Mobile Handedness Equality: Investigating the Speed and Accuracy of Left-Handed Users

Anthony Venditti, Christina Mazza, Krupali Patel, and Vignesh Rajapandi
Dept. of Electrical Engineering and Computer Science
York University
Toronto, Ontario, Canada M3J 1P3
ajv11@my.yorku.ca, cmazza@my.yorku.ca, kp20@my.yorku.ca, vig012@my.yorku.ca

ABSTRACT
The aim of this user study was to examine the possible differences between a default mobile user interface (UI) and a newly developed left-handed layout, in regard to speed and accuracy. Our team utilized Android Studio to create an application that allowed users to swap between two layout options: left and right. The application reflected similarity to the popular Whack-a-Mole game, where dots appeared on the screen one at a time, specifically shifted to the side corresponding to the user's selection. Our team conducted a study consisting of 8 participants, 4 right-handed and 4 left-handed, in order to grasp a better understanding of how handedness plays a role in mobile user experience. The application collected certain data that was relevant for analysis, such as the score and time taken per dot. This study found that, although hand dominance affects performance on mobile, there is simply not enough sufficient data to prove it is a direct result of mobile UI layouts.

Keywords
mobile UI, usability, performance, battery usage, handedness, android studio, user testing

INTRODUCTION
Mobile computing and mobile user interfaces (UI) are a crucial part of our everyday lives and impact the way in which we communicate and interact with machines, as well as one another. These devices' usability, performance, and battery usage all play a key role in how we experience their features. In order for a mobile UI to be effective, while also ensuring efficiency, these three aspects must be considered to the highest extent.

First, the usability of mobile applications should focus equally on its look and behavior as the way it feels. Every user is unique and thus each UI must aim to satisfy the vast majority of users. Their gestures, actions, and behaviors must all be considered in an appropriate manner to ensure the best experience. Is it easy to understand? Can users complete tasks with ease of use? Is the application capable of running on multiple devices? These are all questions to be considered when designing a mobile UI.

Secondly, the performance of a mobile UI is also an aspect that needs to be reviewed throughout the creation of a mobile application. Performance can be broken down into three primary indexes in order to measure its sufficiency: response time, throughput, and utilization. The response time entails the end-to-end speed in which the system takes to complete a task. The slower a system, the less likely users will remain patient and may eventually move on to a different software due to frustration. Next, throughput refers to the number of requests that the system can complete per unit of a specified time. If a mobile application cannot handle large amounts of data being requested within a small period of time, then it is likely that the user will experience buffering and extensive wait times. Along with these two indexes is utilization, which is known as the percentage of time that a part of the system is busy processing some sort of data request. Improving the utilization of a system is key for nerfing the wait times that users experience while attempting to load certain parts of the application.

Last but not least, battery usage is a crucial detail that sometimes becomes forgotten while designing a mobile UI. For an application to be effective, programmers evidently need to include a substantial amount of data in order to develop advanced features that outclass the competition. However, the ability of an app to maintain efficient battery usage is equally as important as its performance and usability. Furthermore, background data capturing is undoubtedly the number one cause of rapid battery drain for mobile devices. Although it is a practical feature for users, it results in drainage of the device's battery even while they are not running the application. Notifications and data collection are also features that must be examined critically due to their negative impacts on battery life.

Overall, our team thoroughly studied the principles required in developing an effective and efficient mobile application UI. Mobile computing plays an extraordinary role in today's society that allows us to develop unique, practical, and simple to use applications. Upon determining a topic to focus on, we examined what steps are involved in creating a mobile UI that users would benefit from utilizing. These, of course, relate directly back to the relationships between mobile computing and usability, performance, and battery usage.

Topic
The subject that our team chose to explore is the disadvantageous impacts of being left-handed in regard to mobile UI interaction. Although only approximately

10% of the world's population is dominant with their left hand, it is still a significant factor that should be taken into account while designing mobile applications, as well as everyday objects in general. It is unjust to have users within this classification be at a disadvantage when it comes to handling certain UI aspects.

Since the majority of users do hold their mobile devices in their right hand, when using only one, and 49% utilize just their thumb, it is understandable as to why designers may target this when creating a UI. However, handedness must be considered as well since focusing solely on right-handed design placements may result in slight difficulty for those who are not. Reachability is an issue that has been solved by some mobile devices, such as swiping down near the bottom of the screen on an Apple device, allowing users to shift the screen's display downwards closer to their thumb. Now, despite the effectiveness of this, it does not entirely resolve the issue of left-handed reachability, since that mainly pertains to east vs west design positioning. By placing interactive elements in a certain "easy" zone, as displayed in **Figure 1**, it allows users to reach them with no efforts required, thus the usability is successful.

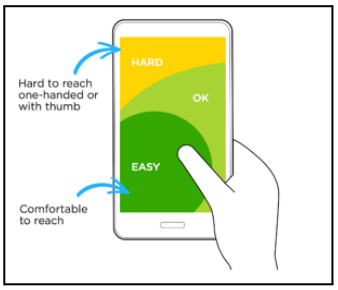

Figure 1. Diagram of reachability difficulty based on hand position. *Credit: Medium.com*

Note that, however, this diagram only emphasizes the ideal placements for right-handed users, so what about those using their left hand? We decided to focus on this topic in order to make an attempt at solving this unfair design problem, and the next part of the paper will describe in detail what our idea was regarding this matter.

Idea

The idea was to create a mobile application that allows users to pick between two different layouts, where each layout focuses on a specific hand placement. With this additional feature implemented, users who are dominant with their left hands are able to have an equal chance at using the application against users who are right-hand dominant. Testing methods were used to determine how the two layouts influence efficiency amongst right-hand users and left-hand users.

Related Works

Similar studies were done regarding the usability of mobile UI and left-hand usage.

A study done by Filip Norman Golles focuses on understanding how certain features on a mobile interface relate to the comfortability and efficiency when used by a left hand. This work's main focus was to implement design elements, specifically the position of menus and navigation on the device. Golles also identified the impact that the orientation has on the usage of the application. From there, the study identified the efficiency each navigation menu had in corresponding to either the left or right hand being used. From this study's post-surveys, Golles concluded that there was no explicit correlation between efficiency and the positioning of the navigation menu [3].

Another study was conducted by Hosam Al-Samarraie1 and Yusof Ahmad, who observed Interface Design Patterns (DP), which are used as mapping guidelines for interfaces. They performed various testing methods to observe the impact DPs have on users who are left- versus right-handed. This study concluded that there was a significant difference between left- and right-handed users and gathered some design patterns that are consistent with both groups of users [1].

Additionally, a study was done by the Faculty of Computer Science from Dalhousie University which focused on left-hand users using left and right-aligned scroll bars. Users were given various selection tasks to complete under four different studies. From there, it was concluded that there was a great advantage for left-hand users using the left-aligned scroll bar, through minimizing scrolling time [4].

Lastly, a study performed by Lucas Bengtson focused on understanding whether efficiency and usability are improved if there are different versions of an application for left and right-handed users. This was done through using an emulator device with a camera interface, and the user had to complete various tasks while a log kept track of relevant timestamps. From this study, Bengston concluded that there was no major difference when choosing hand-focused interfaces (interfaces specifically for left and right-handed users) [2].

All of the studies mentioned implementing different features to their mobile applications to understand how having left-handed interfaces could impact efficiency and other factors.

METHOD

The research involved data collection which collects information about the participants. The research also incorporated an experimental methodology. Each participant tested 2 independent variables with 2 levels each. The first condition was the right-handed layout tested using the right hand. The second condition was the right-handed layout tested with the left hand. The third condition was the left-handed layout being tested with the right hand. Finally, the last condition was the left-handed layout tested with the left hand. Additionally, the data collection was done in the app as users comb through the different conditions. The app then was used to extract the information, such as score and time taken to complete the task. The results were then displayed and analyzed using statistical testing tools.

Participants
This research study involved 8 participants; 4 of them being left-handed and the other 4 were right-handed. Additionally, they were all 14 years of age or older and familiar with using touchscreen phones or any devices with touch capabilities. They were all selected between friends and family of the researchers.

Hypothesis Statement
For the purposes of this study, accuracy is measured by how many dots the participant is able to tap divided by the total number of dots presented on the screen. Speed is measured as the average time the participant takes to tap a dot on the screen of a mobile device.
Null Hypothesis H_0: The use of the participant's dominant hand in conjunction with a layout that is designed for their dominant hand has no effect on the participant's accuracy and speed when reaching to tap dots on the screen of a mobile device.
Alternative Hypothesis H_A: The use of the participant's dominant hand in conjunction with a layout that is designed for their dominant hand will significantly increase the participant's accuracy and speed when reaching to tap dots on the screen of a mobile device.

Apparatus
The study was conducted using both an Android phone and tablet, with an app developed by our team. The key feature of the app that is central to our topic is the right and left-handed modes within the app. These modes can be switched between using a spinner button in the app's main menu, displayed in **Figure 2**.

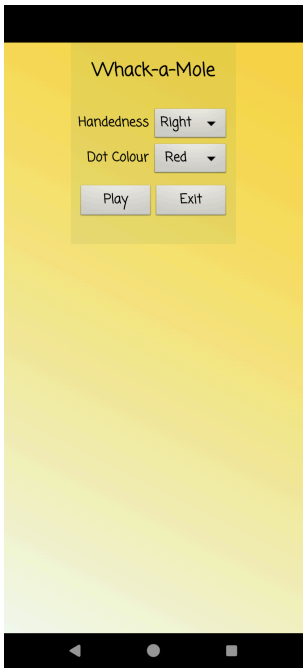

Figure 2. The main menu screen of our app.

The main activity features a game similar to Whack-a-Mole. Dots appear on the screen based on the currently selected mode and dot placement within these modes follow the diagram of reachability difficulty based on hand position (i.e. in right-handed mode dots appear within places easy to reach with the right hand and vice-versa for the left-handed mode), as per **Figure 3** and **Figure 4**.

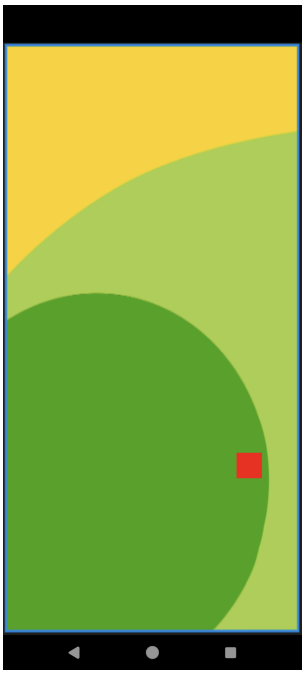

Figure 3. The layout of the app in right-handed mode.

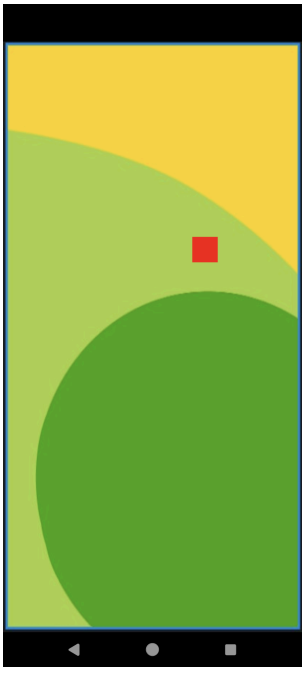

Figure 4. The layout of the app in left-handed mode.

The app also includes features that measure user performance. The app records the score, total time taken, time per dot, and dot accuracy. This data is stored on the device allowing it to be accessed for data analysis and displayed to the user upon completion, seen in **Figure 5**.

Figure 5. The results screen of our app.

Procedure
These are the steps we followed during each of the 8 testing sessions:

- Welcomed the participant.
- Explained the purpose of the study.
- Demonstrated the layout feature of the app to participants.
- Explained the game, its rules, and goals.

The order of the following steps varied since we used a balanced Latin Square to determine the order conditions will be tested in by each participant:

- Set the app to the right-handed mode.
- Asked them to use their right hand to play the game.
- Took a two-minute break.

- Set the app to the right-handed mode.
- Asked them to use their left hand to play the game.
- Took a two-minute break.

- Set the app to the left-handed mode.
- Asked them to use their right hand to play the game.
- Took a two-minute break.

- Set the app to the left-handed mode.
- Asked them to use their left hand to play the game.

After concluding these testing blocks, we:

- Thanked the participant for their time.
- Extracted the testing data for analysis.

Design
This was a within-subjects study. We tested two independent variables with two levels. Testing was balanced using a Latin Square that gave us two 4x4 blocks of testing. The first block was all right-handed participants and the second block was all left-handed. No participant in either block tested the conditions in the same order.

The independent variables of our study were the layout of the app, the hand used to play the game, and the handedness of the participant. There were 2 levels for the app layout, the left-handed layout and the right-handed layout. There were 2 levels for the hand used for the game, either the left or right hand. There were also 2 levels for the handedness of the participant, left-handed or right-handed.

The dependent variables were speed and accuracy. For speed, we measured the time taken per dot and the total time taken to complete the game. For accuracy, we measured the score and the dot accuracy, which was the participant's score divided by total dots. All this data was recorded by the app in the background while the participant was completing a trial and stored on the device for collection later.

There were 8 participants (4 left-handed and 4 right-handed), with 4 test conditions each. This meant that our total number of trials was 8 participants x 4 test conditions = 32 trials.

RESULTS AND DISCUSSION

The following subsections of the paper will discuss the thorough analysis that our team partook in, as well as the findings that we discovered upon conclusion. These results are discussed and examined in depth in order to further understand what they mean in terms of our alternative hypothesis. The data was collected and analyzed by our research team over the course of two weeks, which was made easy thanks to the statistics collected by our application.

Analysis
The analysis that was done was first obtained by gathering all results from the participants and comparing those results based on the different categories they would belong to. The results are distributed based on hand dominance and the hand used by participants. Afterwards, the means of each category's score, total time, time per dot, and dot accuracy were calculated. The two main categories of focus are the four left-handed participants and the four right-handed participants that are using their left hand since our alternative hypothesis states that lefty layouts would benefit participants using their left hand, especially compared to left-handed participants using the righty layout. We first conducted two ANOVA tests to determine the statistical significance of mode, hand used, and handedness on the accuracy and speed of participants during the reachability

ANOVA_table_for_Accuracy (Dots Clicked/Total Dots)

Effect	df	SS	MS	F	p
Handness	1	0.008	0.008	0.191	0.6777
Participant(group)	6	0.246	0.041		
Mode	1	0.011	0.011	0.753	0.4190
Mode_x_Handness	1	0.070	0.070	4.704	0.0732
Mode_x_P(group)	6	0.090	0.015		
Hand Used	1	0.003	0.003	0.439	0.5322
Hand Used_x_Handness	1	0.020	0.020	3.122	0.1277
Hand Used_x_P(group)	6	0.038	0.006		
Mode_x_Hand Used	1	0.038	0.038	1.733	0.2361
Mode_x_Hand Used_x_Handness	1	0.005	0.005	0.229	0.6491
Mode_x_Hand Used_x_P(group)	6	0.131	0.022		

ANOVA_table_for_Speed (Time Per Dots)

Effect	df	SS	MS	F	p
Handness	1	0.054	0.054	0.264	0.6258
Participant(group)	6	1.219	0.203		
Mode	1	0.114	0.114	1.041	0.3469
Mode_x_Handness	1	0.376	0.376	3.437	0.1132
Mode_x_P(group)	6	0.657	0.109		
Hand Used	1	0.060	0.060	0.968	0.3631
Hand Used_x_Handness	1	0.012	0.012	0.186	0.6810
Hand Used_x_P(group)	6	0.374	0.062		
Mode_x_Hand Used	1	0.197	0.197	1.434	0.2763
Mode_x_Hand Used_x_Handness	1	0.000	0.000	0.001	0.9744
Mode_x_Hand Used_x_P(group)	6	0.824	0.137		

Figure 6. ANOVA tables for our dependent variables (Accuracy and Speed).

test, as displayed in **Figure 6**. However, after further analysis, we found that the appropriate statistical test that is both quantitative and tests two groups based on comparison of means is the independent 2-sample T-test. Thus, this test was performed on the results from the four left-handed participants after obtaining the mean, standard deviation, and the number of samples for tests done using both hands individually, as demonstrated in **Figure 7**.

Test	P1 Score	P2 Score	P3 Score	P4 Score	Mean	Std Dev	Num of Samples
Left Hand / Left Layout	18	19	16	18	17.75	1.0897	4
Left Hand / Right Layout	15	18	14	11	14.5	2.5	4

Figure 7. Test results showing mean, standard deviation, and number of samples.

Next, The t-value was calculated using the formula:

$$t = \frac{\overline{X_A} - \overline{X_B}}{\sqrt{\frac{{S_A}^2}{\cap_A} + \frac{{S_B}^2}{\cap_B}}}$$

Figure 8. Formula for calculating t-value.

Where, in our case, resulted in:

$$t = \frac{17.75 - 14.5}{\sqrt{\frac{1.0897^2}{4} + \frac{2.5^2}{4}}}$$

Figure 9. Formula for calculating t-value after results were entered.

Which concluded that $t \approx 2.38$.

Afterwards, a T- distribution graph was conducted:

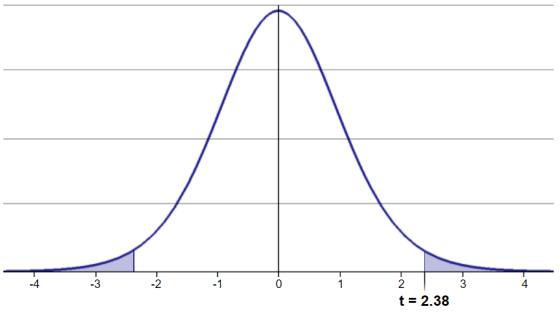

Figure 10. Two-tailed T-distribution graph for +/- 2.38.

Finally, the probability value, p, was calculated using the t-distribution function, which shows that:

$$p = (|t| \geq 2.38) \approx 0.097$$

Figure 11. Probability of t-value occurring.

Findings

During the initial stages of gathering and categorizing the data, we recognized that the group of results that needed to be prioritized would be those of users that were left-hand dominant and were using the left and right mode of the application. The more prominent fields were the score of the users, the total time taken to complete the game, the time taken per dot, and the dot accuracy.

The score of the user was calculated by getting the fraction of dots pressed on correctly by the user out of the total number of dots. For each test, a total of 20 dots would appear on the screen. For left-hand dominant users using the left mode, the average score was calculated to be 17.75 out of 20 dots. On the other hand, left-hand dominant users using the right mode got an average score of 14.5 out of 20 dots.

The total time taken to complete the game was 20.0 seconds for all tests run. This was a constant value within the data collected, as the total time that the dots would appear on the screen would be for 20.0 seconds. As a result, this value would be the same for all of the tests run, for left- and right-hand dominant users playing the game on both modes.

In terms of calculating the time per dot, this was derived from taking the total time and dividing it by the total dots that were correctly pressed by the user. If the user got a perfect score, the time per dot would be 1.0 second. From the data collected, for left-hand dominant users using both left and right mode, the average time

taken to correctly click on the button were 1.13 and 1.38 seconds, respectively.

Lastly, the dot accuracy is the score represented in a percentage format. Simply calculated by taking the user's score and dividing it by 20, then multiplying the decimal value by 100. This accuracy allows us to visually see a correlation between the different tests run, or any small differences that may not be as easily noticeable when only looking at the score. For left-handed users using the left and right mode, the dot accuracy values were 0.89% and 0.72% respectively.

Following these results, we calculated the mean, standard deviation (the number of samples was a constant value of four for all categories). For users that were left-hand dominant using left mode, their mean score was 17.75, and standard deviation was 1.089. On the other hand, for left-hand dominant users using right mode, their mean score was 14.5 and the standard deviation was 2.5. Once the means, standard deviations, and sample numbers were calculated, we used them as input values needed to perform the analysis. We found that using the formula for calculating the t-value, resulted in $t \approx 2.38$. This t-value further allowed us to form a T-distribution graph and calculate the probability value, p. The p value was calculated to 0.097. When comparing the p value to the level of significance, α, which has an assumed value of 0.05, we found that the p value is greater than the significance level ($p > 0.05$).

Discussion

The key findings were the means of each category's score, total time, time per dot, and dot accuracy. Based on these values, the minimal difference between the mean values and dot accuracy between the categories was unexpected. It was understood that this small difference would impact the results to conclude whether the hypothesis was rejected or accepted. This was further proven when calculating the p value. Due to the p value being greater than the significance level, it can be concluded that the null hypothesis is accepted and the alternative hypothesis is rejected. Based on the analysis and findings, there is no significant difference between the scores for left-hand users using left-mode versus left-hand users using right-mode.

There are various limitations that can be considerable factors when discussing as to why the alternative hypothesis was rejected. One limitation may be the variation in devices being used to conduct the experiment. The screen size of each device would be different, and could influence how comfortable the user is with the respective device. If the user is not comfortable holding the device, this would have an impact on the results from each trial. Additionally, another limitation would be the range in the user age groups and time spent on mobile devices. With all of the users being between the ages of 15 to 25, this might have had an effect on the hours spent on their devices. Lastly, external habits may be a limitation. Certain users were more likely to use their right-hand for everyday tasks, but use their left-hand only when using mobile devices. So, when given a task to complete, the results would be in favour of left mode despite being right-hand dominant. These limitations could all potentially impact the overall results obtained from the experiment, influencing the outcome of whether or not to accept the hypothesis.

CONCLUSION

Our study used a within-subjects design to test participants' performance with left-handed vs right-handed layouts. We conducted testing with a group of right-handed users and a group of left-handed users. Our results found a small improvement in performance when participants used a layout geared toward their dominant hand. However, after we further analyzed the data, we found this small improvement was not statistically significant. Ultimately, we could not conclude that having a left-handed layout improved the performance of left-handed users in reachability-based tasks.

Future Work

Future work can consider the effects of left-handedness on other aspects of mobile device usage outside of just reachability.

For one, future research can look at user comfort levels when using a device with their dominant hand vs non-dominant hand. This is not something that was explored in our study, since we wanted to consider the performance aspects of users having access to a left-handed layout. However, comfort is another factor that could lead to people preferring to use a left-handed layout.

Further research in this area can also consider the role of screen size or device type and how this factor affects users' need for a left-handed oriented layout. Screen size and device type were not something we controlled for during our study, thus we may have seen different results had we tested with larger screens. It is possible that a larger screen or other types of devices necessitate the use of a user's dominant hand since these differences could create more difficulties in the one-handed use of a mobile device.

Study Improvements

After concluding the test portion and reviewing our data we identified some areas where our study could be improved. Firstly, we could control for device type by completing all testing using the same device. By testing with four different devices, we likely introduced confounding variables related to differences in the testing environment. Using one device for testing would limit the introduction of these confounding variables.

Next, we could increase our sample size and the diversity of our study. We had two groups representing a between-subjects factor with each group having only four participants. By testing with smaller groups, the generalizability of our findings is low. Additionally, participants were recruited from people we knew so they generally fell into the same demographics. This again

limited the generalizability of our data. A larger and more diverse sample would address this issue.

Lastly, this study should have been geared completely towards left-handed users. We included a group of right-handed users for completeness, but their data ended up going unused as it did not help us determine if our hypothesis was valid or not. The time spent testing with these users could have been used to test additional left-handed users which would have given us more usable data. Future iterations of this study should move away from testing both left and right-handed users, and test solely left-handed users since they were the main focus of the hypothesis.

Conclusion

While we did find that left-handed users performed better while using the left-handed mode of our app, the difference in the means for their performance between the left and right-handed modes was not statistically significant. This likely means that when it comes to the reachability of mobile devices, left-handedness does not have a severe negative impact on left-handed users' experience while using their device. These findings contradicted our original hypothesis where left-handed users would average higher button press accuracy while using the left-handed mode of our app. For this reason, we accepted the null hypothesis instead.

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