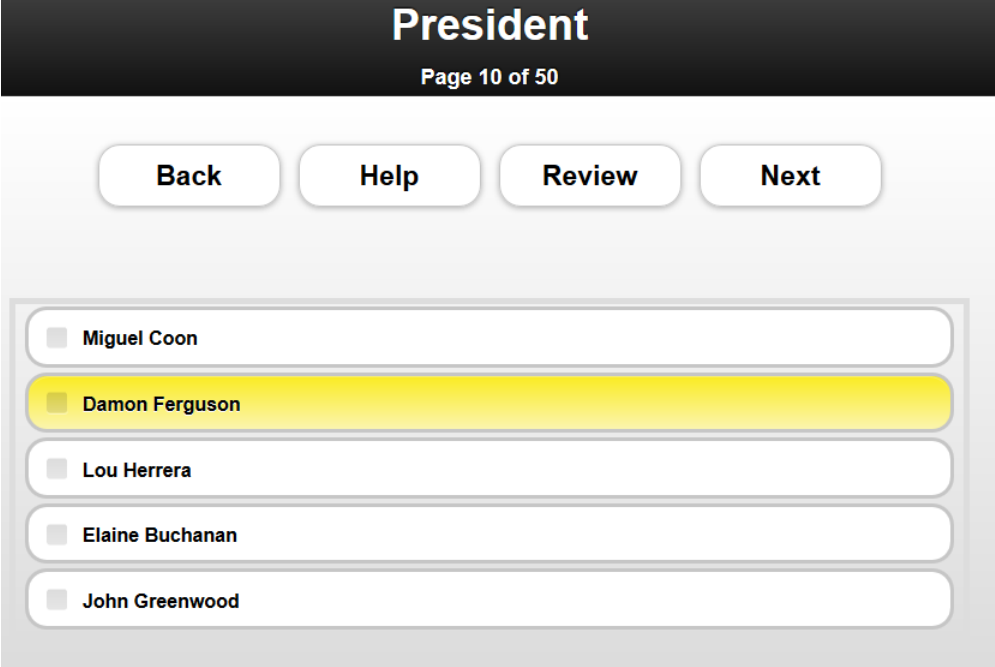


Figure 2. Screen shot of the Voting App.

### Eye Tracking System

A SmartEye eye tracking system was used to track participants' direction of gaze as they voted. Three SmartEye cameras (Basler acA640-100gm cameras with 8mm lenses) with two IR flasher devices were used to sample eye position at 60Hz (Figure 3).



Figure 3. SmartEye eye tracking system.

## User Input Device

Participants used three user input devices: 2-button, 3-button and 5-button (Figure 1). The layout of the buttons and their mappings to actions are described in the Introduction section of this document. The buttons (Enabling Devices Compact Switch #745) were connected to a switch device (X-keys XSI-38-US). The switch device was connected by 3.5 mm switch plugs of the buttons to the PC via a USB port. The switch inputs were mapped onto the desired keyboard inputs to control the Voting App.

## Design

A repeated measures design was used. Each participant used each of the three input devices. Three equivalent ballots were created for use with each of the three input devices. The order in which the devices/ballots were used was counter balanced by Graeco-Latin square.

Input device (2-, 3-, or 5-button device) was the independent variable for all analyses of user performance, user preference, and eye tracking data. Repeated measures ANOVAs were conducted on each dependent variable.

Objective dependent variables were derived from event logs (user selections) and eye tracking data. Event logging variables included the following:

- *Race Time*: The average time spent on the races excluding the prompt pages (seconds). The initial instructions page, practice race, write-in, constitutional amendment, and ballot initiative were excluded, because behaviors varied widely among participants and ballots on these items.
- *Write-in Time*: The total time it took participants to write-in a candidate's name divided by the number of letters in the name (seconds/letter).
- *Click Time*: The time elapsed between selections of any on-screen buttons, including navigation control buttons and candidates' names (seconds).
- *Response Time*: The time elapsed between the onset of a race and the participant's selection of a candidate divided by the position of the candidate in the list (seconds/candidate).

Dependent variables for the eye tracking analysis included the following:

- *Controls Gaze Time*: The average amount of time participants looked at the on-screen control buttons (i.e., back, help, review, next; seconds).
- *Candidates Gaze Time*: The average amount of time the participants spent looking at the list of candidates (seconds).
- *Target Candidate Gaze Time*: The average amount of time participants spent looking at the target candidate (seconds). This is a subset of *Candidates Gaze Time*.

Subjective dependent variables included input device ranking, System Usability Scale ratings (Sauro, 2011), voting system usability ratings, and Wong-Baker pain scale ratings (originally published in Whaley & Wong's Nursing Care of Infants and Children).

## Procedure

Participants completed the experiment in one-on-one sessions with an Experimenter, who was present throughout the session. Participants first signed an informed consent form and received a brief overview of the procedures from the experimenter. Then participants completed a short questionnaire on their arthritis symptoms and voting experience, and each participant's grip strength and pinch strength were measured. Grip strength assessment was performed with a Jamar Hydraulic Hand Dynamometer (5030J1 Serial #30303257). Users were instructed to grip the dynamometer as tightly as possible without experiencing excessive discomfort. Both left and right hands were tested. The pinch strength measurement was performed with a Jamar Hydraulic Pinch Gauge (7498-05 Serial # 60203139). Three pinch types (Tip, Key, and Palmar) were performed. For the tip pinch, users placed the tips of their index finger and thumb on opposing sides of the gauge. For the key pinch, users placed the lateral aspect of the middle phalanx of their index finger on the bottom of the gauge and their thumb on the top of the gauge. For the Palmar pinch, users placed their thumb on the top of the gauge and the pads of their index and middle fingers on the bottom of the gauge.

Next, the participant was seated comfortably in front of the computer and eye tracking system. The experimenter calibrated the eye tracking system and then launched the Voting App. The participant completed the first ballot while the experimenter observed. Immediately afterward, the participant completed a set of rating scales for the input device, which included a pain rating scale, the System Usability Scale (Sauro, 2011), and a usability scale created specifically for the Voting App. These procedures were repeated for the next two input devices.

After all three input devices had been used, the experimenter interviewed the participant. Each participant ranked the input devices based on their subjective preference. Participants explained their rankings and provided any additional comments. To conclude the session, participants were debriefed and compensated for their time.

## Results

### Arthritis Symptoms

All participants reported experiencing arthritis symptoms in their fingers, hands, or wrists on the day of the study. Figure 4 shows the reported distribution and severity of arthritis symptoms. Ten participants reported having only osteoarthritis/degenerative arthritis. One participant reported having osteoarthritis, gout, and systematic lupus erythematosus. Two participants reported having osteoarthritis and fibromyalgia. One participant reported having osteoarthritis and rheumatoid arthritis. One participant reported having only gout.

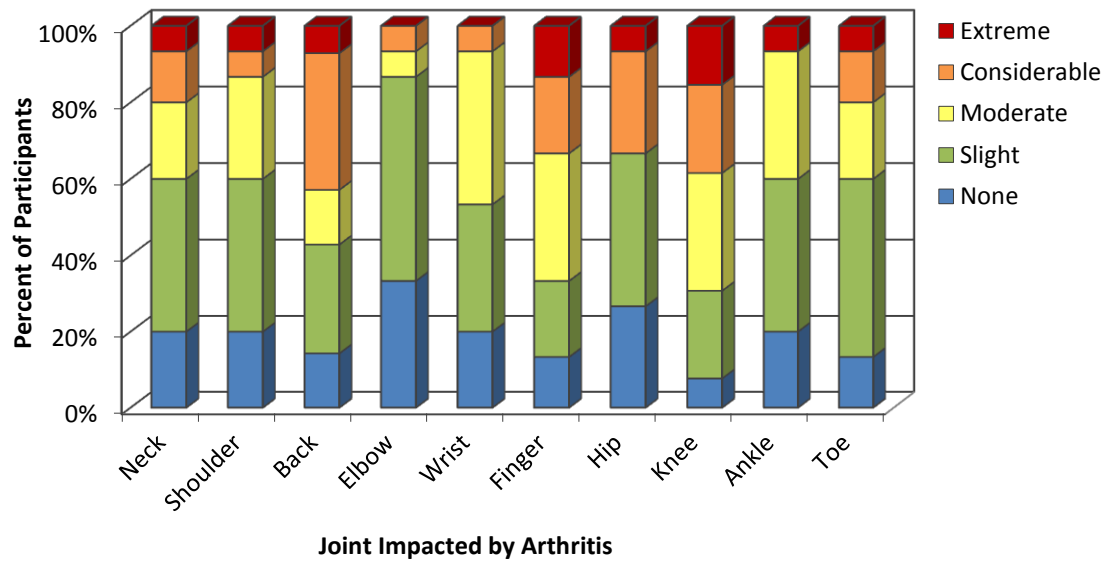


Figure 4. Distribution of arthritis symptoms.

Participants were asked to rate the arthritis-related difficulty that they had experienced using touchscreen devices, buttons, and voting systems (Table 1). Two participants reported having slight difficulty voting. Five participants reported having slight to moderate difficulty using tactile buttons. Four participants reported having slight difficulty using touchscreens.

**Table 1. Arthritis user experience questionnaire.**

Question	No Difficulty	Slight Difficulty	Moderate Difficulty	Extreme Difficulty
Do you have difficulty using a touch screen due to your arthritis?	13	2	0	0
Do you have difficulty pressing buttons due to your arthritis?	10	4	1	0
Did you have any difficulty voting at a polling place due to your arthritis?	10	4	0	0

### Strength Assessment

Grip and pinch strength are related to the use of the button interfaces. It was important to characterize participants' hand strengths to identify any outliers (extremely strong or weak participants). Both the left and right hands were tested. Figure 5 shows the results of the grip strength assessment using a wide (open) grip and a narrow (closed) grip. Figure 6 shows the results of the pinch force assessment for the top, palmar, and key pinch. In both figures, the mean is represented by the filled diamond, median is represented by horizontal line, interquartile range (25<sup>th</sup> to 75<sup>th</sup> percentile) is the shaded box, plus or minus 1.5 interquartile range is represented by the vertical lines, and outliers are unfilled squares. None of the grip or pinch strength measurements showed any participants as outliers, which were defined as measurements three standard deviations above or below the mean.

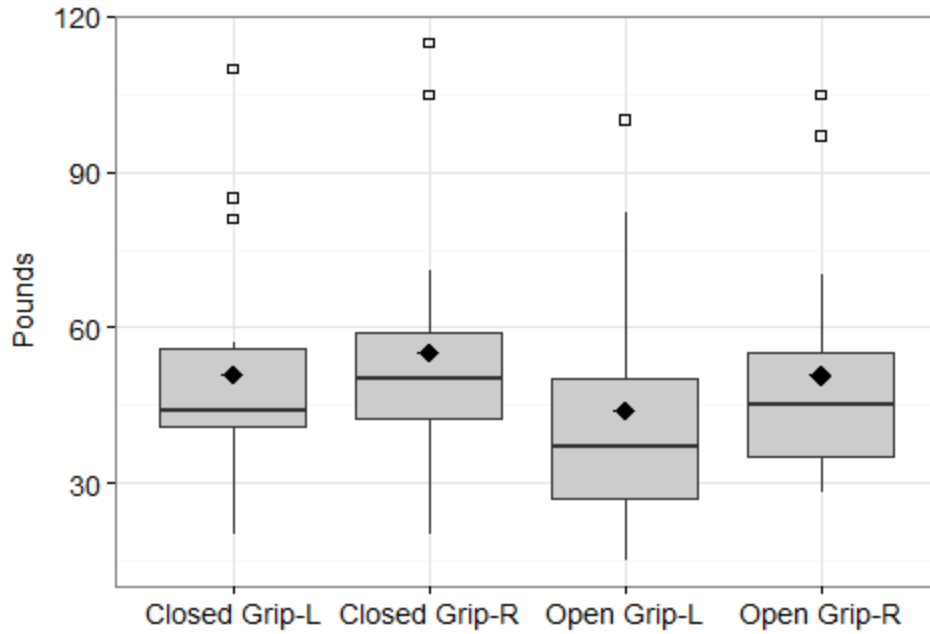


Figure 5. Boxplots of grip strength measurements. The boxplots represent medians, interquartile ranges (boxes), and 1.5 x the interquartile range (whiskers). The mean is represented by the filled diamond.

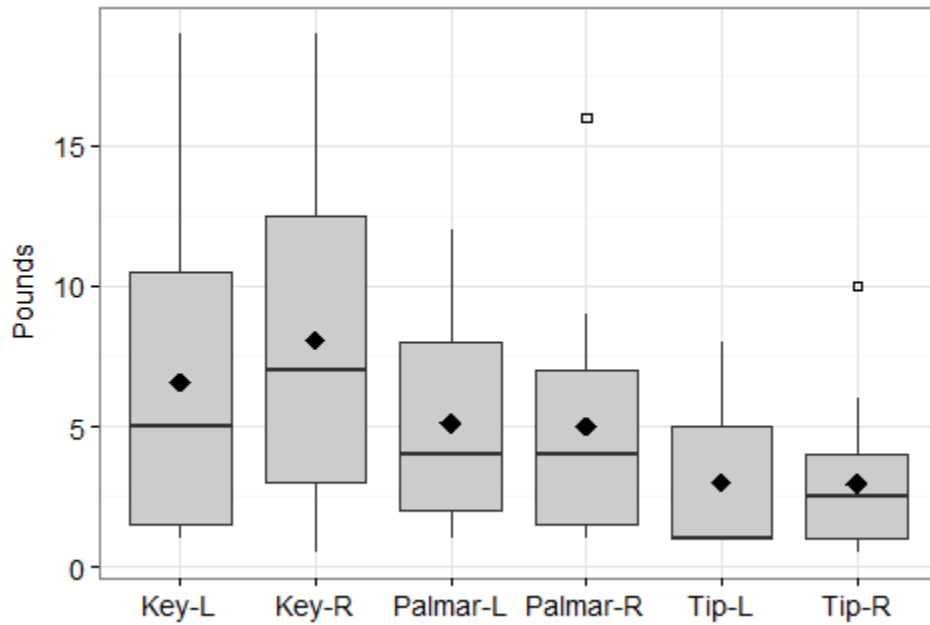


Figure 6. Boxplots of pinch strength measurements. The boxplots represent medians, interquartile ranges (boxes), and 1.5 x the interquartile range (whiskers). The mean is represented by the filled diamond.



## Subjective Data

### Rankings

The 5-button device was expected to afford faster voting times and receive higher user rankings (H1), but the data did not support the hypothesis. A Friedman rank test did not show significant difference in rankings among the three input devices,  $\chi^2(2) = 0.13$ ,  $p = .94$ . Although six participants ranked the 5-button device highest, seven ranked it lowest (Table 2). Total Score in Table 2 was computed for each button by assigning scores of 3, 2, and 1 for favorite, second favorite, and least favorite, respectively, and summing across participants. Also, ratios of favorite-to-least-favorite for each device were computed by dividing the number of votes for favorite by the number of votes for least favorite. Based on both Total Scores and the Ratios, there was a slight but statistically insignificant preference for the 3-button device, although note that it received the fewest “favorite” rankings.

Table 2. Subjective rankings of preference for the three input devices. Cell values in the first three rows represent counts.

	2-button	3-button	5-button
<b>Favorite</b>	5	4	6
<b>Second Favorite</b>	5	8	2
<b>Least Favorite</b>	5	3	7
<b>Total Score</b>	30	31	29
<b>Ratio Fav/Least Fav</b>	1	1.3	0.86

It was expected that the 5-button device would enable users to vote faster with fewer button presses, and therefore it was expected that the 5-button device would be preferred. On the contrary, none of the participants reported that voting time was a determining factor in their preference rankings. Instead, responses from the follow-up interview indicated that some participants were confused by the 5-button device. Five of the fifteen participants reported that it was too complicated or confusing. The 2-button device was ranked the highest by five participants, all of whom reported that they favored its simplicity.

### Usability Ratings

Participants also completed rating scales for each input device. Participants rated ease-of-use with the System Usability Scale and the Voting App Usability Scale. A total score was computed for each usability scale varied System Usability Scale ratings did not differ significantly among the input devices,  $F(2,28) = 0.02$ ,  $p = 0.98$ ,  $\eta_p^2 = 0.002$ , power = 0.053, nor did the ratings differ on the Voting App Usability Scale,  $F(2,28) = .849$ ,  $p = 0.438$ ,  $\eta_p^2 = 0.057$ , power = .181.

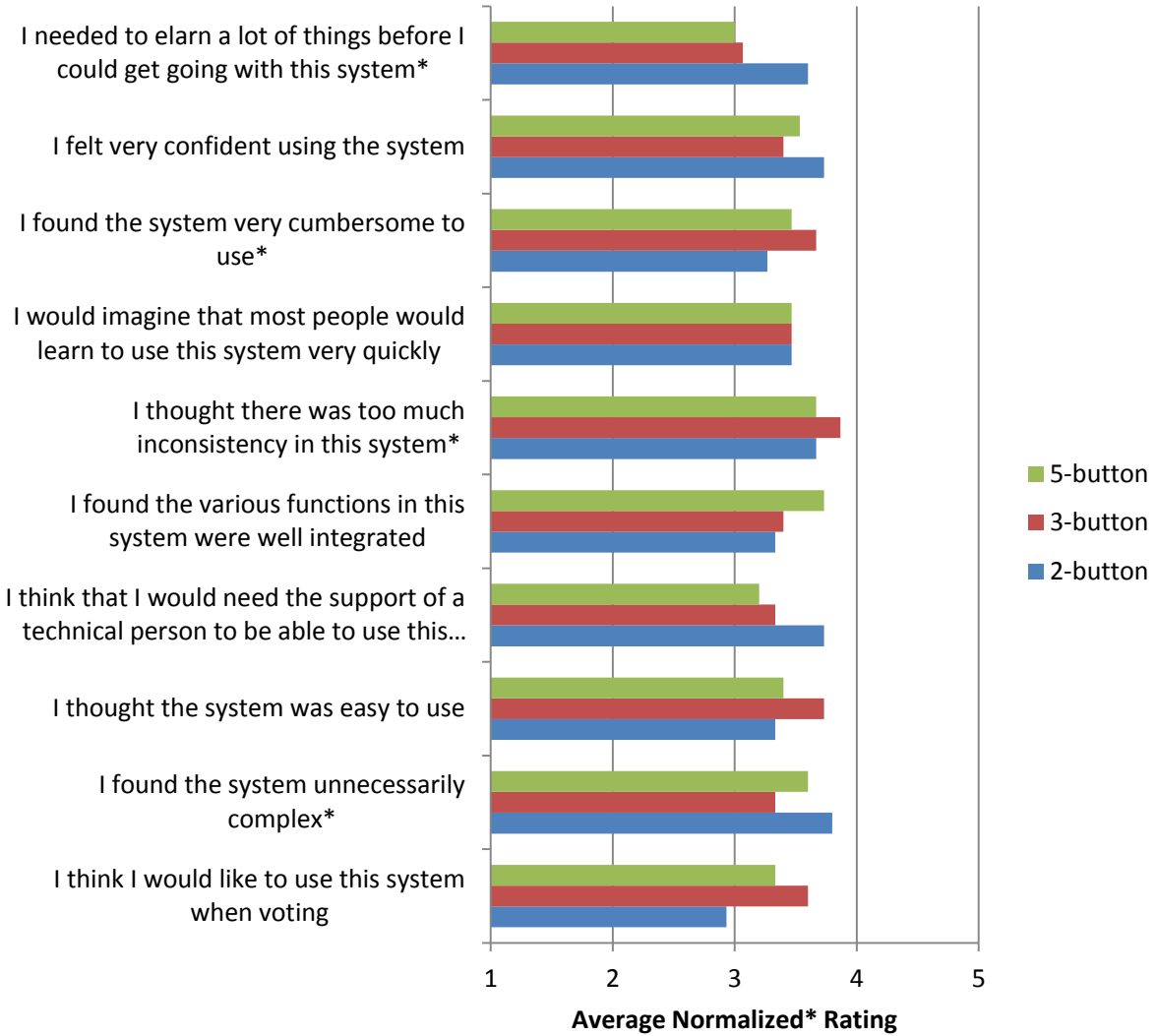


Figure 7. System Usability Scale responses for each input device. Response options ranged from 1 to 5. \*For negative or undesirable statements (see starred statements), the ratings were normalized so that higher scores represented greater desirability.

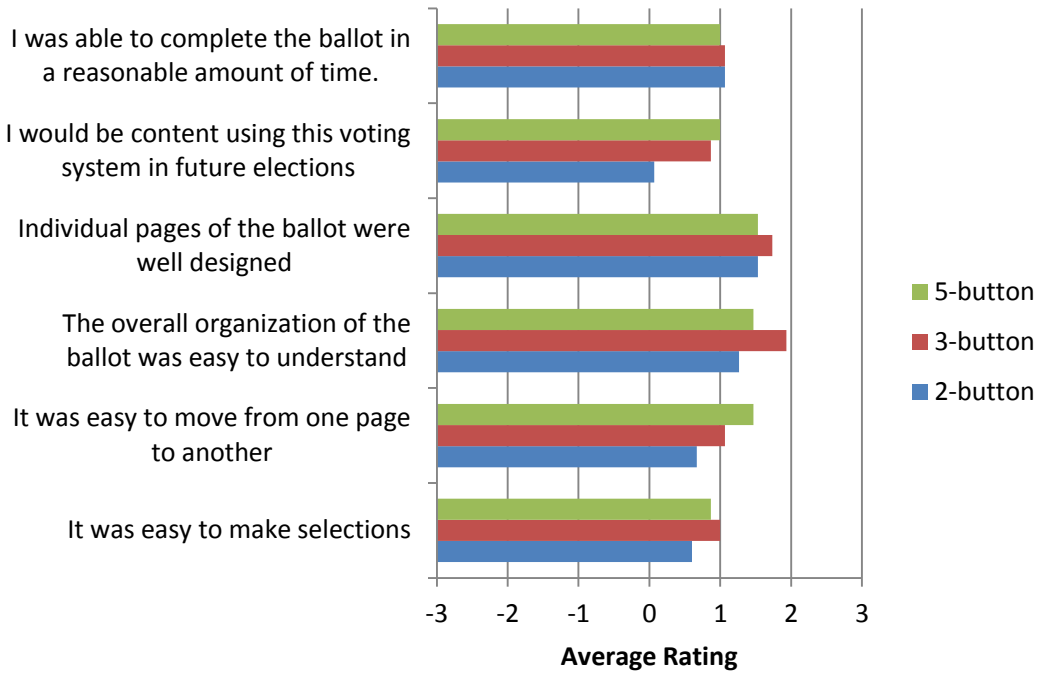


Figure 8. Voting App Usability Scale. Response options ranged from -3 to 3.

## Pain

Participants used the Wong-Baker Faces Pain Rating Scale to indicate the intensity of pain they experienced while using each input device (Results shown in Table 3). It was expected that pain ratings would be affected by the number of button presses required (H2). Ratings were expected to be higher for the 2-button than the 3-button, and higher for the 3-button than the 5-button. Repeated measures ANOVA revealed that average pain ratings did not differ significantly among the different input device,  $F(2,18) = 1.19, p = 0.33, \eta_p^2 = 0.117, \text{power} = 0.227$  (Figure 9).

Table 3. Pain ratings experienced while using each device. Values in the cells represent counts.

	No Hurt 0	Hurts little bit 1	Hurts little more 2	Hurts even more 3	Hurts whole lot 4	Hurts worst 5
2-button	5	2	3	1	0	0
3-button	6	1	3	0	0	0
5-button	7	3	0	1	0	0

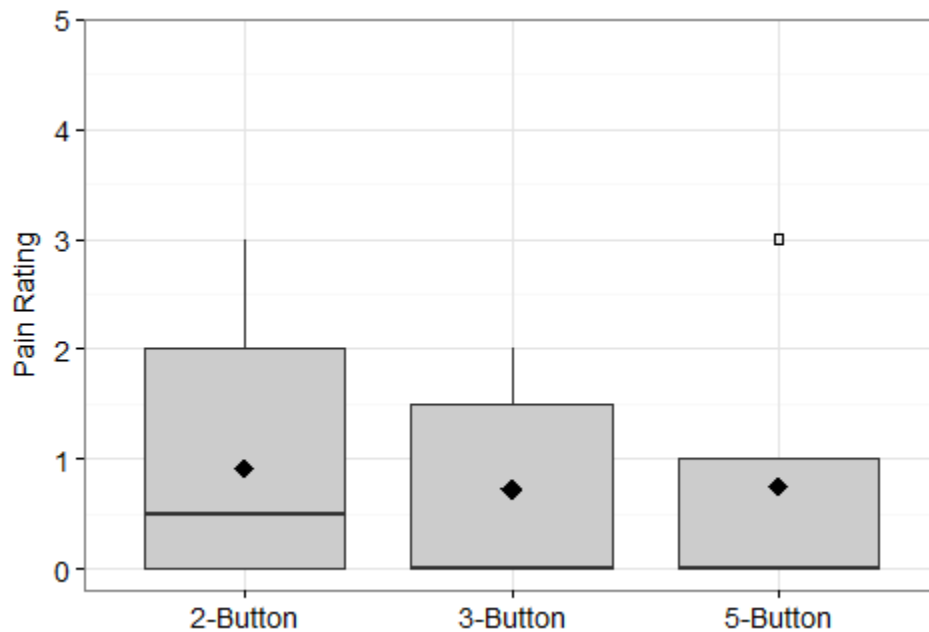


Figure 9. Pain ratings while using each input device. The scale ranged from 0 (least pain) to 5 (most pain).

## Objective Data

### Race Time

Race time represents the amount of time it took participants to vote in the 12 races (Figure 10). This is the sum of reaction time (time to select a candidate) and the subsequent epoch during which the participant navigated from the selected candidate to the on-screen “next” page button. It excluded the prompts before each race. The 5-button device was expected to be faster than the 3-button device, and the 3-button device was expected to be faster than the 2-button device (H1).

Mean race time was highest in the 3-button condition, but this was due to an extreme outlying data point in the 3-button condition, which was 4.7 standard deviations above the mean (Figure 10). Repeated measures ANOVA did not show significant differences among mean voting time for the three input devices,  $F(2, 28) = 0.67$ ,  $p = 0.52$ ,  $\eta_p^2 = 0.046$ , power = 0.151. The differences were not significant when the outlier was excluded,  $F(2, 26) = 0.546$ ,  $p = 0.586$ ,  $\eta_p^2 = 0.04$ , power = 0.13. Thus, the 5-button device did not afford the faster voting times that were expected. Four of the fifteen participants did not use the page-forward or page-backward buttons, and this might have contributed to the failure to find faster race times for the 5-button device. The results also failed to support the hypothesis that the 3-button device would be significantly faster than the 2-button device. It is possible that the amount of time saved by using the bi-directional navigation of the 3- and 5-button devices was not large enough to show a statistically significant benefit over the unidirectional 2-button device. Also, participants’ confusion about the additional button might have slowed their task completion times.

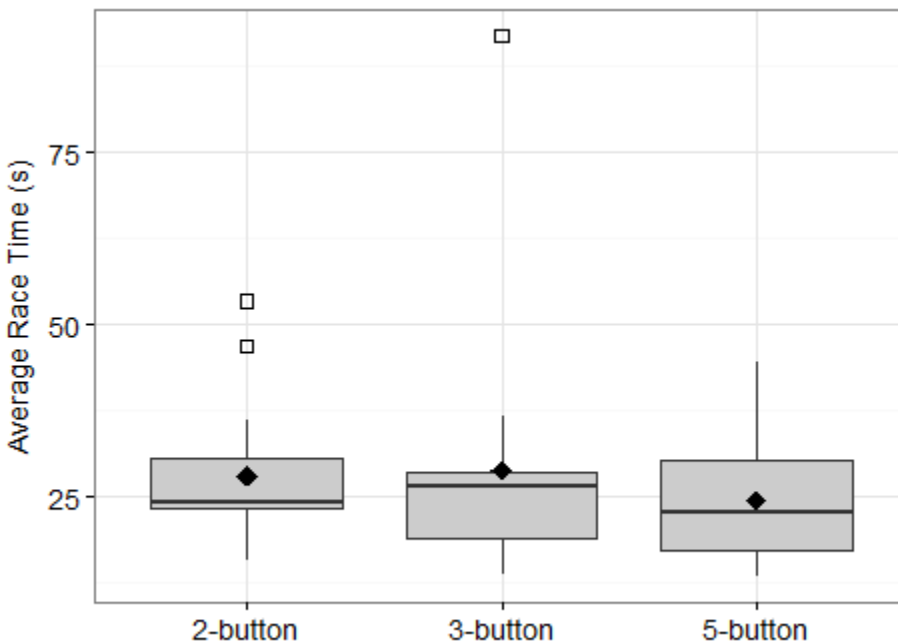


Figure 10. Race time as a function of input device, median and interquartile ranges.

## Subtask Times

The analyses below examined three voting subtask times separately (write-in time; response time; click time). The three subtasks were expected to show slower times for the 2-button device; these included entering a candidate's name on the write-in race (*Write-in Time*), moving the onscreen cursor to a desired button (*Click Time*), and finding and selecting a candidate's name (*Response Time*). Each of these subtasks reflects navigation speed, which is dependent on visual search and cursor movement. Visual search speeds were not measured, and they were not expected to vary across input devices because the same display configuration was used on all three ballots. Cursor movement speed was expected to vary by input device.

## Write-in Time

In the single write-in contest, participants were asked to write-in the name of a specified candidate (see Figure 11). Participants scrolled through the on-screen keyboard to enter the candidate's name. With the 2-button device, participants could not move the cursor backward through the alphabet, and instead had to go to the bottom and wrap back to the top. In contrast, the 3-button and 5-button devices included a back button for bi-directional navigation. It was expected that participants would be slower with the 2-button device when entering names whose letter orders did not match their alphabetical orders (refer to hypothesis H3). Specifically, it was expected that the 3-button and 5-button devices would be faster when entering names that could be entered with fewer button presses by using the back button. For example, to enter the name "Ed" the participant could press the tactile back button once to navigate from "e" to "d", but with a 2-button device they would have to press the tactile next button 25 times to wrap through the alphabet.

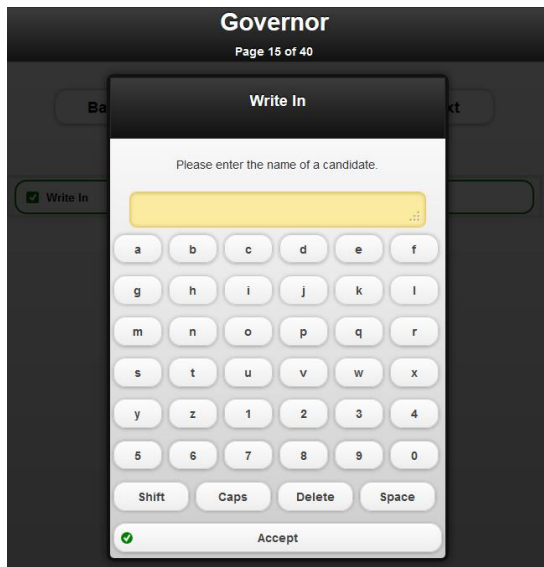


Figure 11. On-screen keyboard for entry of a write-in candidate's name.

Hierarchical linear regression was conducted to analyze the effect of input device on write-in time. A hierarchical model was used to control for (i.e., account for) the variation in the length of the names entered by participants. An interaction was expected between the input device and alphabet reversals, showing that alphabet reversals affected task time for the 2-button device more than the 3- and 5-button devices. The full regression model included input device, number of letters entered by the participants, and the number of times the participant could have reduced button presses by using the tactile back button (henceforth referred to as “alphabet reversals”). Variables were successively removed from the full model, testing the statistical significance of each. The order of removal was as follows: input device, alphabet reversals, and number of letters. Contrary to hypothesis H3, the interaction between input device and alphabet reversals was not significant,  $F(2) = 2.16$ ,  $\Delta R^2 = 0.09$ ,  $p = 0.13$ . The only significant variable was number of letters,  $F(1) = 12.42$ ,  $\Delta R^2 = 0.25$ ,  $p = 0.001$ .

Although the expected difference in write-in time among the input devices was not obtained, Figure 12 shows a pattern in the expected direction (i.e., average time for 2-button device was higher than 3-button and 5-button devices, and 3-button and 5-button devices averages were the same). More importantly, it can be shown that a 2-button device requires more button presses than the other input devices. Given a simple keyboard with only alphabetical characters and a spacebar, the minimum number of button presses to enter the name “BARACK OBAMA” with the 2-button device is 163. In contrast, the minimum number of button presses for the other input devices is 94. Although this difference might not equate to a large difference in time, it increases the physical demands on the user. Moreover, the above calculations assume that the user never overshoots a target. An overshoot with the 2-button device would require an additional 26 button presses to cycle through the alphabet, while an overshoot with the 3-button or 5-button device would require only a single additional button presses.

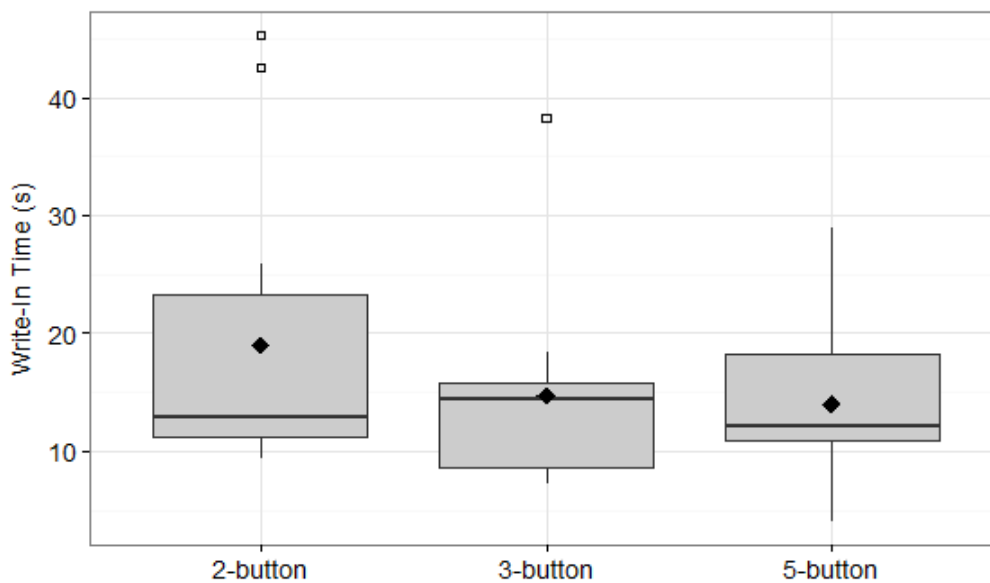


Figure 12. Mean write-in times normalized by the number of letters in the candidate’s name.

### *Click Time*

Mean click time represents the average amount of time elapsed between selections of any on-screen buttons, including navigation control buttons, and candidate names. This is an indication of the amount of time needed to move the cursor to the desired button. Like navigation controls of the onscreen keyboard for the write-in race, the 2-button device was expected to yield a higher mean click time due to its unidirectional character that required participants to cycle through the bottom of the screen to return the cursor to the navigation controls at the top of the screen. However, repeated measures ANOVA indicated that there was no significant difference in mean click time among the three input devices,  $F(2, 28) = 0.22$ ,  $p = 0.81$ ,  $\eta_p^2 = 0.015$ , power = 0.08.

### *Response Time*

A third measure of navigation speed was the average amount of time elapsed between the onset of a race (i.e., when the list of candidates appeared) and the participant's selection of a candidate. This response time was normalized by the target candidate's location in the list. There was no significant difference among mean normalized response time for the three input devices,  $F(2,28) = 0.21$ ,  $p = 0.81$ ,  $\eta_p^2 = 0.015$ , power= 0.08. This implies that once participants reach the candidates list, they really only need to use the advance tactile button and the select button to reach the candidates name, which requires only a 2-button device. The additional tactile back button is useful when the user makes a mistake and overshoots or when the user wants to navigate to the on-screen "next" button by moving backward instead of forward through the candidate list, which sometimes reduces button presses.



## Eye Tracker Results

### Controls Gaze Time

Participants were expected to look at the onscreen navigation controls less for the 5-button device than the other two devices (H4), because they could use the two tactile buttons for page-forward and page-backward instead of the onscreen buttons. Controls gaze time refers to the amount of time participants spent looking at the on-screen navigation control buttons at the top of the ballot (i.e., the on-screen back, help, review and next buttons). An average was computed across the pages of each ballot. Repeated measures ANOVA revealed that there was no significant difference in mean time spent looking at the control buttons among the three devices,  $F(2,12) = 0.871$ ,  $p = 0.443$ ,  $\eta_p^2 = 0.127$ , power = 0.166, although the pattern of means was in the expected direction (Figure 13). The pattern is consistent with the hypothesis that the 5-button device does not require as much gaze time on the on-screen navigation controls.

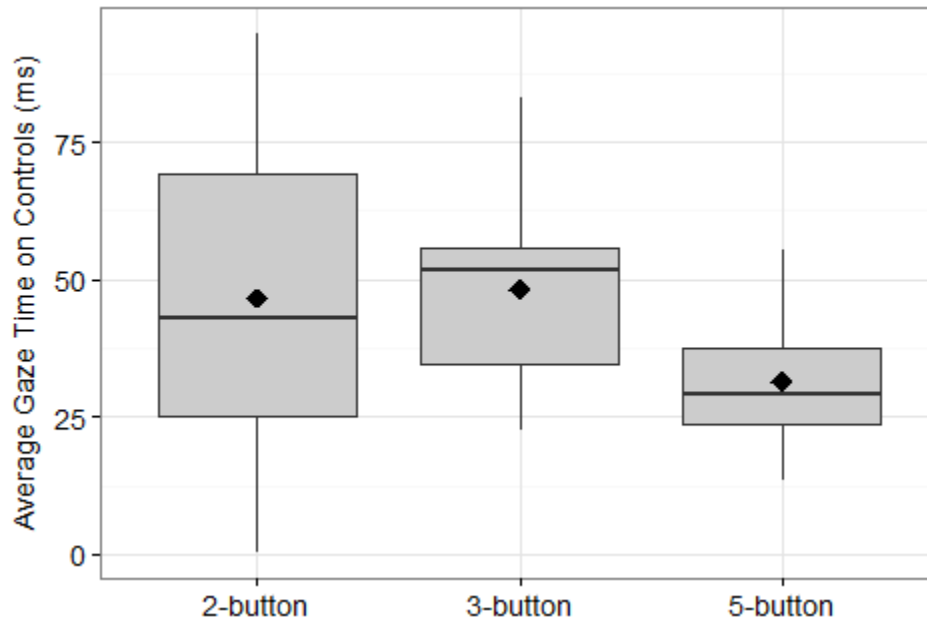


Figure 13. Mean time per page spent looking at the on-screen control buttons.

### Candidates Gaze Time

Candidates gaze time refers to the amount of time participants spent looking at all candidate options on the ballot. An average was computed across all races with each ballot. Repeated measures ANOVA revealed that there was no significant difference in mean time spent looking at the selections among the input device types,  $F(2,12) = 2.327$ ,  $p = 0.14$ ,  $\eta_p^2 = 0.279$ , power = 0.381. However, there was an overall pattern that the candidate gaze time for the 2-button was longer than the 3-button and 5-button devices (Figure 14).

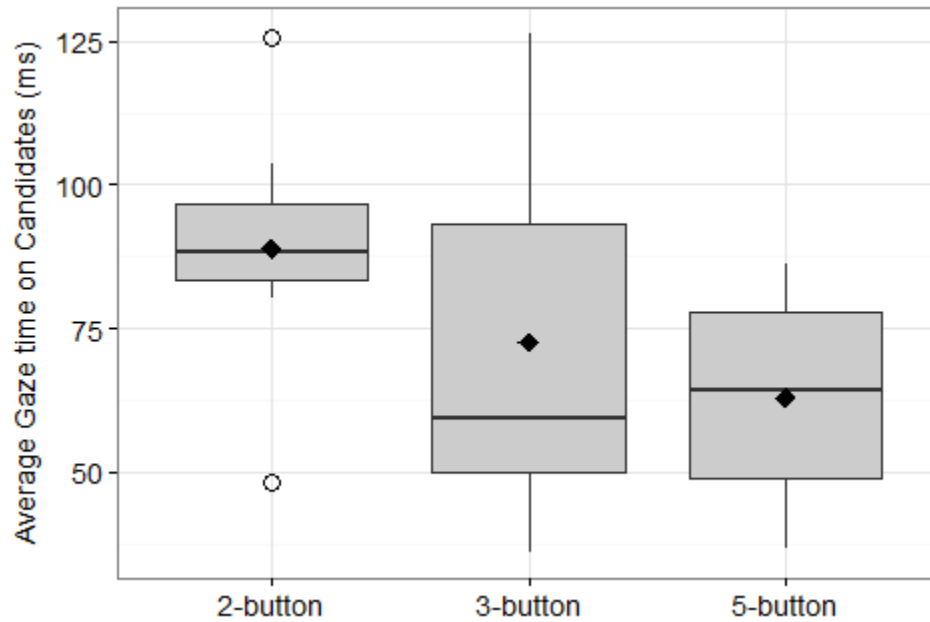


Figure 14. Mean time per race spent looking at all candidates.

### Target Candidate Gaze Time

Target candidate gaze time refers to the amount of time participants spent looking at the target candidate. Times were averaged across all races for each ballot. Repeated measures ANOVA revealed that there was no significant difference in the mean time spent looking at the target candidate among the input devices,  $F(2,12) = 0.742$ ,  $p = 0.497$ ,  $\eta_p^2 = 0.11$ , power = 0.147.

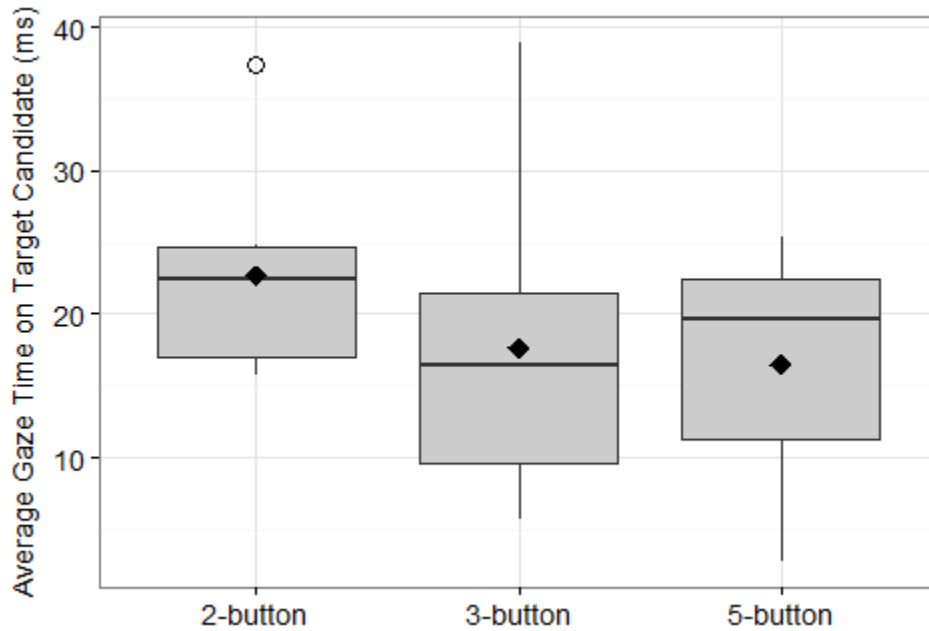


Figure 15. Mean time per race spent looking at target candidate.

## Practice Effects

Participants were expected to improve their skills over time during the experimental session. Specifically, the order in which participants used the input devices was expected to affect task completion time and subjective rankings of ease-of-use (H5). Participants were expected to get progressively faster and more satisfied (higher ranking) over time. The primary measure of voting time, average race time, was used in this analysis.

Note that the order in which the input devices were used was counterbalanced across participants, so order of use could not favor any of the three input devices when averaging across participants. Due to counterbalancing of order, the analyses and figure below have no bearing on differences between the 2-button, 3-button, and 5-button devices. Instead, they examine the effect of practice on race time and subjective rankings.

Figure 16 shows the relationship among average race time (y-axis), rankings of the input devices (x-axis), and order of use (dot color/shape). As expected, the effect of order of use on ranking was significant,  $F(2,28) = 6.72, p = .004, \eta_p^2 = .324$ , indicating that rankings were higher for devices that were used later in the session. This is illustrated in the figure by the distribution of red points (first-used device) and blue points (third-used device). The first-used device was ranked highest by only one participant (the single red circle in the right-most group of points), and the third-used device was often ranked best.

Also as expected, the effect of order of use on average race time was significant; there was a negative correlation between order of use and average race time, indicating that participants became progressively faster<sup>1</sup>,  $t(42) = 2.47, p = .017, r = -.357$ .

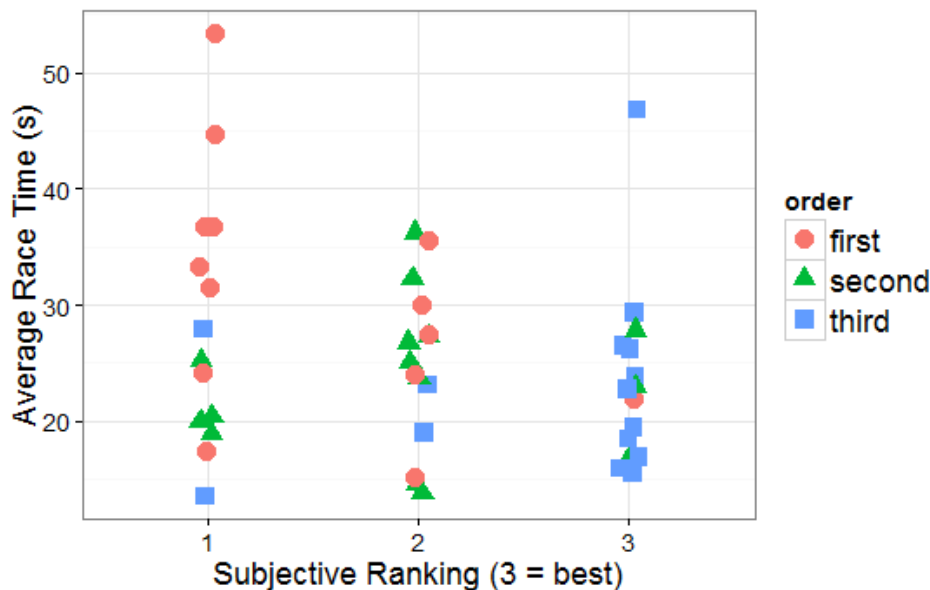


Figure 16. Race time as a function of device preference and order of use. Best fit line excludes the outlier from Figure 10, which is not shown in this figure.

<sup>1</sup> One outlier was omitted. It was 4.7 standard deviations above the mean race time.

## Discussion

This study was designed to determine which of the three voting input devices was the best candidate for older adult users with arthritis in their wrists, hands, and fingers. Several of the variables showed trends that might indicate that the 5-button device was the best, these variables included, race time, write-in time, and pain ratings. However, usability ratings, device rankings, and user comments did not support the conclusion that the 5-button device was the best. Researcher observations and subjective reports by participants indicated that the 5-button device was confusing to some participants, and some participants did not take advantage of the two navigation control tactile buttons (page-forward and page-backward).

Participants in this study did not report that their arthritis symptoms caused excessive pain while using the input devices or prevented them from completing any tasks. An effect of input device on pain was not obtained, so there was no evidence to support the hypothesis that the 2-button device would cause more pain.

Some users experienced difficulty due to cognitive issues associated with the additional buttons on the 3-button and 5-button devices. Many of the participants in this study had difficulty deciding which button to press on the 5-button device, and they reported being confused by the buttons. This replicates and extends the findings of Harada et al. (2010) who found that older adults learned to use a smartphone-like application more easily when decision points were removed. It is also consistent with the Hick-Hyman law, which states that response time is dependent upon the complexity of the decision (Wickens, 2004).

Some of the older adults in this study may have been experiencing cognitive deficits associated with age-related cognitive decline (i.e., reduced working memory capacity, difficulty acquiring new skills or learning new procedures). This may partially explain why some participants had considerable difficulty with the input devices – particularly the 5-button device. During an exit interview, participants expressed their confusion in understanding the additional functions of the 5-button device, and in fact four of the participants used the 5-button device exactly the same as if it was the 3-button device (i.e., they did not use the additional two buttons for navigating between pages). Many participants used only two buttons on the 3-button device, or used two or three buttons on the 5-button device, which could account for the lack of significant differences between the input devices.

It was surprising that no statistically significant differences emerged between the 2-button and 3-button devices. The 2-button device's simplicity, which was preferred by some users, might have outweighed the benefits of having another button that moved the cursor backward on the 3-button device. All five of the participants who ranked the 2-button device as their favorite indicated that their rankings were based on the 2-button device's simplicity. This preference for simplicity might not generalize to younger populations.

There was an overall trend that indicated that task completion times were faster for the 3-button than the 2-button, although the differences were not statistically significant. The added benefit of having the

tactile back button for instances when the participant overshoots the target may outweigh the cost of including such an option.

The lack of statistical significance in many of the analyses may have been due to low statistical power, which was caused by the small sample size and small effect sizes. Power did not exceed 0.4 for any of the non-significant analyses – less than half of the typically desired power of 0.8.

Overall, the results revealed design tradeoffs. Trends in subjective pain reports and voting times suggested that the 3-button and 5-button devices were more efficient. In contrast, many participants reported a preference for the 2-button device due to its simplicity. The recommendation is to proceed with a 3-button device in future studies, because it represents a compromise between the simplicity of the 2-button device and efficiency of the 5-button device.

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