ERGONOMICS ANALYSIS OF TOUCHSCREEN UTILIZATION AS A FUNCTION OF PREFERRED HAND AND GENDER

A Thesis

presented to

the Faculty of California Polytechnic State University,

San Luis Obispo

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Industrial Engineering

by

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December 2015

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ABSTRACT

Ergonomics Analysis of Touchscreen Utilization as a Function of Preferred Hand and Gender

Jordan E. Odell

The growth of touchscreen technology has changed the way users interface with a wide range of computing and communication products and systems. Examples range from personal tablets and laptops to industrial applications such as process control, point-of-sales, and ticketing kiosk systems. An important area of application is the automobile industry which is designing cars with touchscreen control panels to replace the previously designed mechanical knobs and buttons. However, interacting with touchscreens does not provide the same tactile feedback as physical mechanisms, therefore they require more precise movement and visual attention, which distracts the user from the primary task.

The purpose of this thesis was to investigate the optimal location of small touchscreen devices with respect to the user and her/his ability to perform secondary touchscreen tasks. Specifically, the goal was to see if there is a significant interaction between the user's gender and utilization of the touch pad by her/his preferred versus non-preferred hand. A randomized, between-subject experiment was designed and tested using five independent two-way ANOVAs. Each ANOVA tested a different type of touchscreen interaction; button clicking, dragging and typing, with typing further broken down into three two-way ANOVAs based on word length. Results indicate that in typical tasks such as navigation and selecting thumbnails there are no significant interaction or main effects with hand dominance and gender as the factors. There was a significant interaction for dragging tasks (p-value = .056) with females performing better with their dominant hand, whereas males performed better with their non-dominant hand. There was also a significant main effect for typing three letter words. Gender was the source of variability (p-value=.066) with females completing the task faster than males. Four and five letter words had no significant interaction or main effects. However, with a larger sample size there is a possibility for more significant findings. Qualitative results also revealed some important patterns which complimented the quantitative results and should be taken into consideration by designers of these systems. This study examined a small sample of different factors that may affect the use of touchscreens, and simulates just one application. There are still questions that should be answered in order to best utilize touchscreen technology. Future research in relation to touchscreens in automobiles could include testing effects of car speed, driving conditions and ideal height, angle and distance placement of screen.

ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Pouraghabagher, for all of his instruction and support. His knowledge in human factors and experimental design was an asset to my research. I would also like to thank my thesis committee members, Dr. Macedo and Dr. Pan for their encouragement and feedback to build a strong defense. Lastly, a special thanks to all of my family and friends who have supported me through my college journey and my decision to pursue a Masters Degree in Industrial Engineering.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1: Introduction

Touchscreen technology, which was developed in the 1960's, is a display that senses the touch of a finger or stylus as an input device [1]. Even though it has been in existence for quite some time, the release of smart phones with touchscreen interfaces is what popularized and brought the technology into peoples' everyday use [2]. Almost every phone has touchscreen capabilities, and as the population has become accustomed to this type of interface, it has started to appear in more applications. Some common uses of touchscreen technology include [3]:

- Point of Sale Devices
- Interactive Displays
- Ticketing Machines
- Gaming Systems
- Industrial Process Control
- Transportation systems

Touchscreen technology is becoming more prevalent in these applications due to its intuitive means of navigation, enhanced user experience, and elimination of mechanical devices to interface with the system. Touchscreens exhibit intuitive graphical user interfaces, so that even people with limited technological experience can navigate through systems by simply using their fingers to press the desired buttons until a goal has been reached. Interfaces offer diagrams, symbols and simple menus to ease this navigation and selection options. With this ease of use comes a decrease in the time it takes to perform actions. Users no longer have to control the system with a mouse, joystick or any other mechanical device, which often takes longer and is more difficult to work with. By eliminating these attachments and controls, spacing requirements and equipment footprint also decrease [4].

Despite the numerous advantages, touchscreen technology has its downfalls. One of the main disadvantages is the lack of feedback. When using mechanical components, users experience a recognition of task completion. These physical mechanisms allow users to feel buttons being pressed, have the ability to slide switches, or rotate knobs. Having tactile feedback is especially important when performing rapid tasks while not looking at the screen [4]. In some situations this lack of feedback is not a major issue. For example, if the user is performing a primary task such as browsing the web on her/his tablet, or a checkout clerk is navigating a point of sale system, the lack of feedback isn't as imperative. These users are focused on the touchscreen task at hand and receive visual feedback from their actions. However, in situations where touchscreen usage is a secondary task, this lack of feedback can cause problems. A secondary interaction occurs when the user is supposed to be devoting attention or focus to one activity, while using a touchscreen to complete side tasks. One device that has been around since the early development of touchscreens is the GPS navigation system. These devices utilized touchscreen interfaces and required the user to input a location that the GPS would navigate to. When the user entered the location prior to driving, this touchscreen interface did not affect the user's ability to drive. This simple idea has now grown into full car infotainment controls, which allows users to make changes while driving. These in-vehicle touchscreens have the ability to control sound, climate, navigation, phone and other functions, and are appearing in most new vehicles. "IHS Automotive estimates sales of vehicles with touchscreen interfaces will grow from 16.7 million units in 2015 to more than 61 billion units in 2021"[5]. With this estimated growth of automobiles containing touchscreen interfaces, it is important to be aware of factors that affect secondary touchscreen interactions, in order to ensure safety for all drivers utilizing these devices.

When a user is operating a vehicle, her/his primary task should be focusing on controlling the vehicle and being aware of her/his surroundings. Adjustments made on the control panel are considered secondary tasks. One user commented on the flatness and lack of feedback on a touchscreen control panel while driving a new Ford Focus 2012 and stated, "And because you can't feel anything, you are obligated to look to see if what you pressed was the right thing"[6]. This demonstrates that users have to look at the screen instead of the road, resulting in safety conditions becoming compromised. Pitts et al. [7] looked into this same issue and made the remark that by not having haptic feedback, "This places significant demand on visual attention which raises potential issues with respect to safety; road accident study data indicate 60 percent of crashes, near-crashes and incidents can be attributed to glances away from the forward roadway." Therefore, this application must be further investigated to design an optimal environment for users of either gender, and users with different hand preferences, so that secondary touchscreen task completion time is minimized.

There have been various amounts of research done in the field of touchscreen technology. Many researchers have focused on topics such as: what the ideal size is for screens and thumbnails, where on the screen is the best location for menus, buttons and thumbnails, how accurate are users in completing tasks and what are the effects of feedback, or lack thereof. Some researchers have looked into touchscreen angles in relation to sitting or standing and how different tasks result in different recommendations. With the growth of touchscreens in numerous applications, understanding implications of the touchscreen setup in relation to the user is key for successful utilization. The objective of this research was to investigate the optimal location for small touchscreen devices with respect the the user and her/his ability to perform secondary touchscreen tasks.

Chapter 2: Literature Review

This section reviews current literature in the field of ergonomics and touchscreens. This is a very large field, so in order to narrow the research, the focus was looking at touchscreen ergonomics applied to secondary tasks and different types of input methods. The main area of study was how touchscreens apply to automobiles, which implies the primary task is driving a car and any adjustments made on the touchscreen control panel are considered secondary tasks. Some examples of current research in this field include: in-vehicle interface comparisons, differences between touchscreen styles and sizes, and mechanical components or other methods of controlling car settings. However, no research was found on how secondary touchscreen interactions may be affected by the user's gender or ability to use her/his preferred or non-preferred hand.

2.1 In Vehicle Interfaces

Studies have been conducted comparing different interfaces for controls in vehicles. These range from touchscreen interfaces, rotary controls and voice recognition systems. When comparing a touchscreen interface to a rotary control, the study performed by Rydstrom, Brostrom and Bengtsson [8] revealed that interface efficiency was dependent on the task performed. Tasks that included alphanumeric input resulted in quicker completion time with less glances when using a touchscreen rather than a rotary control. However, continuous tasks such as scrolling and level adjustments, volume,climate etc, were more efficient with the rotary knob.

Even though touchscreen inputs were better than rotary controls for alphanumeric tasks, this doesn't indicate that touchscreen is the most effective interface for these tasks. Another study was performed that tested inputting addresses on a touchscreen device versus voice recognition in automobiles [9]. Voice recognition was faster than keyboard typing for most scenarios and produced less errors. This experiment also found that vehicle control was affected by the different input methods. Entries via a keyboard increased the probability of lane departure, and vehicle control was deteriorated when compared to the voice recognition system [9]. This is just one validation that driving performance decreases when touchscreen tasks are incorporated at the same time.

When using a touchscreen device there are multiple ways to interact with the screen, these interaction types can be considered tasks. One study explored differences between button tapping, flicking, panning and pinching as secondary tasks. Results indicated that tapping and flicking did not have significant differences in completion time, but panning, similar to dragging, and the pinching motion were executed quicker than button clicking [10]. These differences in task completion time helped determine that for this thesis research different tasks should be studied, and tasks were to be analyzed independent of each other due to their differences.

2.2 Effects of Visual and Haptic Feedback for Touchscreens

One of the mentioned disadvantages of touchscreen interactions is the lack of feedback received by the user. Studies have investigated different types of feedback and if feedback does indeed affect the user's interactions. An experiment compared visual feedback and haptic feedback (haptic being a slight vibration that is produced when touched), and found that haptic feedback is just as effective as visual feedback [7]. This is important to note depending on the environment of the touchscreen and which type of feedback would be most effective. In the case of a secondary task, when visual attention is on a primary task, haptic feedback should be implemented. Another experiment conducted, compared a physical keyboard, a touchscreen keyboard and a touchscreen keyboard with tactile feedback on a mobile device [11]. Results showed that a physical keyboard produced the fewest errors in the quickest time. The touchscreen keyboard with the tactile feedback yielded the next best results, and the keyboard without feedback resulted in the worst completion time. This demonstrates that tactile feedback does improve the user's performance when working on touchscreen interfaces.

2.3 Hand Dominance

There was no specific research found on hand dominance in relation to secondary touchscreen interactions, however, there were important findings on applicable studies. These results helped decide if hand dominance should be considered as a factor for this experiment.

As researcher Flowers was performing his research, he made a distinction that when discussing hand dominance, it important to consider the type of movement being performed [12]. He found from researcher Oldfield that there are two different types of dexterity, a corrective mode of control and ballistic movements. Corrective control encompasses movements such as, "making precise or graded responses, such as aiming movements, or controlling the tone of a piano or accelerator on a car." Ballistic movements are actions that are triggered automatically and after time require no form of feedback due to the muscle memory. Navigating secondary touchscreen interactions would be considered corrective control movement, thus these are the results that were studied. In order to test corrective control movement, Flowers ran an experiment using Fitts' tapping test as his task [12]. The results showed there was a significant difference in preferred versus non-preferred hand when it came to mean time per movement, however there was no significant difference in the error for the different hand groups. Perry and Hourcade studied hand dominance, but focused just on one handed, thumb interactions. This experiment produced results supporting Flowers, yielding a significant effect of handedness for performing certain tasks on a mobile device touchscreen [13].

However, there were researchers that found opposing results regarding significance in hand dominance [14]. This experiment compared computer input (tapping and dragging) on three different devices: a mouse, a trackball and a stylus on a touch pad. The results showed that handedness did not affect time or accuracy for any of the devices.

With a mix of results from different studies, there is potential for a significant difference to exist between preferred and non-preferred hands as applied to secondary touchscreen usage. This is crucial to investigate, especially due to the nature of safety in cars being affected by the time users eyes are not focused on the road.

2.4 Gender

2.4.1 Implications of Gender on Secondary Tasks

Gender is a common factor studied throughout a variety of research topics. Since this research project is focused on gender differences while completing secondary touchscreen tasks, it is important to research if gender affects touchscreen input, as well as the ability to attend to a secondary task (multitasking). A secondary task is something that takes place concurrently with a primary task, requiring the user to be able to split her/his focus and attention. "When the demands of the secondary task cause it to become the user's primary focus, negative performance effects on the primary task can occur"[15]. When applying this principal to situations such as driving, this can lead to an decrease in vehicle control and driving awareness. Karam performed research on the ability to balance attention between a primary task and two different types of secondary tasks [15]. Even though the secondary tasks didn't relate directly to touchscreen usage, the results did indicate gender differences in multitask awareness. It was found that females performed the secondary task slower, but were able to recover focus on the primary task quicker.

This could lead to females performing better due to their ability to focus on the road and the screen simultaneously.

2.4.2 Gender Differences for Touchscreen Interaction

Next, research was conducted that studied gender differences in touchscreen inputs. According to research done by Antal, Bokor and Szabo [16] there are differences in the way males and females swipe across touchscreens. These differences are significant enough that device algorithms can categorize which gender is using the touchscreen by a single swiping motion. This gender effect could also be found significant for other touchscreen interactions. One potential explanation for the gender significance on touchscreens is due to the size of fingers, and the corresponding button sizes on the touchscreens [17]. This is illustrated by the results of comparing the effects of different Netbook sizes on touchscreen, touchpad and keyboard usage. The different tasks tested encompassed both basic and complex maneuvers, all being some of the most commonly used interaction types. These tasks included simple button clicking, a series of button selecting (navigating through the screen), a dragging action and typing. Even though there was not a significant gender effect on task completion time, there was a significant gender difference for errors made during two of the tasks. Males made more errors during the button series navigation task as well as type task [17]. When applying this significance to secondary tasks, if males produce more errors this can result in longer task completion time, which then creates a longer period of distraction from the primary task.

By combining the findings of these different research areas, it has narrowed the author's research focus. Does hand dominance and gender, significantly affect the use of secondary touchscreen interactions as applied to automobiles? Chapter 3 describes the design of the experiment conducted in order to answer this question.

Chapter 3: Design

The goal of this experiment was to test how different secondary touchscreen interactions are affected by hand dominance and gender, specifically in driving applications. In order to emulate this application, the subjects had a primary task which consisted of watching a video of a recorded drive down the Pacific Coast Highway and were required to recall certain aspects of this drive at the end of the experiment. Simultaneously, the subjects had to attend to secondary tasks using the touchscreen. The primary task and secondary task designs are described in the following sections.

3.1 Primary Task

The purpose of the primary task was for subjects to focus on a video which required an attention level comparable to driving. The chosen video found on YouTube [18] shows a drive along the California Coast between Point Mugu State Park and Malibu. In this video there are a variety of signs that are passed on the highway. As these signs are passed, the creator of the video edits it so that pictures of these signs appear in the corners of the video and stay there for approximately 7-10 seconds so the viewer can read the signs that she/he is passing. A screen shot of the video with two signs pasted into the corners is shown in Figure 1. In the top two corners of the figure there are two signs that have been pasted on the screen and are held there as the video continues to run. The two green boxes in the bottom two corners represent other places that signs may be pasted. The subjects' task was to watch the video and count how many signs were shown (in those corners) that would lead the driver off of the highway and to the ocean. Sign names consisted of coastal access, beach names or cove names. There was a total of five signs throughout the video which lead to the coast. The subjects were told that at the end of the video, they would be questioned on how many signs they saw, so it was important that their focus was on the video so they wouldn't miss a sign.

Figure 1: Primary Video Screen Shot with Signs

3.2 Secondary Tasks

The secondary tasks needed to represent interactions that happen most frequently with touchscreens. The author of this research designed an application that was programmed with the assistance of a Software Engineer to test three different types of interactions: button clicking, dragging and typing. Figure 2 shows the home screen of the application with the three icons representative of button clicking, dragging and typing, in that order from left to right. The sections below describe the tasks and how the application simulated the real life interaction for each task.

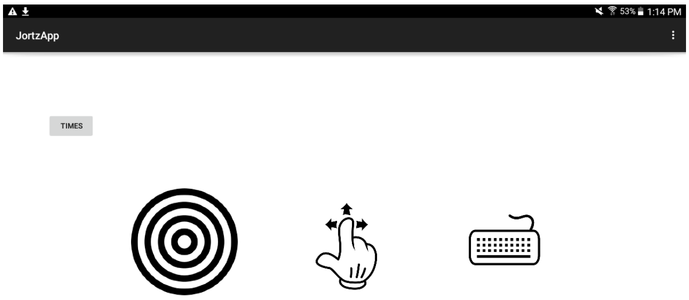

Figure 2: Application Home Screen

3.2.1 Button Clicking

One of the most common interactions with touchscreens is navigating to an end goal through the clicking of thumbnails. One example would be the navigation to a specific song a user wanted to play. The user would activate the touchscreen, find and select the music thumbnail, then select either a play list or an artist and finally select the desired song. This series of navigating requires the user to find the correct button, make the selection and then repeat that process until the target is reached. In order to simulate this navigation process, a task was designed called button clicking. When the subject selected this task icon from the home screen, it brought her/him to a screen which had a keypad consisting of the numbers 1-9, however, the numbers were randomly generated as opposed to the typical 1-9 sequence. The goal of the subject was to find and press a stated target number three times in a row. After each press of the target number, the keypad would re-order the numbers, which left the subject having to search for the target number in order to select it again. After the subject correctly found and selected the target number three times in a row, the subject pressed done (in the top right hand corner) which ended the trial. A picture of the keypad can be seen in Figure 3.

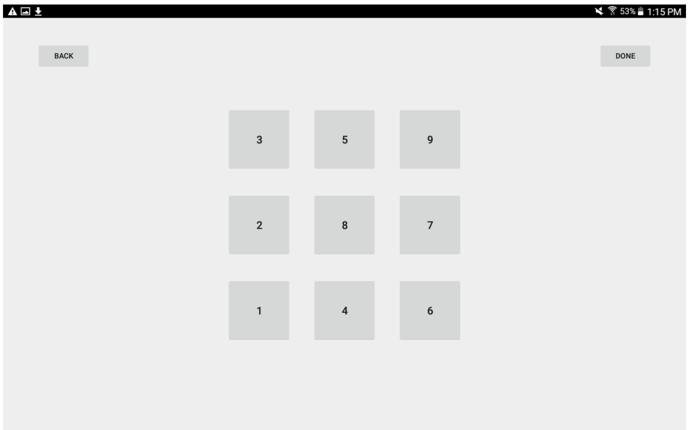

Figure 3: Task 1 - Button Clicking

3.2.2 Dragging

The dragging task was the most complicated interaction to design. First a distinction needed to be made between swiping and dragging on a touchscreen, both being common interactions. According to Google's definition of gestures a drag is a "fine gesture, slower, more controlled, typically has an on screen target" whereas a swipe can be described as a, "gross gesture, faster, typically has no on screen target"[19]. Dragging was chosen because it requires users to execute an action with focus and control, whereas swiping requires very minimal coordination. Examples of dragging include dragging a volume level, manipulating a video or song to a specific time point or dragging a tab to control the temperature. In order to simulate this, the dragging task screen consisted of three bars. Each bar had a circular tab which the user could drag from left to right. Above each bar was a target number that was randomly generated between 0 and 100. To the right of each bar was a fraction which represented where on the bar the circular tab was located on the scale of 0-100. The goal of the subject was to drag the circular tab, so that the fraction on the right matched the target number on the top. After successfully dragging all three tabs to the correct locations, the subject would click done, ending that trial. Figure 4 shows the starting point of the task and Figure 5 shows a completed trial before clicking done.

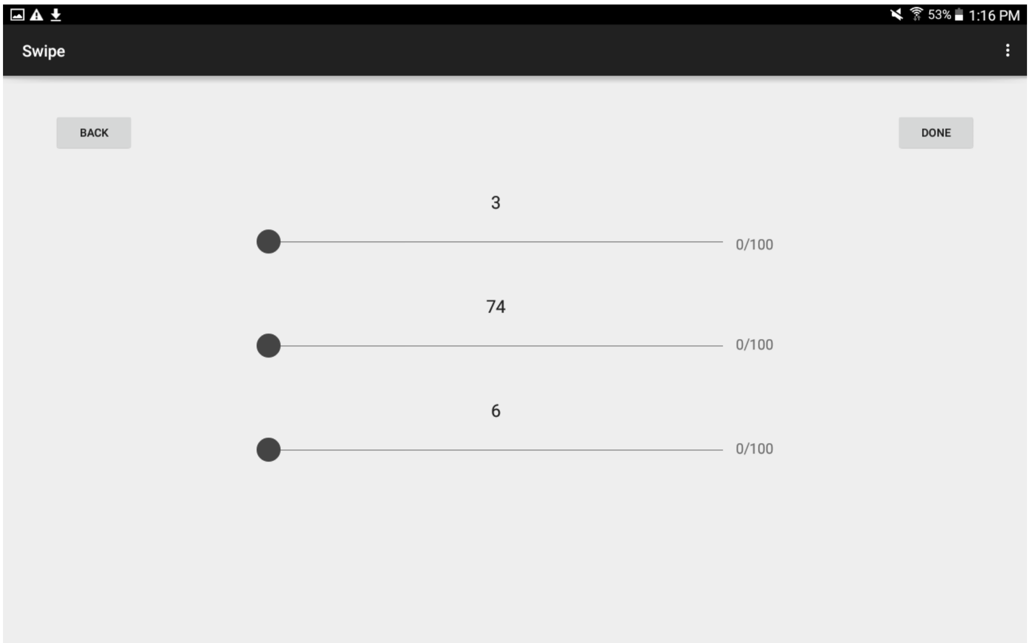

Figure 4: Task 2 - Dragging

Figure 5: Task 2 - Dragging Completed

3.2.3 *Typing*

The typing task is another common interaction on touchscreen devices. Typing can be used in multiple ways, the most common way used in automobiles would be for navigation. Once the user selected the typing task icon, it brought up a screen with a keypad and a text line. The subject would have to type the stated target word and then click done to end the trial. The target words selected ranged from three to five letters in length. Since there were six trials, there were two words with three, four and five letters. There were two considerations for how to convey the target words to the subjects. One method was to flip a note card in front of the subject and have that be the cue to type that word. However, this added another visual element that would require attention from the subject which did not seem as applicable in a driving situation. The chosen method was for the experimenter to state the word as an audio cue at the start of the trial. The words chosen are listed in the next chapter. Figure 6 shows the typing screen before a word is typed and Figure 7 shows a completed trial with a word typed.

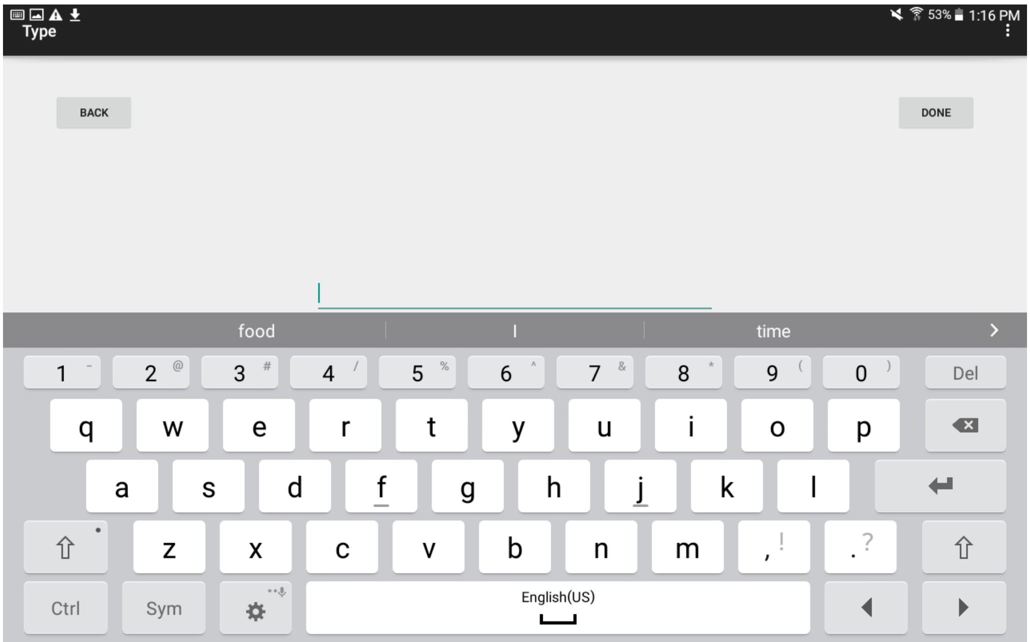

Figure 6: Task 3 - Typing

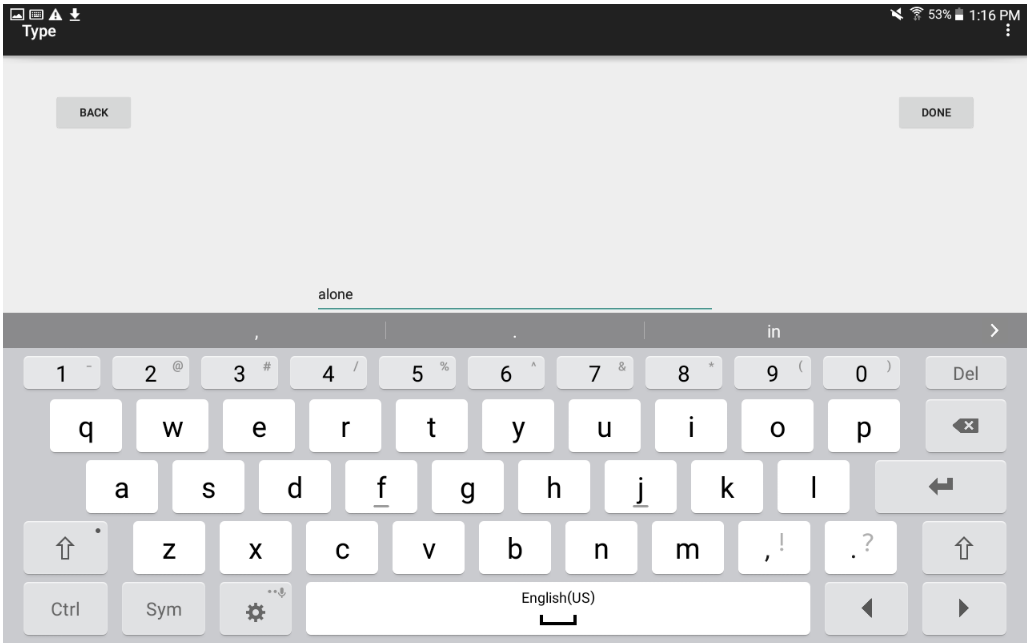

Figure 7: Task 3 - Typed Word

3.3 Technical Development

The experimental tasks were designed by this author and developed with the assistance of a Software Engineer using Visual Studio with JAVA and XML. The created application was run on a Samsung Galaxy Tab 2 with a 10.1” screen.

Chapter 4: Methodology

4.1 Design

The experimental design consisted of five separate two-way ANOVAs. Each task was tested independently since they all had different objectives and furthermore the typing task was broken down by word length. When analyzing the ANOVA results, significance for the interaction between hand dominance and gender was checked first, and if that was not significant the main effects were studied. Table 1 shows the different types of factors and their respective levels.

Table 1: Factors and Levels

Factors	Levels	Type of Variable
Gender	2	Fixed
Hand Dominance	2	Fixed

A between - subjects design was used, meaning each subject only performed one condition. The subjects were randomly assigned the condition when they arrived to the experiment. Table 2 shows the experimental conditions broken up by task. By having each subject only perform one condition, no counterbalancing was necessary and bias and fatigue were not of concern. Each condition consisted of five subjects, tested six times.

Table 2: Experimental Conditions

Task 1	Dominant	Non-Dominant
Male		
Female		
Task 2	Dominant	Non-Dominant
Male		
Female		
Task 3	Dominant	Non-Dominant
Male		
Female		

Learning curve was considered when designing this experiment. Since each subject performed six trials, there was a potential for reduced completion time after the first couple trials. In order to minimize any learning there were multiple steps taken throughout the experiment. First, subjects were screened, and one requirement was at least one year of touchscreen experience so each subject was familiar with using a touchscreen interface. Next, each subject was given a practice trial, creating familiarity and gaining exposure for the task at hand. After the experiment, statistical differences in trials were checked, with the consideration of dropping the first trial if differences were proven true. Analysis on these trials will be discussed further in the results (Chapter 5). Lastly, for each subject the median of the trials was taken rather than the mean. Outliers can skew mean numbers, so if there were outliers or a slight learning curve, this would not affect the median. This created one data point (median) per subject, with five subjects for each condition. The analysis of variance was conducted using these medians.

4.2 Hypothesis

The goal of this experiment is to test if there is a significant interaction between gender and hand dominance or if the additive model holds. Each of the following null hypothesis conditions is being tested for each task independently. In Table 3 the different null hypotheses are listed with the type of effect.

Table 3: Hypotheses

Null Hypothesis	Type
The population means for Gender are equal	Main Effect
The population means for Preferred and Non-Preferred hands are equal	Main Effect
There is no interaction between Gender and Hand Dominance	First Order Interaction

4.3 Variables

4.3.1 Independent Variables

There are two independent variables being tested. The first is hand dominance, which has preferred and non-preferred hand as its two levels. Next is gender, which has males and females as it's two levels.

4.3.2 Dependent Variables

The dependent variable tested was time (in seconds). Time was captured through a feature in the application. Once the subject clicked the button that would bring him/her to the task page, a timer was started. The time was stopped when the subject clicked done in the top right hand corner. These times were stored on the application and were recorded after each experiment.

4.3.3 Controlled Variables

Many variables were held constant in order to maintain equality among tests. These include:

- Location: Cal Poly Ergonomics Lab
- Lighting: The cubicle chosen was farthest away form the windows, with the blinds shut and all of the lights on
- Set - Up: Cubicle with a table, a subject chair and an experimenter chair
- Apparatus: Monitor and tablet
- Procedure and Script
- Consent Form
- Survey

4.4 Participants

Subjects were recruited for this experiment through department emails, faculty collaboration and social media networking. Subjects came from a variety of backgrounds including both undergraduate and graduate students in different majors. Subjects were given a five dollar Starbucks gift card as an incentive for their time in participating. The subjects were screened in order to meet the following criteria.

- Background: Cal Poly Student

- Age: 18 - 29
- Gender: 30 males and 30 females
- Vision: Normal or corrected to normal
- Health: No disabilities in fingers, hands or wrists
- Experience: Familiar with touchscreens (at least 1 year experience), but little to no experience with use in cars (less than 5 times in the past year)

4.5 Task

4.5.1 Predetermined Constants

In order to keep consistency between watching the video and performing tasks, there were set times that were used to initiate the subject's secondary touchscreen task. Even though the times were selected at random, some times were slightly manipulated in order to overlap with the appearance of signs in the video that needed to be counted. For the button clicking task there needed to be consistency for which number would be the target number for each trial. The target numbers were different for each trial in order to reduce any number recognition effect that could occur. For the typing task the target words were also predetermined. Table 4 outlines the times when tasks were initiated, as well as the target number or word associated.

Table 4: Predetermined Constants

Time for Tasks	Target Numbers	Target Words
1:00	3	bikes
1:27	2	food
2:13	9	alone
2:54	8	mat
3:41	6	time
4:40	1	run

4.5.2 Subject Condition Randomization

Before any of the experiments took place a list was randomly generated with the different testing conditions for the total number of experiments necessary. As subjects came to participate the experimenter went down the list to determine which condition to test. Since the order of subjects that were males and females didn't align with the testing condition orders, if one gender had already completed the condition that the list suggested, the next condition on the list was used.

4.6 Procedure

4.6.1 Pre-Experiment

The experiment was expected to take approximately fifteen minutes so subjects were scheduled in twenty minute blocks. Subjects were asked to place their belongings outside the cubicle to eliminate any distractions when testing. When the subjects entered the cubicle there was an adjustable chair and a consent form on the table in front of them. First, participants were screened to make sure they met the criteria, they then read and signed the consent form. A copy of the consent can be found in Appendix A. After the subjects signed the consent form a script was read to them that consisted of a brief overview of the experiment, their primary task and assigned secondary task. A copy of the experiment instructions can be found in Appendix B. Subjects were allowed to ask questions after each task description. In order to fully understand the task at hand, each subject performed one trial run of her/his touchscreen task. After the trial the subjects had one more chance to ask any questions before beginning.

4.6.2 Training Trial

After the instructions were read each subject performed a trial run. The primary task video was not involved in this trial, just the touchscreen task. The trial experiment used separate numbers and words than the actual experiment. The purpose of the training trial was to expose subjects to the task in order to understand what needed to be completed, as well as give the subjects a practice to reduce learning curve effects.

4.6.3 Task Set Up

Once the subject had no further questions the proper environment was set up. The subject was asked to adjust the chair to a comfortable height in relation to the table and to be centered in accordance to the monitor ahead. The monitor screen size was 23.6" (diagonal measure) and was placed at the opposite end of the table. Next, the touchscreen had to be aligned at a constant distance for each participant. To do this, the subject was asked to place the elbow of the chosen hand in line with the edge of the table with arms flat, fingers together. The tablet was aligned with the outside tip of the subject's ring finger, and parallel to the edge of the table. The tablet angle was set consistently using a notch in the cover. After the tablet was set in place, the subjects were asked to extend their arm and touch the far side, upper corner of the tablet. This was a check to ensure that the subject could comfortably reach the whole screen, but had to extend his/her arm to do so. Figures 8-10 show different parts of the set up process.

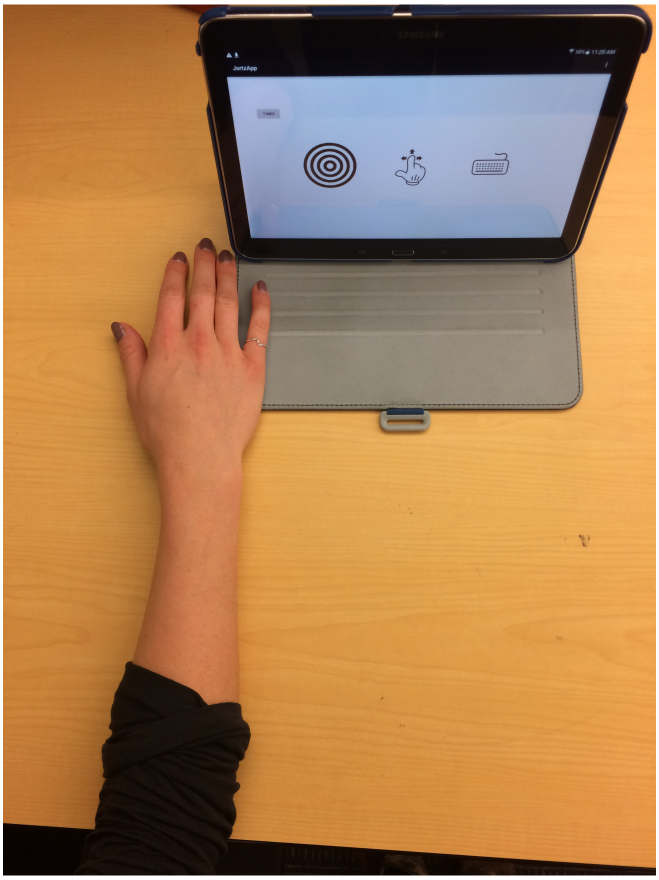

Figure 8: Aligning Tablet with Ring Finger

Figure 9: Reach Check

Figure 10: Tablet Angle

Once the setup was complete the test began. The experimenter started the video and a stop watch at the same time, and initiated the touchscreen tasks at the predetermined time marks. The experimenter sat slightly behind and to the side of the subject to observe that the touchscreen task was completed correctly.

4.6.4 Post-Experiment

At the end of the video the subject was asked how many signs were shown that would lead a driver off the highway and to the ocean. This number was recorded in the data sheet. Subjects were then given a short qualitative survey to complete after the experiment. This survey asked questions about how difficult it was to complete the touchscreen task, the difficulty in completing both primary and secondary tasks simultaneously and the confidence level of correctly completing the tasks. A copy of the survey can be found in Appendix C.

4.7 Pilot

A pilot experiment was completed beforehand to determine how to best conduct the experiment and confirm that the tasks were reasonable. For this pilot six subjects were chosen, three male and three female. One subject from each gender performed one of the three tasks. It was randomly decided which subjects would perform which task and with their dominant and non-dominant hand. Since there wasn't enough subjects to balance the pilot, no analysis was run on the data to confirm hypotheses. However, the pilot subjects did confirm that completing the primary task and secondary touchscreen tasks simultaneously was challenging, but a manageable and realistic expectation. Certain changes that resulted due to feedback during the pilot experiment were a more descriptive script when explaining the primary task, as well as showing a screen shot of the video to help visualize what will be happening. There was also feedback on the delivering of audio cues for when the subject would perform a touchscreen task and revisions of wording for the post-experiment survey to help clarify the questions.

Chapter 5: Results

5.1 Primary Task Results

In order to analyze the performance of the subjects for the primary task, it was decided if subjects identified at least four of five signs, the data would be accepted. Data obtained from subjects that recalled less than four signs would be omitted. There needed to be a required level of success for the primary task in order to analyze the data points and consider the driving situation emulated. The subjects that didn't meet this required level, focused more on the touchscreen task instead of the primary task, which could lead to skewed result times. After analyzing the primary task results, fifty seven of sixty subjects recalled five out of five signs. The remaining three subjects recalled four of five signs. This determined that all of the data collected from the touchscreen task was going to be used and considered valid.

5.2 Quantitative Results

This section contains the quantitative results that were collected from the experiment. The response variable is represented by time in seconds that it took for the subjects to complete the touchscreen task correctly. Before any ANOVA tests were run, assumptions had to be checked, assumptions include: normality, equal variances and independence. These assumptions can be found in section 5.2.2. After assumptions were met, two-way ANOVAs were used to test for any significant interaction or main effects.

5.2.1 Learning Curve Tests

Since each subject repeated the chosen condition six times, it was important to check for a learning curve or significant difference in any of the trials. Typing was not included in this test due to the different word lengths also having a potential effect.

Figures 11 and 12 show scatter plots of the results with relationship to the trial for task one and task two, respectively. Task one seems like the means are fairly close, whereas task two does have a decrease in time after the first trial. An analysis of variance was conducted with trials as a factor. This test confirmed that there was no significant differences between trial times. Task one had a p-value of .056 and task two was .1200. Therefore, no data was removed due to learning effects. These ANOVA results from the trials can be found in Appendix D.

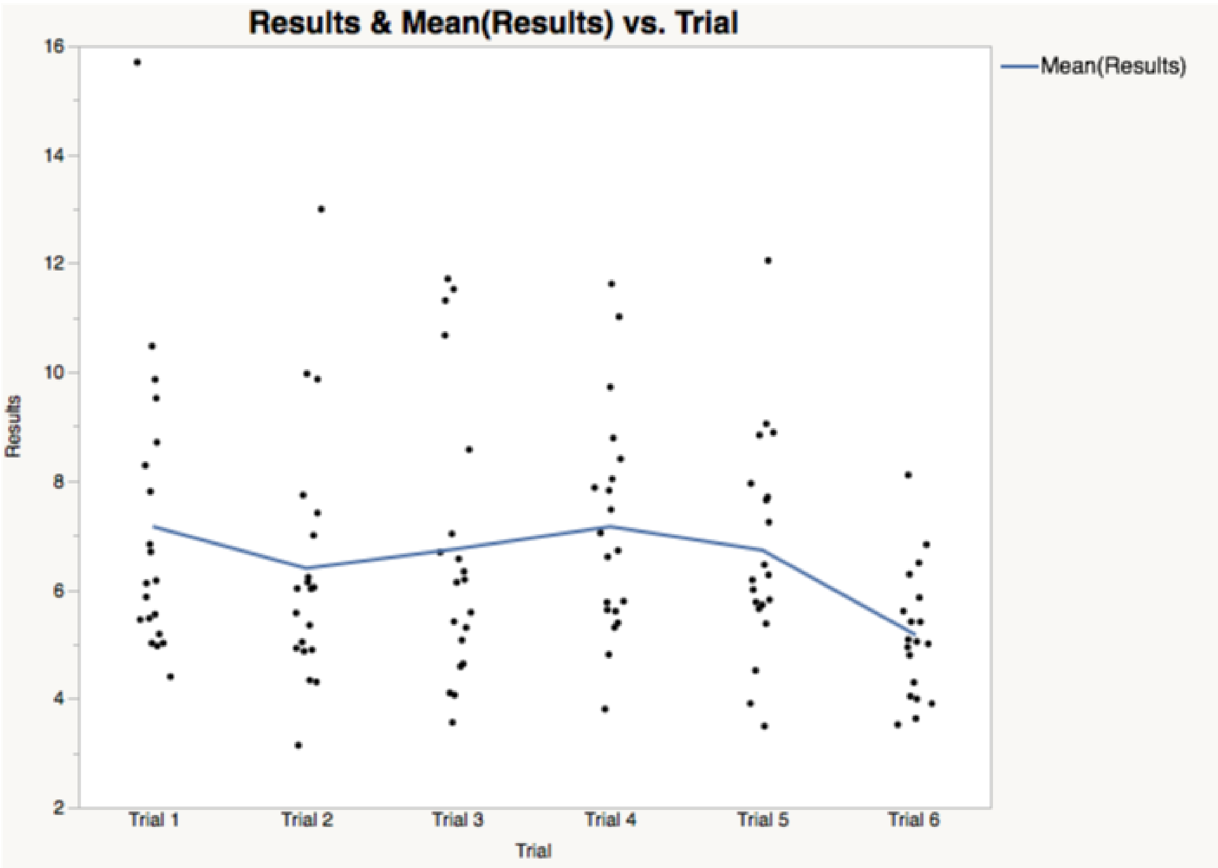

Figure 11: Scatter Plot of Task 1

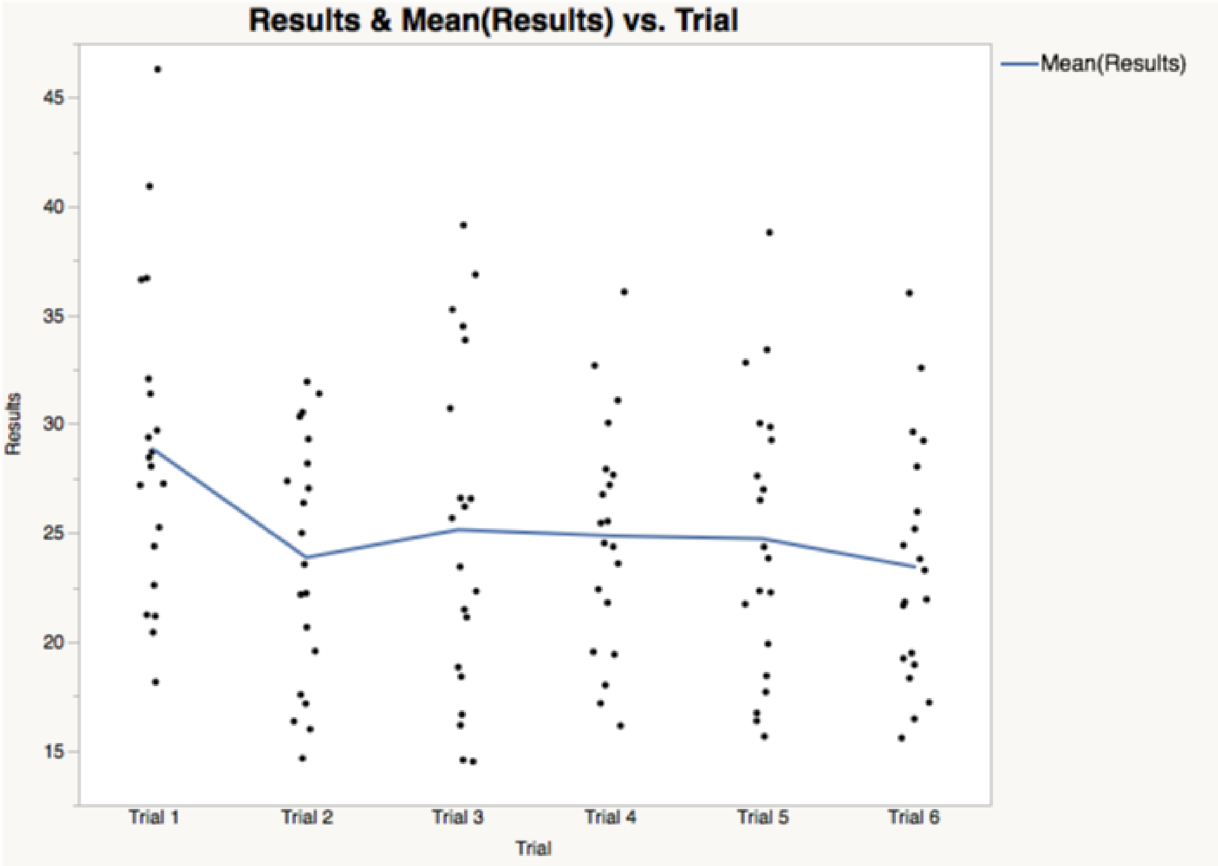

Figure 12: Scatter Plot of Task 2

5.2.2 ANOVA Assumptions

Each assumption used a different method to determine if it could be considered valid. Normality was checked by creating a normal probability plot of the residuals and checking the Anderson-Darling p-value. Equal variances was checked by performing a Bartlett test and using the p-value. When looking at p-values, a number greater than .05 is desired in order to conclude that the data is normal and the variances are equal. Independence was met due to the random run order developed before the experiments took place and this can be visually supported by the residuals versus order plots not exhibiting any patterns or trends. As shown in Table 5 of p-values, since all of the p-values are greater than .05, the assumptions can be considered met without having to perform any transformations. The third task was the typing task which consisted of three different word lengths. The author did not want to assume that there was no significant difference between three letter, four letter and five letter words, so they were all tested separately. All assumption graphs can be found in Appendix E.

Table 5: Assumption Tests

Task	Normality	Equal Variance
Task 1	.552	.299
Task 2	.521	.084
3 Letters	.163	.322
4 Letters	.353	.379
5 Letters	.343	.408

5.2.3 ANOVA Results Task 1

The first term looked at was the interaction term. Table 6 shows the interaction term with a p-value of .2022. Next the main effects were studied, but those too showed insignificant p-values of .387 for gender and .266 for hand dominance.

Table 6: Task 1: ANOVA Results

Source	Df	Adj SS	Adj MS	F-Value	P-value
Gender	1	3.3089	3.3089	.79	.3873
Hand Dominance	1	5.556	5.556	1.33	.2664
Gender * Hand Dominance	1	7.409	7.409	1.77	.2022
Error	16	67.012	4.188		
Total	19	83.285			

5.2.4 ANOVA Results Task 2

As shown in Table 7 the interaction between gender and hand dominance (p-value = .056) is significant when testing at the .10 significance level. Even though gender is significant with a p-value of .0126, the main effect term is ignored due to the significance of the interaction term. Looking at the interaction plot in Figure 13 the this shows the lack of parallelism which indicates that the relationship between completion time and hand dominance is dependent on gender.

Table 7: Task 2: ANOVA Results

Source	Df	Adj SS	Adj MS	F-Value	P-value
Gender	1	100.558	100.558	7.90	.0126
Hand Dominance	1	1.853	1.853	.15	.7079
Gender * Hand Dominance	1	54.048	54.048	4.24	.056
Error	16	203.75	12.734		
Total	19	360.209			

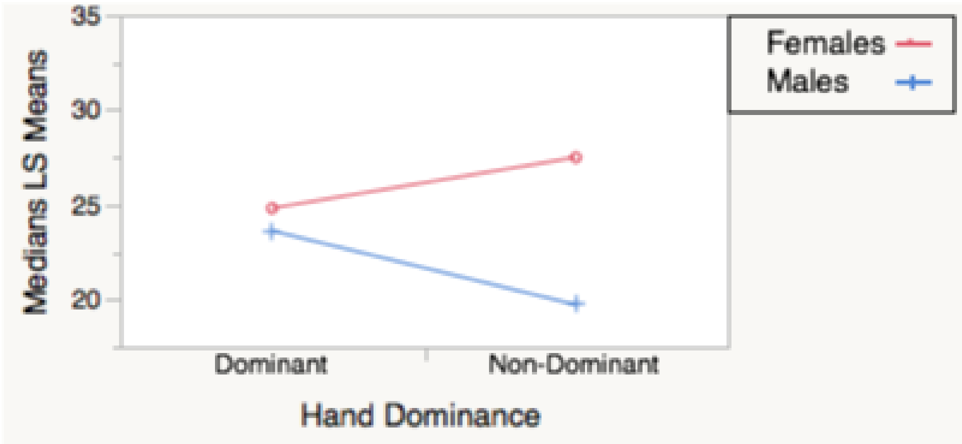

Figure 13: Task 2: Interaction Plot

5.2.5 ANOVA Results Task 3

The typing task was broken down to three separate ANOVAs based on the different word lengths; 3 letter, 4 letter and 5 letter words.

When examining the interaction term in Table 8 it is not significant with a p-value of .4614. Next, the main effects are studied and it is found that hand dominance is also not a significant with a p-value of .1593. However, gender has a p-value of .066. This is considered significant at the .10 level which means gender is a source of variability. When looking at gender's main effects plot in Figure 14 there is some overlap in the variability of the means, which is expected since it is not significant at the .05 level. This overlap is very minimal though, which is why gender can still be considered significant at the .10 level.

Table 8: 3 Letter Words: ANOVA Results

Source	Df	Adj SS	Adj MS	F-Value	P-value
Gender	1	8.352	8.352	3.89	.066
Hand Dominance	1	4.661	4.661	2.18	.1593
Gender * Hand Dominance	1	1.218	1.218	.57	.4614
Error	16	34.219	2.139		
Total	19	48.424			

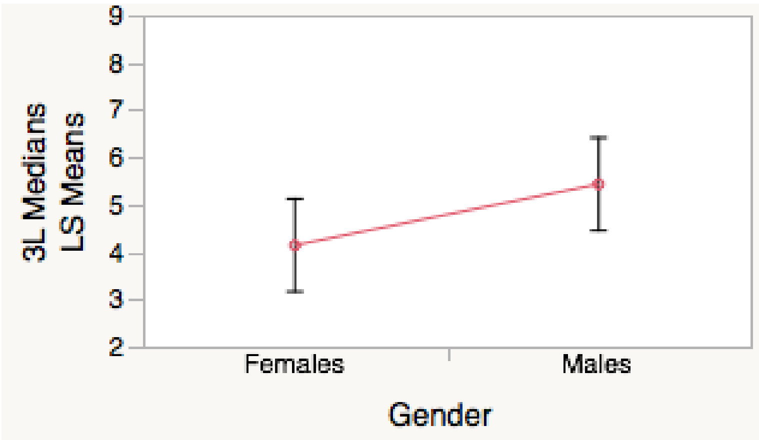

Figure 14: 3 Letter Words - Main Effects Plot

When looking at 4 letter words, Table 9 shows that the interaction term is insignificant with a p-value of .476. The main effects are also insignificant at the .10 level with p-values of .1303 and .1796 for gender and hand dominance, respectively.

Table 9: 4 Letter Words: ANOVA Results

Source	Df	Adj SS	Adj MS	F-Value	P-value
Gender	1	5.99	5.99	2.54	.1303
Hand Dominance	1	4.64	4.64	1.97	.1796
Gender * Hand Dominance	1	1.254	1.254	.53	.476
Error	16	37.71	2.36		
Total	19	49.603			

Similar to four letter words, the five letter words also has both insignificant interaction and main effect terms. Looking at the interaction term in Table 10, the p-value is .595. The main effects p-values for gender and hand dominance are .229 and .129, respectively.

Table 10: 5 Letter Words: ANOVA Results

Source	Df	Adj SS	Adj MS	F-Value	P-value
Gender	1	3.84	3.84	1.57	.229
Hand Dominance	1	6.26	6.26	2.55	.129
Gender * Hand Dominance	1	.773	.773	.29	.595
Error	16	39.25	2.45		
Total	19	50.08			

These results are important to the scientific community due to the significant differences that were found. Button clicking type tasks do not seem to differ based on hand dominance or gender. The mean completion time did vary for the dragging task. This task had interesting results showing that males perform better with their non-dominant hands, and females perform better with their dominant. Typing also showed a difference in completion time with females completing the task faster than males for three letter words. These differences prove that hand dominance and gender are sources of variability when completing touchscreen interactions. This variability can affect drivers based on how we currently design in-vehicle touchscreen interfaces.

5.3 Qualitative

After collecting survey results, bar charts were graphed to see how subjects completing different conditions felt about the experiment. The three questions asked about the difficulty level for the touchscreen task, the difficulty to perform both primary and secondary tasks simultaneously and the confidence level of completing the tasks correctly. Many of the results varied, however there were a few graphs worth noting.

In the survey chart in Figure 15 it shows the that on a scale from one to five (one being easy and five being difficult) more males found that multitasking (performing both the primary and secondary task) was difficult compared to the females.

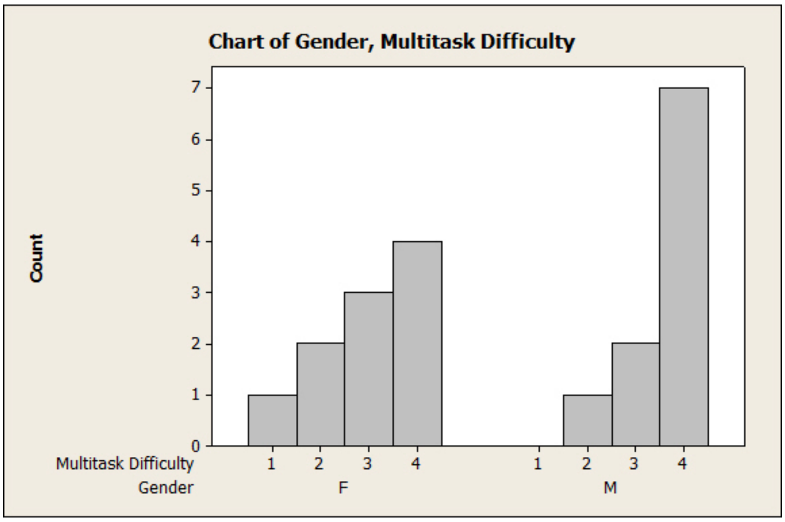

Figure 15: Task 1 - Multitasking Difficulty Survey Results

After examining the ANOVA results for the dragging task, there was a significant interaction between hand dominance and gender. This was also shown in the survey results regarding level of difficulty for this touchscreen task (one being easy, five being difficult). In Figure 16 the females using their dominant hands found it slightly easier than females with with non-dominant. Then when looking at the males, they found it more difficult to use their dominant hand and easier with their non-dominant.

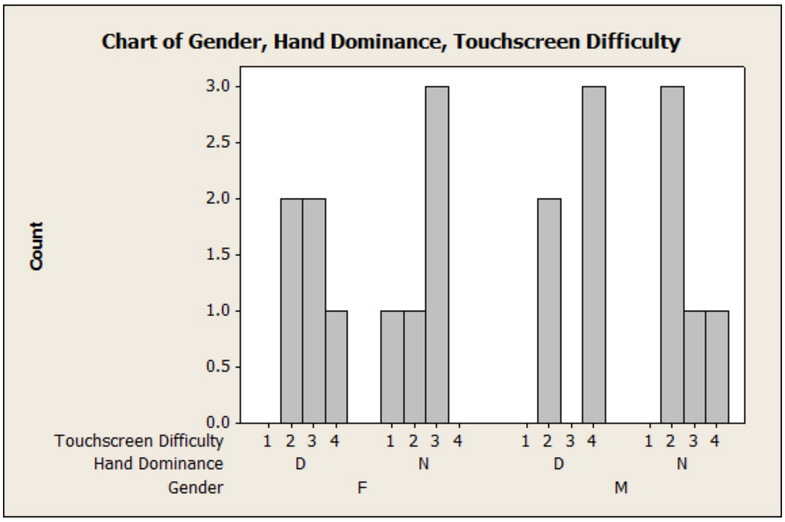

Figure 16: Task 2 - Touchscreen Difficulty Survey Results

For the typing task, the ANOVA analysis was broken down by the word lengths, but for the survey results, the answers were based on typing as a whole, regardless of letter length. In Figure 17 the results indicate that for touchscreen task difficulty females were slightly skewed left, meaning the task was easier, whereas males are slightly skewed towards the right indicating difficulty. Figure 18 shows that the dominant hand also was slightly easier when compared to the results of non-dominant hand.

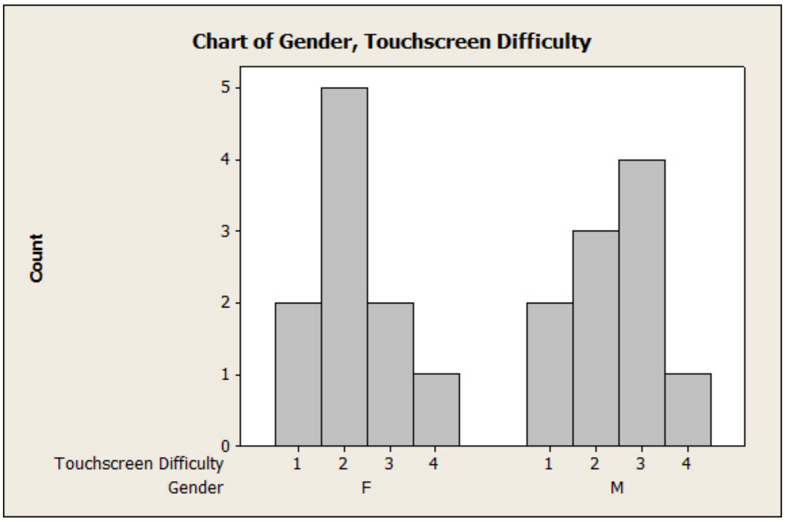

Figure 17: Task 3 - Touchscreen Difficulty With Respect to Gender

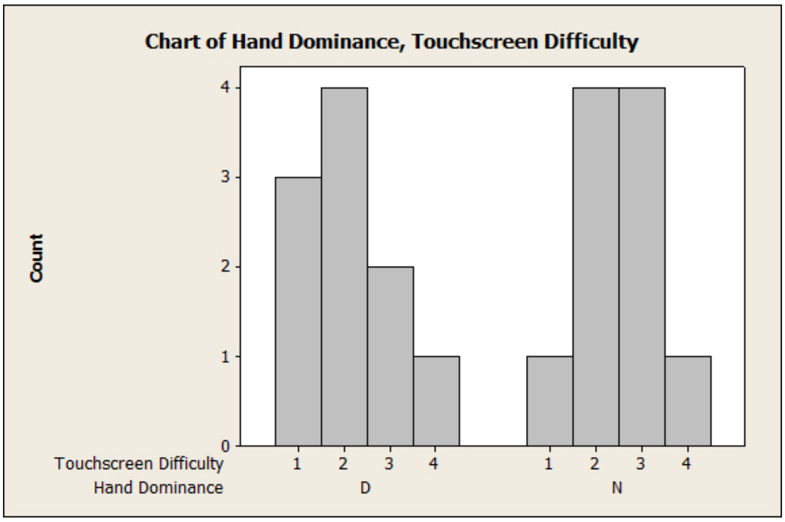

Figure 18: Task 3 - Touchscreen Difficulty With Respect to Hand Dominance

These qualitative findings are important because they support quantitative findings and provide personal insight to the user's perspective. The first graph which represents females finding it easier to multitask compared to males supports an experiment found in literature. Karam [15] found females were able to direct focus between multiple tasks quicker than males. This can lead to future research on sources of variability for multitasking, and what those implications are related to multitasking while driving. It was also interesting to see the results for the dragging task match the quantitative results. This shows the importance of touchscreen placement because not only do the completion times show females performing better with dominant hands and males with non-dominant hands, but the subjects themselves felt the same way for ease of use. The typing task also exhibited some results that should be considered. As mentioned before, three letter words was the only world length to have a significant source of gender variability, however the sample size is very low. The qualitative graphs supported the finding showing females found it generally easier than males. This was also the case for dominant and non-dominant hands. If a larger sample was tested, the quantitative results might show significance among other words, or significant variability in hand preference based on the qualitative findings.

Chapter 6: Conclusion and Future Work

6.1 Conclusions

This thesis looked at hand dominance and gender as factors that can affect the use of touchscreens when users are focused on a primary task (driving) while having to perform secondary tasks on a touchscreen interface. The goal was to make design recommendations based on three separate tasks; button clicking, dragging and typing.

There were no significant sources of variability found for button clicking tasks. This means that college age drivers, regardless of gender and hand dominance, will complete button selecting tasks on a touchscreen equally. When applying this conclusion to the automobile industry, the placement of in-vehicle touchscreen interfaces can be located to either side of the driver without it affecting the driver's ability to drive and complete secondary adjustments on the touchscreen.

The significant interaction found between hand dominance and gender for dragging tasks is important for future designers to create an environment all users can succeed in. In this situation females perform better with their dominant hand, but males perform better with their non-dominant hand. This means that user's efficiency will be dependent on which hand is preferred and non-preferred as well as gender. When this environment is driving, safety becomes involved. It is crucial that automobiles are designed for safety, and that includes ergonomically placing controls in the best location.

Gender also proved to be a significant source of variability as applied to typing three letter words. For this task, females were much quicker at typing three letter words, regardless of using preferred or non-preferred hand, than males. This is another example of how different users perform secondary touchscreen tasks differently, and these differences need to be taken into consideration. Designers should find ways to have multiple placements of screens to accommodate all types of drivers needing to perform various types of tasks. Another option is to create a new type of touchscreen interface or even take out touchscreens completely and use a different mode of interaction.

These findings are an important discovery due to the scalability of applications. Even though the goal was to emulate a driving scenario, any environment in which the users are focused on a primary task and need to perform a secondary touchscreen task can use these results as a basis for further investigation. The findings in this study were also based on a limited amount of subjects and data points. By increasing the sample size and number of observations, more significant findings may arise.

6.2 Future Research

The research performed in this thesis explored just one specific application of how touchscreen usage can be effected by the user's gender or hand dominance. This idea can be expanded on to better recommend placement or interface design based on the touchscreen application. Some recommendations of how this research can be continued are:

- Does screen placement affect interactions? (ie: Varying heights, angles and distances away) Where would the ideal placement be?
- Does level of primary task difficulty affect user's performance? (Freeway driving, traffic, city, rural)
- Is there a significant difference between length of words for secondary typing tasks?
- What types of touchscreen tasks take longer? Should automobile touchscreen interfaces only allow certain functions when the car is in drive?

Another important area for future research is how car speed affects the drivers performance on these secondary touchscreen interactions. As car speed increases, adrenaline in the driver may also increase, which may affect the driver's ability to complete these tasks. This would be an important factor to look into based on the different driving environments users encounter.

An additional area to research includes studying how users interact with touchscreen interfaces that lack visual controls and uses different types of gestures to manipulate the system. For example one video [20] shows a driver making adjustments to his vehicle's settings on a touchscreen interface with no buttons. In order to make changes he had to memorize different finger gestures to complete different tasks. For example two finger swipe up and down could control volume, whereas three finger swipe up and down could control temperature. This idea may have a learning curve to understand and memorize the different controls, however this eliminates the user from having to look at the screen in order to complete a task. This form of interaction is an interesting area that should be looked into.

Overall, the research found through this thesis helps expand the knowledge in the field of ergonomics with touchscreen devices. The factors tested were limited to gender and hand dominance, which are just two factors out of many that can affect secondary touchscreen usage. Future research on other factors is extremely important, especially for the automobile industry. The ergonomic placement and design of touchscreen interfaces in vehicles can affect the safety of drivers, therefore any significant findings help improve the design within automobiles.

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APPENDICES

Appendix A: Participation Consent Form

INFORMED CONSENT TO PARTICIPATE IN A STUDY TO TEST THE EFFECTS OF HAND DOMINANCE AND GENDER ON SECONDARY TOUCHSCREEN INTERACTIONS

A research project on touchscreen interaction is being conducted by Jordan Odell, a student in the Department of Industrial Engineering, at Cal Poly, San Luis Obispo, under the supervision of Dr. Reza Pouraghabagher. The purpose of the study is to test different factors that could affect the ease of use of touchscreen interactions. By focusing on secondary interactions, conclusions can be made to give recommendations in automobiles or workplace designs where touchscreens are being used in conjunction with a primary task.

You are being asked to take part in this study which consists of completing a task 6 times with either your dominant or non-dominant hand, while also paying attention and noting certain activities in a video. You will be given one of the following touchscreen tasks: button pressing, swiping and typing. After you are finished you will be asked to complete a short survey, in which you may omit any items you prefer not to answer. Your participation will take approximately 15 minutes. Please be aware that you are not required to participate in this research and you may discontinue your participation at any time without penalty.

There are no risks anticipated with your participation in this study. Your confidentiality will be protected by not using your name with any data collection and using subject numbers instead. The survey that will be completed at the end will remain confidential to protect your privacy. While there are no direct benefits to you, your participation in this study may result in the optimization of touchscreen applications for use while driving or while performing similar tasks.

If you have questions regarding this study or would like to be informed of the results when the study is complete, please feel free to contact the researcher, Jordan Odell at (916) 337-1235. You can also contact Dr. Reza Pouraghabagher at rpouragh@calpoly.edu. If you have concerns regarding the manner in which the study is conducted, you may contact Dr. Steve Davis, Chair of the Cal Poly Human Subjects Committee, at (805) 756-2754, sdavis@calpoly.edu, or Dr. Dean Wendt, Dean of Research, at (805) 756-1508, dwendt@calpoly.edu.

If you agree to voluntarily participate in this research project as described, please indicate your agreement by signing below Please keep one copy of this form for your reference, and thank you for your participation in this research.

______________________________	____________
Signature of Volunteer	Date
______________________________	____________
Signature of Researcher	Date

Appendix B: Experiment Instructions

Participant Screening

1) Have you frequently used touchscreens while driving? (must be less than 5 times in past year)

2) Do you have any disabilities in your fingers, hands or wrists?

3) Is your vision normal or corrected to normal?

Script I will read

*O*verview

For my research I am interested in touchscreen technology usage and if there are factors, such as gender and hand dominance that affect these interactions. I appreciate your participation and by doing this, my goal is to make recommendations to the scientific community on how safety in cars may be affected by the touchscreen technology.

Primary Task: Remembering highway signs during a video

Your primary task is to watch a video and try to accurately remember the number of times a highway sign is shown that would direct you to the ocean. These signs may include the name of a beach, cove or coastal access, for example. As you are watching the video there will be multiple signs that pass by quickly, as certain signs pass by the video will paste these signs in either of the four corners and leave the signs there for a period of time in order to view what they say. Here is an example of what signs pasted in two of the corners look like (show screen shot). The two green boxes in the corners are also places where the signs may appear. Do you have any questions on this task?

(Only the randomly selected secondary task will be read for each participant)

Task 1: Button Clicking

For this task when I say go, you will click on the circular icon located on the far left. This will bring you to a keypad that consists of 9 numbers. These numbers will be presented randomly as opposed to the typical 1-9 sequence. I will state your target number at the start of each trial. Your goal will be to find and press the button labeled with target number 3 times in a row. After you find and press the button with the target number 3 times, you will press done in the top right corner. The keypad will regenerate the order of the numbers each time you press the button, so your target will not be in the same location each time. We will perform a trial to help you better understand the task. Do you have any questions?

Task 2: Swipe

For this task when I say go, you will click on the finger icon located in the middle of the home screen. This will bring you to a screen that has 3 bars with a circular tab that you can drag left to right. Above each bar there will be a randomly generated number that falls on a scale between 0 and 100. To the right of the bar is a fraction, which represents where on a scale of 0 to 100 the circular tab is located. Your goal is to drag the circular tab so the scale to the right matches the target number listed immediately above the bar. After you drag all three bars, click done in the top right hand corner. We will perform a trial to help you better understand the task. Do you have any questions?

Task 3: Type

For this task when I say go, you will click on the keyboard icon located on the far right. This will bring you to a text box and a keyboard. You will use the keyboard to type the word that I state at the beginning of the trial. I will say go, followed by a word, you do not need to type go this just signifies the start. You do not need to capitalize the word either. Once the word is correctly typed you will click done in the top right corner. We will perform a trial to help you better understand the task. Do you have any questions?

Appendix C: Post Experiment Survey

Personal Questions

Email (if interested in the results/defense) ______________________

Age __________ Class Level ________________

Gender? Male Female

Which hand is your dominant? Left Right

Which hand were you using? Dominant Non-Dominant

Which task were you completing? Button Click Swiping Typing

Survey Questions:

1) On a scale of 1 to 5, 1 being easy and 5 being difficult: How difficult was it to complete your touchscreen task?

1 2 3 4 5

2) On a scale from 1 to 5, 1 being easy and 5 being difficult: How difficult was it to focus on the video while completing the touchscreen task?

1 2 3 4 5

3) On a scale from 1 to 5, 1 being not confident and 5 being confident: How confident did you feel in your completion of the touchscreen task and your accuracy? (ex: unsure if the button registered, if you pressed the right button or swiped to the correct value)

1 2 3 4 5

Appendix D: Learning Curve ANOVA

Task 1 Trials ANOVA

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	54.08119	10.8162	2.2330
Error	114	552.18299	4.8437	Prob > F
C. Total	119	606.26418		0.0557

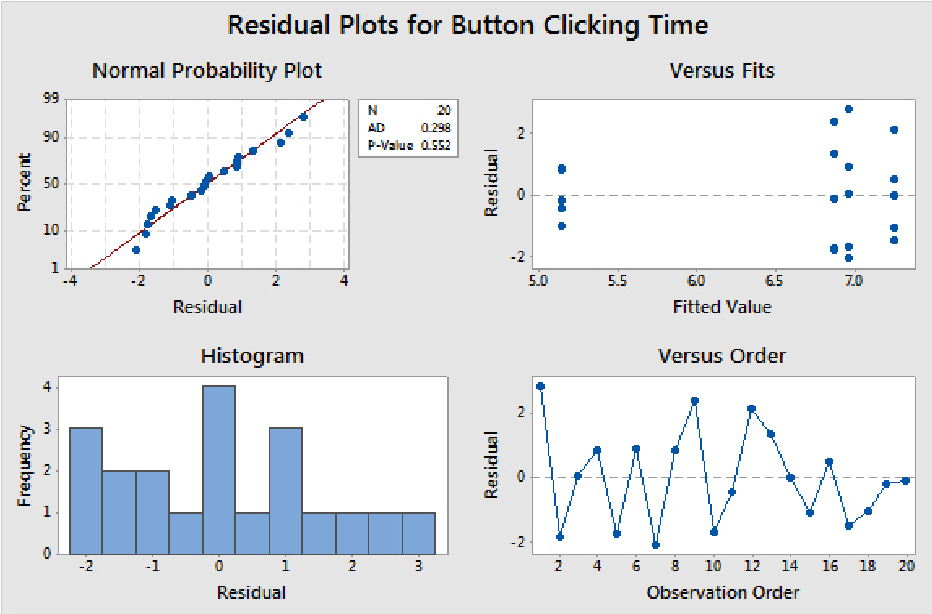
Task 2 Trials ANOVA

Analysis of Variance

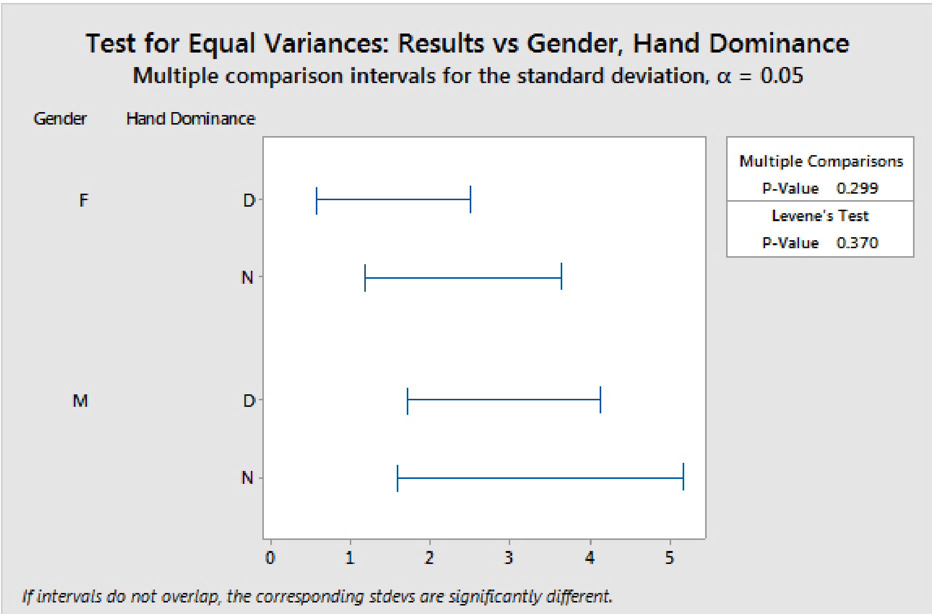
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	363.5403	72.7081	1.7918
Error	114	4625.8271	40.5774	Prob > F
C. Total	119	4989.3673		0.1200

Appendix E: Assumption Graphs

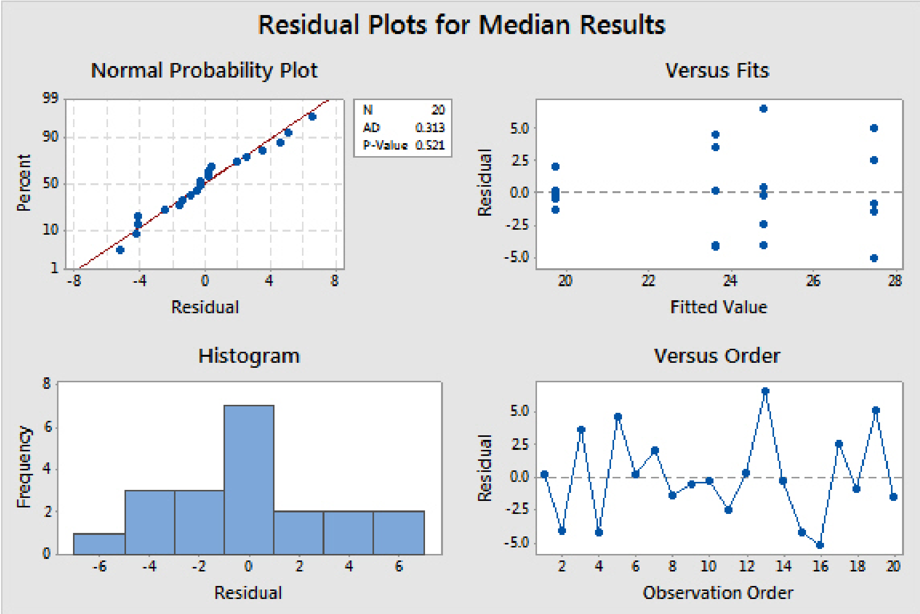
Task 1 Residual Plots



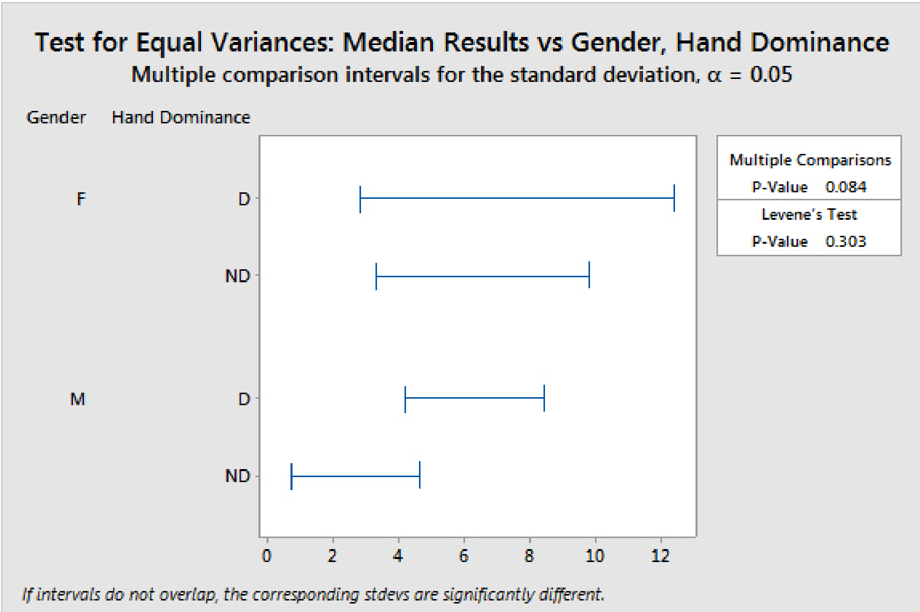
Task 1 Equal Variance Plot



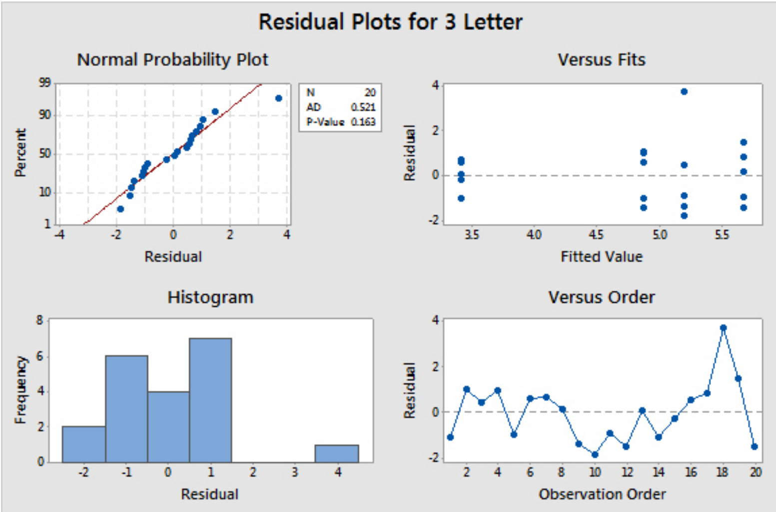
Task 2 Residual Plots

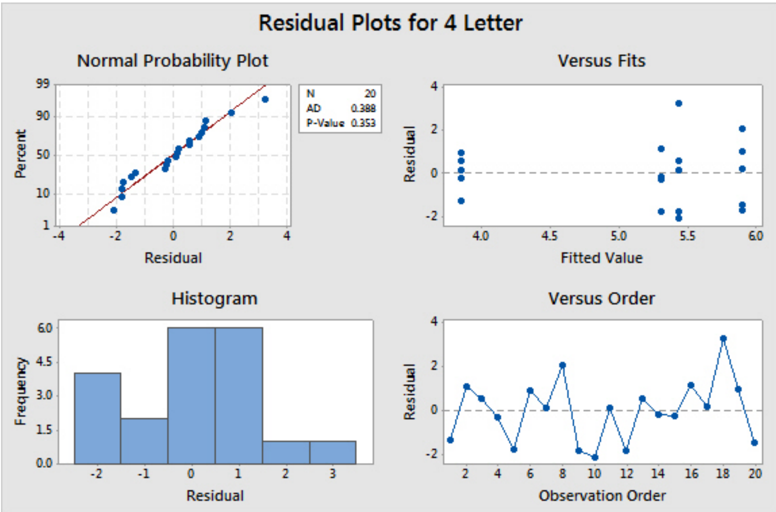


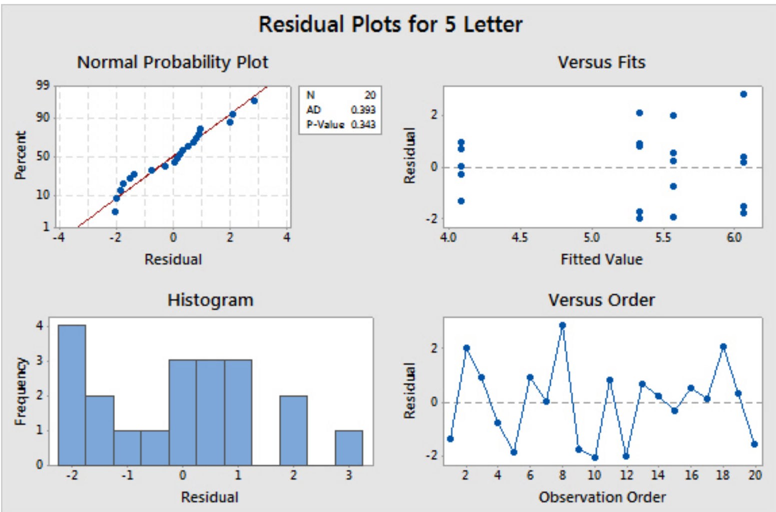
Task 2 Equal Variance Plot



Task 3 Residual Plots







Task 3 Equal Variance Plots