

# Impact of Motor Impairment on Full-Screen Touch Interaction

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## Abstract

Although an increasing number of new assistive technologies are being designed for use with touchscreen systems, such as Android or iOS tablets, many users of assistive technology may have upper limb motor impairments (e.g. tremors, spasms, or reduced mobility) that make using standard touchscreen technology difficult and frustrating. This work explores alternative approaches to the standard “lift-move-touch” interaction sequence on current touchscreens. To help improve the accessibility of touchscreen technologies, we studied the movement patterns of 15 individuals with progressive neurological disorders and upper limb motor impairments. This paper presents the quantitative results of our study, observations of functional compensation patterns, and the personal feedback from study participants. The results of this work are an evidence-based roadmap towards more personalized and adaptive touchscreen interfaces, especially for users of assistive technology.

## Keywords

Compensation, interaction, mobility, movement, tablets, touchscreens

## Introduction

Touchscreen technologies have rapidly increased in sensitivity and availability over the last decade. Most modern mobile devices are touchscreen systems that support multiple simultaneous touches and gestural interactions. The accessibility of these devices, however, has not kept pace with the general technological improvements. Accessibility features for people with upper limb motor impairments, in particular, are often limited to switch control, stored gestures, and adjustment of click timing. Users are often programmatically prohibited from toggling or adjusting sliding functionality. Users are also prevented from modifying the location, size, shape, and orientation of many buttons and toolbars.

It is difficult to quantify the touchscreen usage patterns, needs, and behavioral compensation of people with upper limb motor impairments because of the diversity of the population and available devices; however, there is a growing body of research in this area. Button sizes and spacing effects in layout-specific selection tasks have been compared between users with and without motor impairments (Chen et al), and researchers have obtained basic usage patterns through surveys (Kane et al) or by watching online videos (Anthony, Kim, and Findlater). Related work has demonstrated the potential advantages of swabbing (i.e. sliding) as a selection technique (Wacharamanotham et al) and explored the effects of form factor on pointing tasks (Gilliot, Casiez, and Roussel). No study to date, however, has examined the combined effects of handedness and motor impairment on full-screen touch interactions. In this paper, we present the results of a controlled study comparing the touch behavior of left-handed and right-handed subjects with upper limb motor impairments as they performed full-screen tapping and sliding tasks.

### *Approach*

We conducted a motor skills assessment study in which participants were asked to play a touchscreen game, called “MoGUI” (Motor Optimization Graphical User Interface), that involved popping animated balloons by touching them. We recruited 15 adults (10 females and 5 males) from The Boston Home, a residential facility for people with progressive neurological diseases, especially multiple sclerosis (MS), multiple system atrophy (MSA), and muscular dystrophy (MD). All participants used wheelchairs and had some level of speech and motor impairment. Participants were screened by a speech-language pathologist (SLP) to verify that they had adequate hearing, vision, and cognitive abilities to fully consent and complete the tasks. The SLP also categorized their impairments and verified that all participants could interact with a touchscreen computer using their fingers, hands, or a stylus. They had a combined average age of 56 years, with a minimum of 35 and a maximum of 71. Seven of the participants were left-handed: four naturally and three due to MS. The remaining participants were right-handed.

The tablet computer used in the study was an Asus Transformer TF101 with a 10.1-inch diagonal display size at 1280x764 pixel resolution, running Android 4.4.2 with default settings. All participants were familiar with touchscreen tablets, but only 8 of them used one on a regular basis. Of these 8 participants, 7 used iPads and 1 used a Kindle. Although 6 of the participants indicated that they wanted to use a stylus, 4 of these participants had difficulties opening their fingers and requested that the stylus be placed in their hands. For these participants, the stylus served to separate their hands from the screen to prevent accidental touches from the non-pointing portions of their hands, such as their palms or knuckles.

When prompted for the most comfortable position to place the tablet, such that they could physically touch all areas of the screen, 9 users requested that the tablet be placed on a table in

front of them at approximately a 45-degree angle. One participant asked for the tablet to be placed flat on the table. Two participants regularly used their tablets with wheelchair desk-mounts and requested that the study tablet be positioned in the same way. Two other participants requested that the tablet be placed in their laps; one of these participants requested that the tablet lie flat and the other requested that it be propped towards him with a rolled up towel. The last participant held the tablet against her body with one arm and used her other arm for interaction.

Each participant provided data during two sessions, separated by at least one full day of rest. Each session was approximately 30 - 45 minutes long and consisted of 10 levels, with 3 rounds per level. During each round, a series of balloon-shaped targets were displayed, labeled with consecutive numbers (Figure 1). One balloon was shown for each round during level one, two balloons were shown for each round during level two, three balloons during level three, etc. Thus, each session required a participant to touch 165 targets. Users were asked to touch each target balloon in ascending numerical order. Target balloons were 256x256 pixels in size and were randomly generated in one of 16 locations on the screen using a 4x4 grid. As soon as a balloon target was touched, it popped and disappeared from the screen; balloons touched out of order did not pop.



Fig. 1. Example Screenshot of MoGUI

In one of the two order-balanced sessions, participants were asked to use discrete movements (i.e. tapping or pointing) and avoid touching the screen except to hit a target. In the other session, participants were asked to use continuous motion (i.e. sliding or goal-crossing) and avoid disconnecting from the screen as much as possible. Users were offered a stylus, but were also allowed to use their fingers. Users were encouraged to hit all targets as quickly as possible, but also to rest whenever necessary.

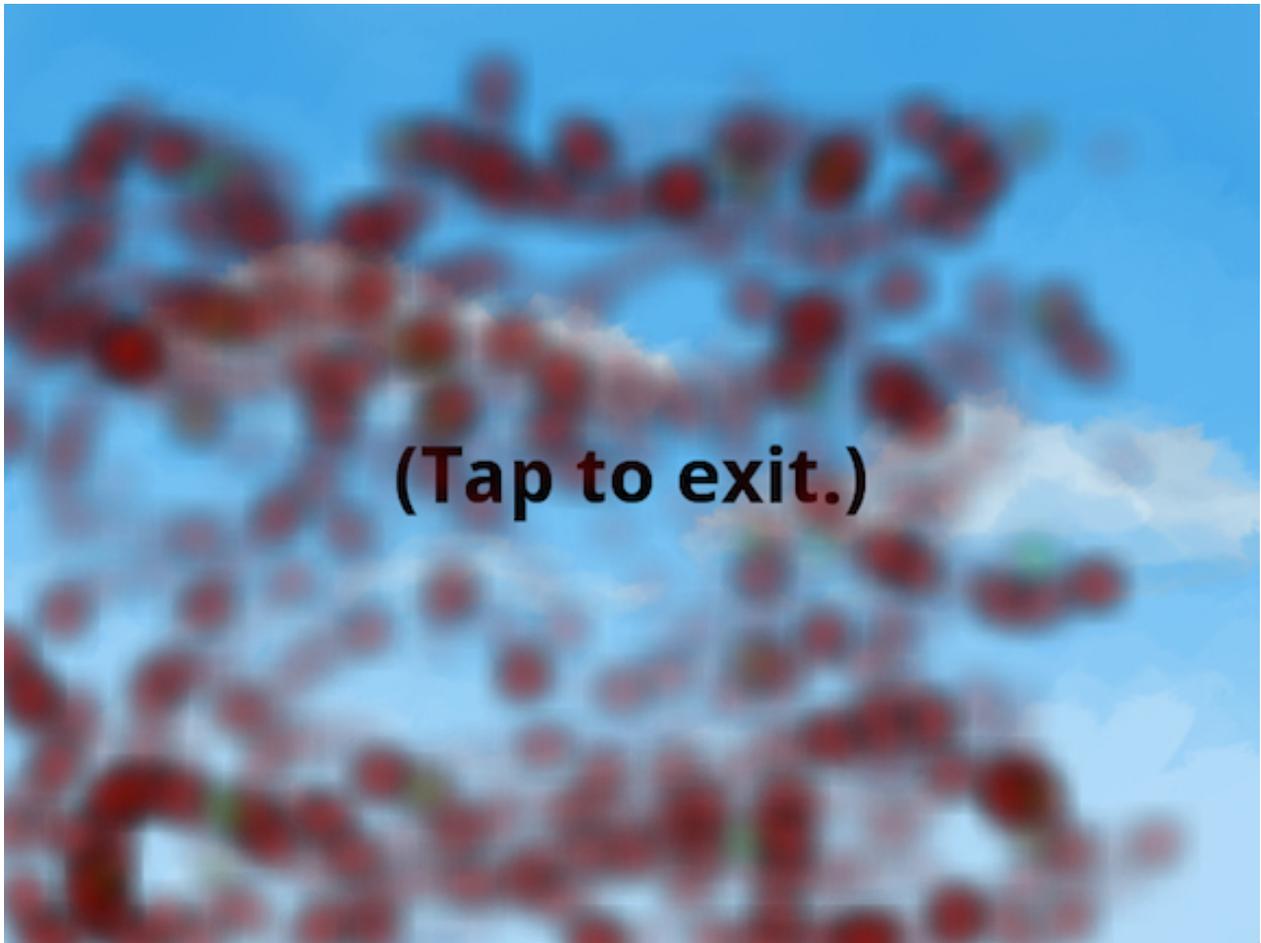


Fig. 2. Example Interaction Heatmap Generated by MoGUI

All interactions with the touchscreen were recorded by the system, including the *on\_touch\_down*, *on\_touch\_up*, and *on\_touch\_move* events. After both sessions were completed, study participants were asked the following questions:

- Did you find any areas of the screen easier or more difficult to reach than others?
- Did you prefer tapping, sliding, a combination of both, or neither?
- Were the balloon targets too big or too small?
- What would you like to see improved in touchscreen tablets?

For the severely dysarthric and non-speaking participants, the questions were rephrased as multiple “yes or no” questions and combined with pointing:

- Was this area of the screen easy for you to reach?
- Was this area of the screen difficult for you to reach?
- Did you like tapping?
- Did you like sliding?
- Would you like to use a combination of tapping and sliding?
- Were the balloons too big?
- Were the balloons too small?
- Would you like to use a touchscreen tablet in the future?
- Would touchscreen tablets need to be changed before you could use them?

Study participants were also shown the resulting “heat maps” generated by MoGUI (Figure 2), depicting their touch interactions with the screen during each session.

### *Results*

We observed high variability in motor profiles between participants, especially with regard to which locations on the screen had the highest accuracy or fewest misses (Figures 3, 4, 5,

and 6) and which areas were fastest or easiest to reach (Figures 7 and 8). There were also significant differences between left-handed and right-handed participants; however, it is important to remember that 3 of the 7 left-handed participants were right-handed prior to the onset of MS. For left-handed participants, there were numerous accidental touches, often from other fingers or knuckles, on both the bottom and left sides of the screen (Figure 9); for right-handed participants, these accidental touches occurred on the bottom and right sides of the screen (Figure 10). The average speed-to-target of left-handed participants was 365 pixels per second compared to 429 pixels per second for right-handed participants. For each handedness, there were significant time delays when reaching for targets on the far side of the screen: there was approximately a one second difference, on average, between touching targets on the nearest versus the farthest side of the screen.

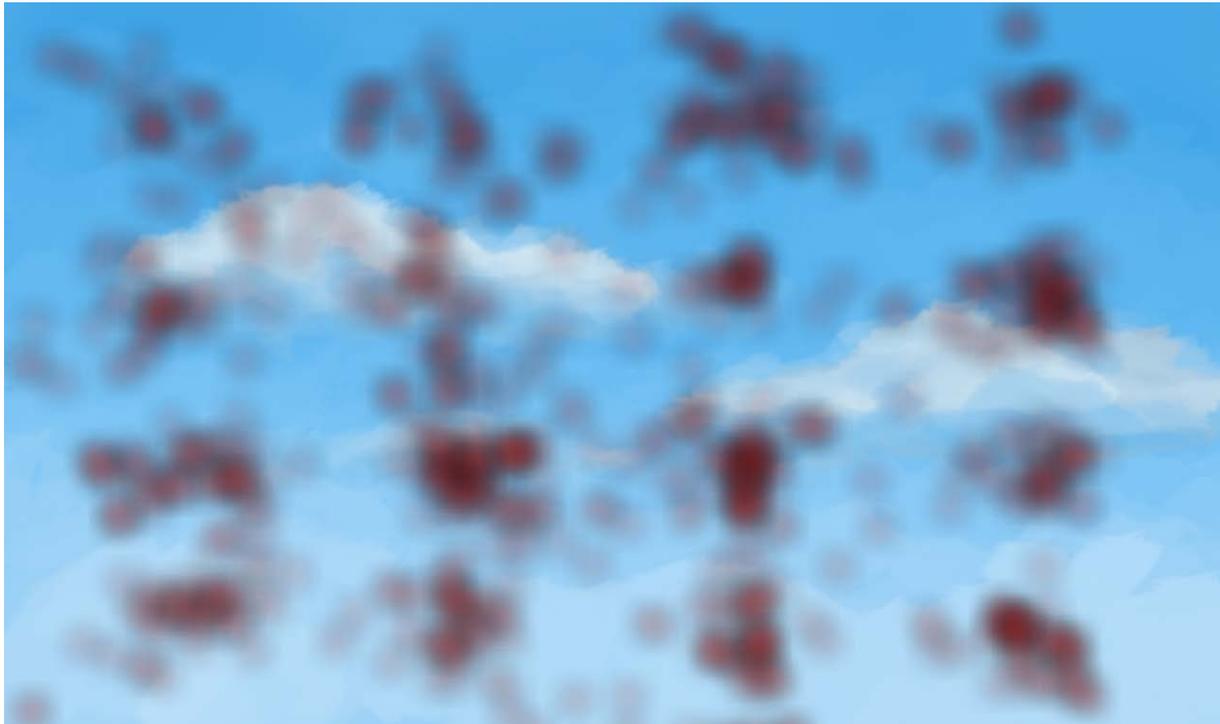


Fig. 3. User Variability with Multiple Taps.



Fig. 4. User Variability with Finger Dragging.

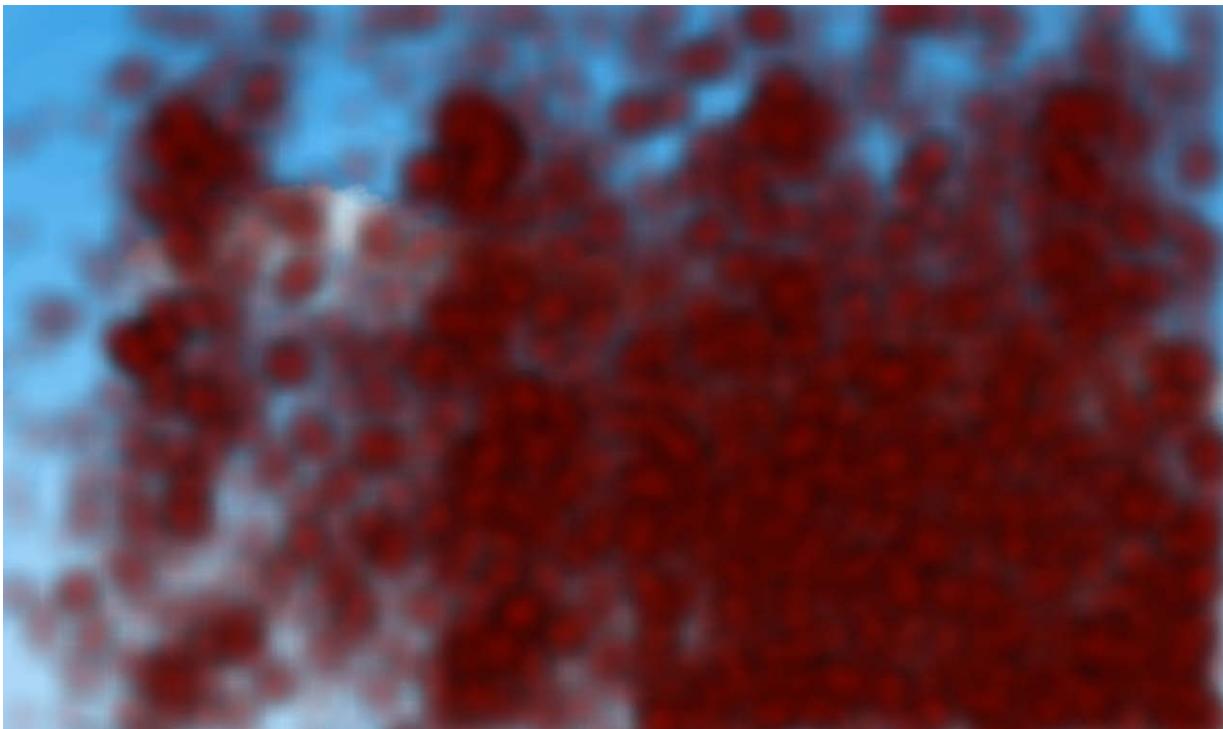


Fig. 5. User Variability with Hand Resting.

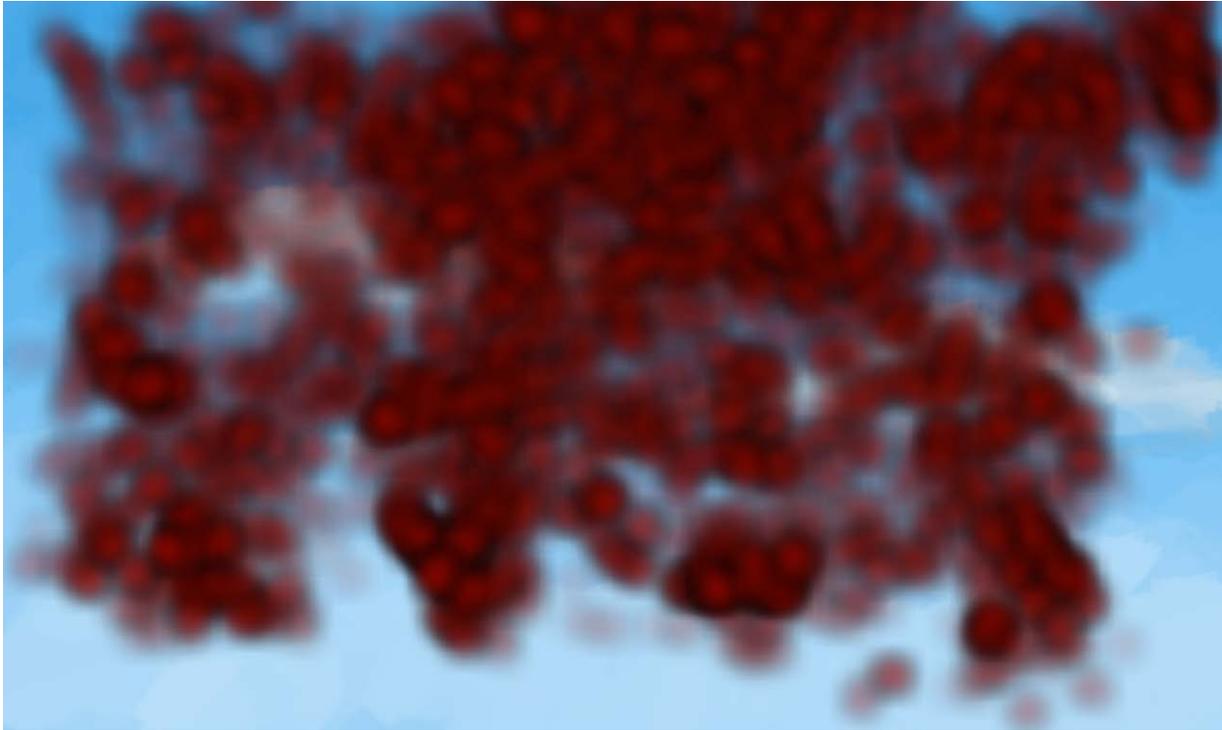


Fig. 6. User Variability with Thumb Usage.

382	285	343	348
372	317	302	359
374	300	388	371
395	395	557	412

Fig. 7. Mean Speeds-to-Target of Left-Handed Users (Pixels/Second).



Fig. 8. Mean Speeds-to-Target of Right-Handed Users (Pixels/Second).

There were also significant differences in the average directional speeds for each handedness: for left-handed users, moving down and to the left was approximately 1.5 times faster than moving up and to the right (Figure 11); for right-handed users, moving down and to the right was almost 4 times faster than moving up and to the left (Figure 12). In general, participants were much faster when returning their hands and arms to a natural resting position than when moving away from that resting position.

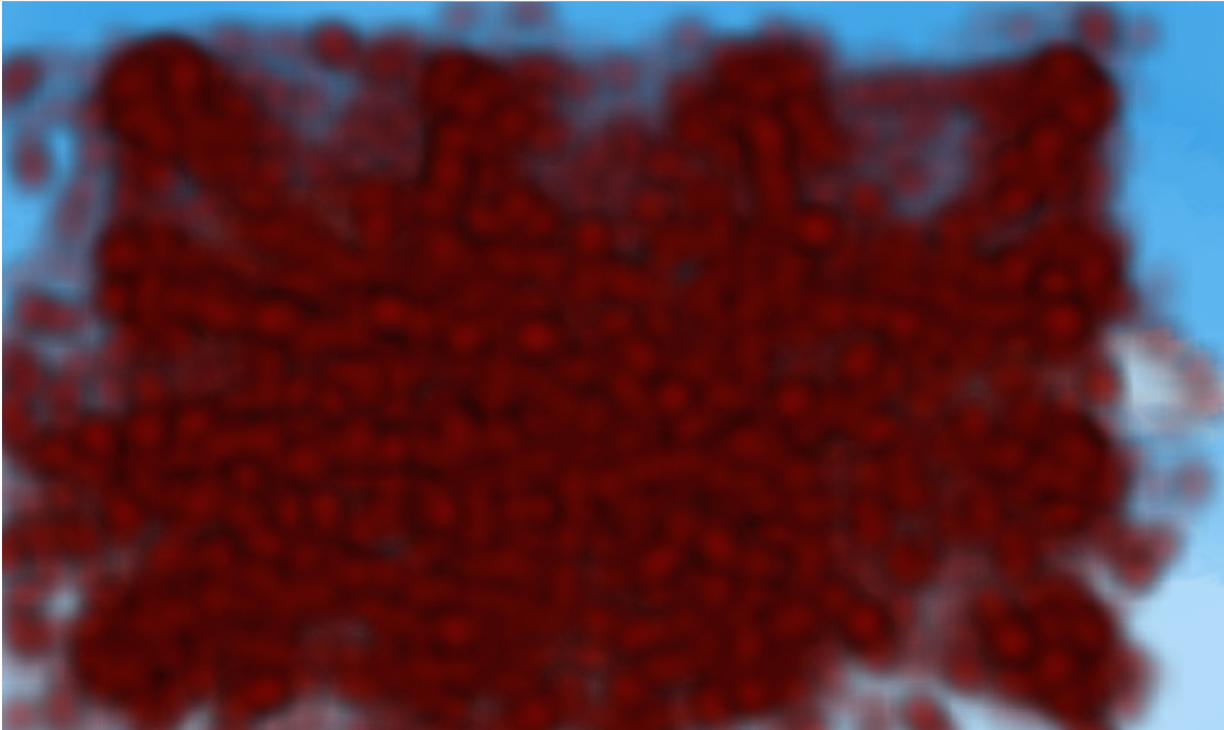


Fig. 9. Non-Target Touches by Left-Handed Users.

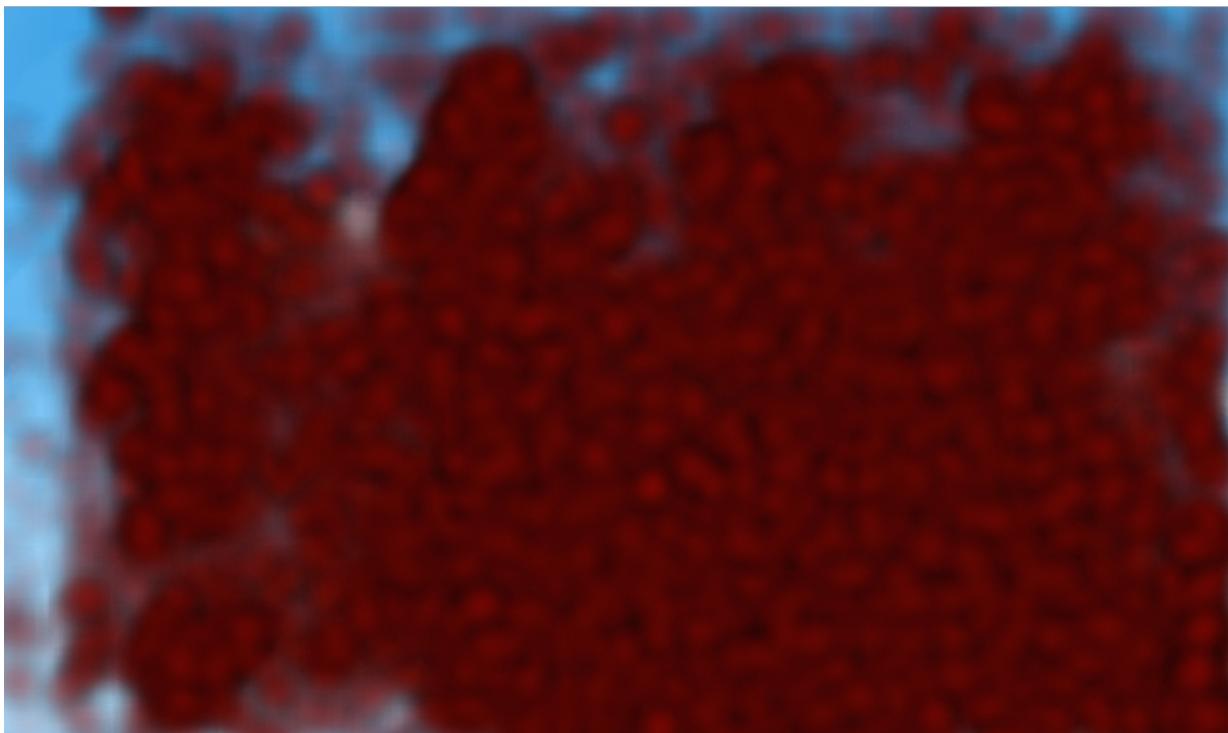


Fig. 10. Non-Target Touches by Right-Handed Users.

There were speed differences between discrete movements and continuous motion in this study, regardless of participant handedness; however, they were not significant. The average speed-to-target of all participants while sliding was 407 pixels per second compared to 392 pixels per second while tapping. It is important to note, however, that we saw numerous accidental slides during designated tapping sessions, and vice versa. During designated tapping sessions, the average participant tapped 84% of the targets and slid into 16% of the targets; during designed sliding sessions, the average participant slid into 57% of the targets and tapped the remaining 43%. This behavior appeared to be caused by physical issues rather than confusion: we observed problems with friction, finger humidity, tremors, and spasms.

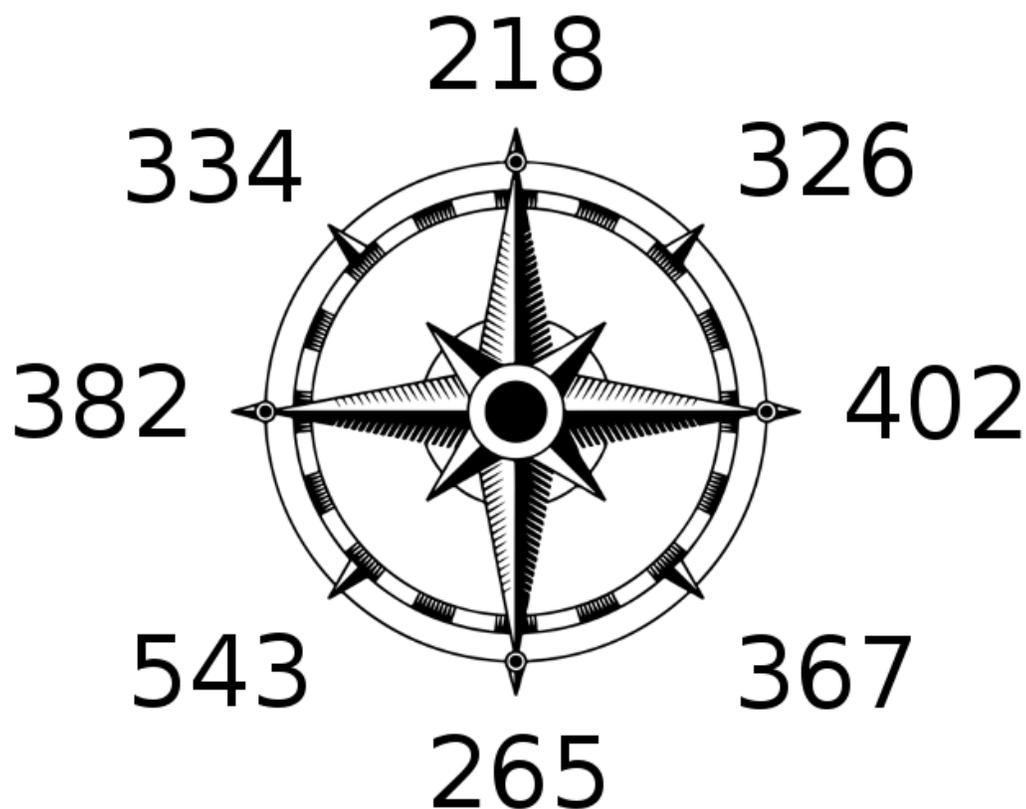


Fig. 11. Mean Directional Speeds by Left-Handed Users (Pixels/Second).

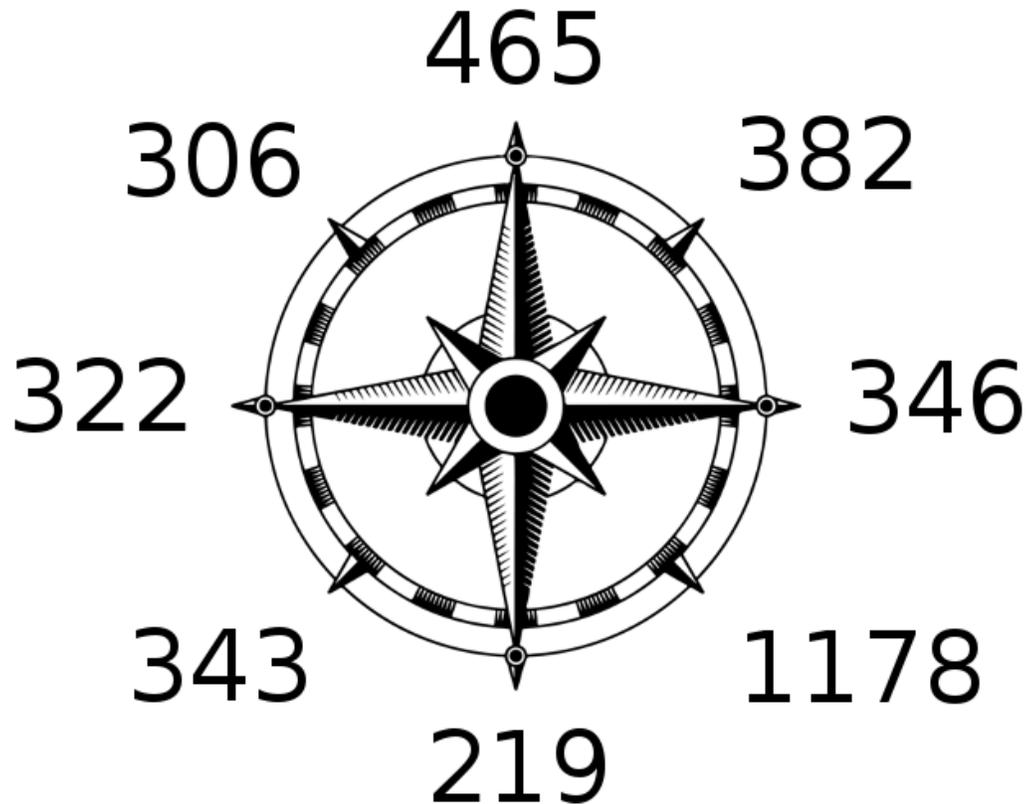


Fig. 12. Mean Directional Speeds by Right-Handed Users (Pixels/Second).

## Discussion

At the end of the study, 3 participants said that they preferred tapping the screen, 5 participants preferring sliding over the screen, 5 participants preferred a combination of both input methods, and the remaining 2 participants had no preference. Ten participants mentioned that sliding required planning out a path ahead of time and required lifting your hand or arm to see the screen. Out of all the participants, 8 pointed out that sliding felt “faster” and “easier,” but only for short distances. Over longer distances, participants said that there problems with skin friction and difficulties with stylus pressure. Additionally, this study involved arbitrary targets in random locations, which is fundamentally different than a user interface that is primarily static and can be learned over time.

One participant alternated hands numerous times during the experiment and explained that interacting with a touchscreen required him to use his shoulder muscles, which fatigued rapidly. Another participant rested frequently (approximately 1 of every 5 minutes), but explained that it was because of his eyes, not due to upper limb fatigue. For this individual, focusing his vision to read numbers and moving his eyes to search for items on the screen was extremely tiring.

Certain areas of the screen were especially susceptible to accidental touches. In particular, the Android Action Bar, statically bound to the bottom of the screen, caused significant issues for 8 participants and resulted in repeated triggering of Google Now or window management functionality. Rather than starting their finger or stylus at the physical margin of the tablet and moving upwards, as they attempted to do naturally, participants were forced to try to control their arms enough to touch the middle of the screen and move downwards. Although there were similar problems when participants tried interacting with the top of the screen, these problems were observed less frequently.

We observed a number of unusual hand positions. One participant was a former athlete; because of his larger physical size and musculature, tremors and spasms were especially severe in his upper limbs. For this participant, the tablet was placed on a table immediately in front of him, tilted at a 45-degree angle. The participant rested his entire hand on top of the tablet, and used his thumb to touch the screen; this interaction method made it very difficult to the participant to touch items at the bottom edge and lower corners of the screen. To reach these items, the participant needed to push the tablet farther away and rest his hand on the table, then try to raise his fingers upwards. This movement often resulted in hitting the Android Action Bar

instead of the targets, activating Google Now functionality or switching between available windows.

Another participant requested that the tablet be placed in her lap, but not propped up and tilted towards her. Instead, the tablet rested on her thighs and occasionally shifted in angle to tilt slightly away from her, triggering the auto-rotate functionality and flipping the screen upside-down. This participant indicated that the position was how she normally interacted with her iPad, so auto-rotate was disabled in order to support her preferences.

Anecdotally, two participants mentioned that they would appreciate more confirmation dialogs on their tablets. Due to tremors and spasms, they said that they often activate a feature or perform an action by accident. They acknowledged that non-disabled users would probably find such repeated confirmation dialogs very annoying, but they would be invaluable for users with motor impairments.

One of the non-speaking participants used a letter-based Alternative and Augmentative Communication (AAC) system that primarily consisted of a QWERTY keyboard with word prediction. During the consent process with this participant, we made several observations about how he used his system. Because of severe motor impairments, this participant often made multiple accidental taps on each letter. He also missed the screen occasionally, perhaps due to vision impairments, when attempting to touch a button, resulting in omitted characters. This individual also rarely used the space bar to separate words, perhaps to increase communication speed, and never used the Text-to-Speech (TTS) functionality. Instead, conversation partners looked over his shoulder at the tablet screen and watched for confirmation while trying to guess his intended utterances.

## Conclusions

Current accessibility techniques group users with motor impairments together and assume uniform interaction over the entire touch surface. It is understood that users with motor impairments have different touchscreen behavior than non-disabled users; however, there is further diversity within the population of users with motor impairments. Our results show that functional compensation and attributes such as handedness have significant effects within this population.

For right-handed users, both the upper left and lower right corners of the screen required significantly more time and effort to reach; for left-handed users, this difficulty was associated with the upper right and lower left corners of the screen. Additionally, all study participants had significant amounts of unintentional interaction near the edges of the screen closest to their primary hand: for right-handed users, these were the right and bottom edges of the screen; for left-handed users, these were the left and bottom edges of the screen. Unfortunately, current touchscreen interfaces have essential system functionality located in almost all of these areas, especially the top and bottom edges of the screen. Because these system functions are often activated by sliding gestures, our results show that they are easily triggered by users with motor impairments.

Simply shifting the positioning of the tablet relative to the user is probably insufficient: users would be unable to reach all parts of the screen. Although our results could suggest that the study tablet was too large, users may benefit from a “safety margin” around their particular device, or on configurable sides, to mitigate accidental touches. System functionality should also be customizable: statically binding behavior to the top or bottom of the screen can be problematic for many users.

There appeared to be an optimal movement area for each user, strongly correlated to both handedness and tablet positioning. For most users, the shape of this area was an arc, approximately 3 - 4 inches wide, that could be found by fixating the user's elbow and rotating his or her hand across the screen. We observed reduced performance when attempting to hit targets outside of this arc, possibly because our study participants all used wheelchairs and positioned their elbows on the arm rests. Hitting targets outside of these areas required users to depart from a comfortable, homeostatic position in order to lift their elbows off of the chair.

There may be tangible advantages to departing from grid-based button positions and statically located system functionality, especially for users with upper-limb motor impairments. For optimal performance, or even acceptable performance in many cases, touchscreen interfaces may benefit by allowing users to relocate buttons away from the screen edges and closer to optimal touch areas. Users should also be allowed to toggle or relocate sliding and swiping gestures, especially for essential system functionality. Finally, the results of our study suggest that sliding to arbitrary targets is not significantly faster than tapping; however, users with motor impairments may benefit from systems that are able to combine the benefits of both movement styles, especially given that many users encounter difficulties when restricted to only one interaction technique.

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