ABSTRACT

Title of Document:	OF MICE AND MEN: AN ERGONOMIC AND MARKET ASSESSMENT OF CURRENT COMPUTER MICE
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Work-related Musculoskeletal Disorders (WMSDs) are conditions that develop over time due to repetitive motion and can painfully affect the fingers, wrist, arm, shoulder, back, and neck. Studies indicate a correlation between heavy computer mouse use and the prevalence of WMSDs. Our team evaluated current ergonomic mouse designs to determine which features of mice reduce excessive muscle activation and harmful arm and hand positioning while still maintaining ease of use and marketability. A motion capture system tracked arm and hand positioning, EMG analysis measured muscle activation, force sensors quantified the user’s clicking force, and a Fitts’ test evaluated mouse use efficiency. To determine the marketability of mice features, surveys generalized user preferences, while focus groups closely examined specific market factors. All these systems were combined to identify areas of improvement in ergonomic mouse design.

OF MICE AND MEN: AN ERGONOMIC AND MARKET ASSESSMENT OF CURRENT COMPUTER MICE

By

Team MICE
(Modifying and Improving Computer Ergonomics)

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(1) $MT = a + b \log2 (2A/W)$

(2) $MT = a + b \log2((A+W)/W$

(3) $IP = 1/b$, (see equation 2)

(4) $B = -2 (1 - r) \ln(1 - A)$

(5) $W_{xe} = \sqrt{}((2B/(1 - r^2))$
$\{SD_x^2 + SD_y^2 - \sqrt{}(SD_x^2 - SD_y^2) + 4 (SD_x^2) (SD_y^2) r^2 \})$

(6) $W_{ye} = \sqrt{}((2B/(1 - r^2))$
$\{SD_x^2 + SD_y^2 + \sqrt{}(SD_x^2 - SD_y^2) + 4 (SD_x^2) (SD_y^2) r^2 \})$

(7) $W_{xe} = \sqrt{}((2B/(1 - r^2))$
$\{SD_x^2 + SD_y^2 + \sqrt{}(SD_x^2 - SD_y^2) + 4 (SD_x^2) (SD_y^2) r^2 \})$

(8) $W_{ye} = \sqrt{}((2B/(1 - r^2))$
$\{SD_x^2 + SD_y^2 - \sqrt{}(SD_x^2 - SD_y^2) + 4 (SD_x^2) (SD_y^2) r^2 \})$

(9) $We_x = 2u_x((1 - A)/2)\ SD_x$

(10) $We_y = 2u_y((1 - A)/2)\ SD_y$

(11) $ID_e = \log2(d / s + 1.0)$

(12) $Time = a + b \log (d/ s + 1.0)$

(13) $Time = a + b\ ID_e$

(14) $IP = \frac{Time}{ID_e}$

(15) $\theta = \cos^{-1} \frac{v_1 \cdot v_2}{\|v_1\| \|v_2\|}$

(16) $ID_e = \log_2 ((d / s) + 1)$

(17) $\text{Throughput} = ID_e / t_m$

(18) $$V_{sensor} = V_{source} \frac{Zsensor}{Zsensor + Zconst}$$

(19) $$Z_{sensor} = -\frac{Vsensor \times Zconst}{Vsource \times (\frac{Vsensor}{Vsource} - 1)}$$

(20) $s = \min(W_{xe}, W_{ye})$

Chapter 1: Introduction

1.1 The Problem

Work-related musculoskeletal disorders (WMSDs) are degenerative conditions caused by repetitive motion that result in injury to muscles, nerves, tendons, joints, cartilage, and/or spinal discs. WMSDs most often occur in the forearm, upper arm, shoulder, neck and back. Common WMSDs include sprains, strains, tendonitis, and most notably Carpal Tunnel Syndrome (CTS). In 2001 alone, there were 522,528 reported cases of WMSDs that caused employees to take days off work[1]. There is a positive correlation between WMSDs and occupations that involve repetitive hand motions as part of the daily routine, such as operators, laborers, sales, administrative support, and data entry personnel. [2]Undeniably, WMSDs cause a large societal impact.

One of the most ubiquitous daily tasks across most industries is using the computer mouse. Common mouse tasks such as pointing-and-clicking and dragging-and-dropping involve repetitive motions of the forearm and fingers that are correlated with WMSDs. In a study published in the *American Family Physician,* researchers discovered that mouse use of more than 20 hours per week was related to tingling and numbness associated with WMSDs and use of more than 30 hours per week carried an increased risk of CTS symptoms.[3]

In order to address this problem, many companies have attempted to design ergonomic computer mice to decrease the risk factors that lead to WMSDs. Although these new designs are more beneficial to the body, they are not as commercially successful as would be expected. Research indicated that these mice were not as efficient or usable as their counterparts.[4] In addition to this, ergonomic mice are not marketed to the average computer user. These concerns, coupled with a lack of innovation, mean that the average consumer has been purchasing the same basic mouse design for years.

1.2 Research Question:

The societal impact of WMSDs and the overall market situation led to the research question: Which features of current ergonomic mice can be combined to optimize activity in muscle groups affected by Work Related Musculoskeletal Stress Disorders while remaining marketable and efficient? In order to effectively address every part of this complex question, Team MICE defined specific research objectives:

- To identify and explore consumer preferences concerning computer mice
- To evaluate the efficiency of current computer mice
- To determine which hand and arm positions are optimal in reducing stress on the body
- To measure computer mouse users' button activation force
- To quantify and compare the activity in different muscle groups during mouse use

These five objectives were converted into design parameters that provided the basis for the methodology.

1.3 Outline of the Study

In order to address every design parameter, we pursued a mixed methodology that can be divided into two major sub-sections: business research and experimental research. The business research consisted of market and consumer research that addressed the first research objective. Both surveys and focus groups were used to gather data about consumer preferences and what type of mouse designs may be successfully marketed. The experimental methodology focused on the last four design parameters through a multi-part approach: a Fitts' test served as a metric for mouse use efficiency; a motion capture system evaluated hand and arm positions and movements; a force sensor quantified user's button activation force; and EMG analysis measured muscle activation. Conclusions from the two sub-sections were combined to provide overall mouse design recommendations that would best satisfy all of the design parameters.

Chapter 2: Literature Review

2.1 Work-Related Musculoskeletal Disorders

Work-Related Musculoskeletal Disorders (WMSDs) are a group of disorders caused by frequent and repetitive work activities that require awkward or non-neutral postures.[5] This group of disorders primarily affects the hand, wrist, elbow, neck, and shoulder; however, cases of WMSDs have also been reported in the legs.[6] The group of Work-Related Musculoskeletal Disorders includes a range of inflammatory and degenerative disorders that affect the muscles, tendons, ligaments, joints, peripheral nerves, and supporting blood vessels.[7] The U.S. Department of Labor defines Work Related Musculoskeletal Disorders as "injuries or disorders of the muscles, nerves, tendons, joints, cartilage, and spinal discs, associated with exposure to risk factors in the workplace. Work-Related Musculoskeletal Disorders do not include disorders caused by slips, trips, falls, motor vehicle accidents, or similar accidents."[8] In addition to the name "Work-Related Musculoskeletal Disorders", this group of disorders is also referred to as: Repetitive Motion Injuries/Disorders, Repetitive Strain Injuries, Cumulative Trauma Disorders, Occupational Cervicobrachial Disorders, Overuse Syndrome, Regional Musculoskeletal Disorder, and Soft Tissue Disorders.[9] For the purposes of our research, the disorders will be referred to as Work-Related Musculoskeletal Disorders.

Common WMSDs

Included in this group of disorders are a number of more commonly known disorders, such as Carpal Tunnel Syndrome, Tendonitis, Thoracic Outlet Syndrome, and Tension Neck Syndrome. Of the more well known WMSDs, Carpal Tunnel Syndrome

(CTS) is most common and causes the greatest number of days away from work.[10] CTS is a painful, progressive condition that can cause sensations ranging from tingling and numbness to shooting pains within the arm, wrist, and hand. CTS is caused by the compression of a key nerve in the wrist. Compression occurs with certain positions of the hand, especially those characteristic of repetitive, every-day tasks. In various occupations, such as data entry and graphic design, there is a positive correlation between CTS and computer intensive work that involves extended hand and wrist usage.[11]

Tendonitis is the inflammation, irritation, or swelling of a tendon, the tough, flexible band of fibrous tissue that attaches muscles to bone. Common causes of tendonitis are overuse and aging, which reduce the elasticity of the tendon. Tendonitis mostly affects joints in the heel, wrist, elbow, and knee. To prevent tendonitis, one should avoid repetitive motion and overuse of the joints.[12]

Thoracic Outlet Syndrome is a disorder that is a result of compression of the brachial plexus or subclavian vessels in the upper extremity. This disorder is characterized by pain in the arm, shoulder, and neck.[13] It can also cause weakness and discomfort in the upper limb. These symptoms can be exacerbated by elevating the arms or making exaggerated movements of the head and neck.[14] Thoracic Outlet Syndrome is often difficult to diagnose because the symptoms are similar to other injuries and disorders.[15]

The final common disorder that qualifies as a WMSD is Tension Neck Syndrome, which is a disorder caused by a combination of factors including repetition, forceful exertions, and constrained or static postures. There is evidence for a causal relationship between highly repetitive actions and neck and shoulder musculoskeletal disorders.[16]

Symptoms and Effects

Work Related Musculoskeletal Disorders can have serious physical and thus health related consequences. It is difficult to study how WMSDs affect human muscles and tendons because there are a number of confounding factors that can contribute to the inflammation and degeneration of the muscle, therefore researchers tested the effects on rats. Researchers found that WMSDs caused more inflammation than degeneration in rat muscles and tendons. With chronic repetitive tasks, they saw that the muscles were injured initially, and then they showed signs of inflammation. The repetitive motion causes the myofiber within the muscle to split and be replaced by a smaller muscle unit called the myofibril. Muscles are much more adaptive than tendons; even so, they are unable to recover from repeated strains at fast velocities, such as in clicking the mouse.[17]

In addition to the effects on muscles and tendons, WMSDs can also have neurological effects. Studies show that repetitive hand intensive tasks can affect the Central Nervous System's ability to control your hand movements. The nerve tissue damage and inflammation can result in reduced functionality, which can cause overexertion of neighboring nerves, resulting in further nerve damage and inflammation.[18] In another study that looked at the effects of low repetition tasks with negligible force on the muscles and nerves of rats, it was found that after an extended period of time the rats experienced inflammation in their bones and peripheral nerves.[19]

Work Related Musculoskeletal Disorder symptoms are often intermittent and episodic, especially when they first develop which makes them difficult to diagnose. In the early stages of WMSDs, patients experience aching and tiredness in the affected limb; the fatigue usually goes away when the patient is done working, and there is no loss in productivity. In the intermediate stages of the disorder, the patient experiences aching and tiredness early on in their work shift, and it continues after the work day. In the intermediate stage, there is some reduction in productivity, and the patient is not able to engage in repetitive tasks for extended periods of time. Finally, in the late stages of the disorder the patient experiences aching, tiredness, and fatigue, even at rest. The fatigue and pain may continue into the night and cause sleep difficulties. In addition to aching and fatigue, other symptoms include joint stiffness, muscle tightness, swelling of the affected area, numbness, and decreased sweating of the hands.[20]

Societal Impact

Work Related Musculoskeletal Disorders are the largest category of work related illness.[21] They encompass a wide range of disorders that affect major parts of the body. These disorders are widespread in countries all over the world, and they incur high costs and impact one's quality of life. WMSDs make up a major proportion of registered work related diseases in a number of countries. In the United States, the Nordic countries (Denmark, Finland, Sweden, Iceland, and Norway), and Japan, WMSDs represent a third or more of all registered occupational diseases.[22] Of the new employees working at a computer workstation, about half experienced or reported symptoms associated with musculoskeletal disorders within one year of employment.[23]

In Britain, 2400 people out of every 100,000 people suffer from a WMSD, and a total of 11.6 million sick days are used to recover from a WMSD. The 11.6 million days accounted for about one third of the total days taken off, including vacations. WMSDs cause more work absenteeism and disability than any other group of diseases; as a result, WMSDs cause the greatest loss in productivity.[24]

Though these numbers seem high, there is a great deal of underreporting of WMSDs. The symptoms are often episodic and subjective; some people have a higher pain tolerance than others and in most cases WMSDs are self reported. The limitations in diagnostic technologies coupled with the inconsistency from one examiner to the next makes it difficult to standardize diagnostic criteria.[25]

Causes of WMSDs

A number of studies have been conducted to determine causes of Work Related Musculoskeletal Disorders. The National Institutes of Health (NIH) released a report that associated WMSDs with the performance of repetitive and forceful hand intensive tasks. The effects of the repetitive and forceful motions were worsened by awkward wrist positions and forearm postures, cold temperatures, and vibrations.[26]

In an extensive literature review, the National Institute on Occupational Safety and Health (NIOSH) found that there is a strong correlation between a combination of repetition and force and Carpal Tunnel Syndrome; there is also a strong correlation between a combination of force and posture and Carpal Tunnel Syndrome. In a follow up literature review by the National Research Council (NRC), conclusions similar to those of the NIOSH review were made.[27]

Later studies show that the greatest risk factor for Work-Related Musculoskeletal Disorders is repetitive movements because it involves a fixed posture and an increasing amount of force. When completing a computer task, the worker must sit in the same position and repeatedly use the same muscles, which can lead to muscle strain. If there is not a sufficient break between tasks, the muscles are not able to recover and slowly become fatigued. The muscles are continuously contracting and putting pressure on the surrounding blood vessels, resulting in decreased blood flow to the working muscles, further contributing to muscle fatigue. As the muscles become strained and fatigued, the worker must exert more force to complete the same task, which further strains the muscle, which can then damage the surrounding nerves.[28]

In addition to repetition and force, the NIOSH and NRC literature reviews revealed that awkward or sustained upper extremity postures can contribute to tendonitis in the hand and wrist or strains and sprains. The literature review also indicated that workers who use the computer mouse for extended periods of time, which is defined as more than 20 hours a week, are at an increased risk for Carpal Tunnel Syndrome and other Upper Extremity Work Related Musculoskeletal Stress Disorders.[29] In a study examining the postural differences between mouse use and keyboard use researchers found that non-neutral hand positions were maintained for longer periods of time during mouse use than keyboard use. The same study determined that the pressure in the Carpal Tunnel of the wrist increases with non-neutral positions.[30]

There are a number of sources that link computer use to Upper Extremity WMSDs. Epidemiological studies of physical and psychosocial exposures show that people who use computers have an increased risk of WMSDs. Interventions for upper extremity WMSDs call for the controlled use of computers.[31] In general, computer users spend about one to two thirds of their computer work time using the mouse, engaging in various tasks such as clicking and dragging and dropping.[32]

Other studies show a more specific correlation between mouse use and upper extremity Work Related Musculoskeletal Disorders, as well as mouse use and Carpal Tunnel Syndrome. When using a computer keyboard or mouse, the wrist flexes dorsally and there is ulnar deviation, both of which can cause wrist joint friction. The friction can lead to tensynovitis, a type of inflammation associated with tendonitis, which is considered a WMSD.[33]

The evidence suggests that these effects are more pronounced in actual computer mouse use versus statically placing the hand on the mouse. For the specific mouse tasks, such as clicking and dragging and dropping, the carpal tunnel pressure was found to be greater during dragging and dropping tasks versus pointing tasks. Researchers who examined the increase in carpal tunnel pressure during mouse use were concerned with how high the pressure was. Previous studies showed that high pressure of that magnitude for prolonged periods of time were associated with altered nerve function and structure.[34]

2.2 Mouse Studies

There are many different mouse designs that are available on the market. While some have been subtle modifications of traditional designs, others have been re-imaginings of what a mouse should look like or what it should do.[35] Different designs have focused on different user needs, including ergonomics, functionality, and portability.[36] Significant work has also been done towards replacing the current mouse and keyboard computer interface with one that is more efficient.[37]

Evolution of the Mouse

Several prominent designs are clearly improved versions of Douglas Engelbart's original traditional mouse design from 1963(seen in Figure 1 below).[38] Advances in technology have led to improvements in how the mouse senses movement, leading to mouse balls, optical mice, and gyroscopic mice.[39] While the first mouse designs used two rollers to detect 2-D movement, researchers in the 1970s developed the ball-mouse that recorded movement in any direction. The next major advancement in terms of sensing movement happened when researchers at both MIT and Xerox each came up with ways to use optical sensors and light-emitting diodes (LEDs) to detect movement of the mouse.

Figure 1: Doulas Englebart's original mouse design[40]

There have also been changes in how the mouse interfaces with the computer, both in terms of wired and wireless technologies. There have been improvements in the physical connectors, evolving from bulky DB-9[41] to the smaller PS/2, and eventually to the multipurpose Universal Serial Bus (USB)[42]. Wireless mice can function using wireless USB receivers or by utilizing standards like Bluetooth[43]. These open wireless protocols make it possible to exchange data over small distances, and are thus very useful in acting as a relay for wireless mouse designs.

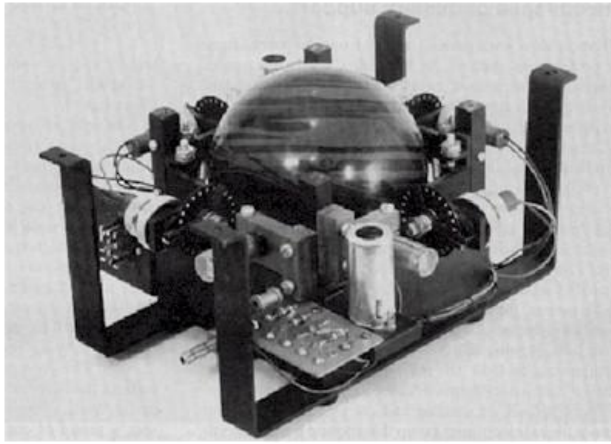


Figure 2: The user interface for the Canadian Navy's DATAR system

The trackball has been an alternate design for a computer interface that existed since 1952 as part of a project of the Canadian military[44]. The original design can be seen in Figure 2 above. It uses a freely rotating ball to direct the pointer, and has a side button for item selection. This type of input prevents the problem of getting debris caught in the mouse ball, as the ball touches the user's hand and not a mouse pad. Early designs used rollers to detect the movement of the ball, but as technology improved there was a shift towards using dotted balls that could have their rotation monitored by optical sensors.[45] However, as newer mouse designs gained increasing market share, retailers cut back on their willingness to stock trackball mice, in turn leading to a reduced number of different trackball designs on the market.

As available technology becomes both smaller and cheaper, there have been more and more new ideas for the shape of the computer mouse. Some new designs focus on changing the hand orientation to one similar to a handshake in order to improve the ergonomics of the design by promoting a neutral wrist and forearm posture. A neutral posture is one where the wrist is flat, and the forearm is halfway between palm up and palm down.[46] Other designs focus on providing more support for the wrist and forearm in order to reduce the stresses caused by mouse use. Another approach for reducing stresses caused by mouse use is reorganizing the button layout to change the motions required to move and activate the mouse into ones that require less movement.

However, many designs do not focus on ergonomic benefits at all. Some designers aim to create smaller, easier to use mice that are specifically designed for children[47]. Others create more portable, yet fully functional, wireless mice for use with laptops. There are even more designers who work on various handheld mice with built in pointers for use in presentations. With all of these new ideas, very diverse competitors have made their way into the market for computer mice.

Current Designs on the Market

There are many different mouse designs available to consumers. Through the power of online shopping and the emergence of secondary markets, it is possible for manufacturers to produce and sell many very different designs. These designs are created with different purposes or features in mind. Some mice, such as Logitech's Optical Mouse USB, are designed to be used with desktop systems while others, like Dell's 5-button Bluetooth Travel mouse is made to be used as a laptop mouse. Several designs, like Hillcrest Labs' oddly shaped Loop Pointer, are made to be used during presentations. For those who favor a trackball mouse, there are a few manufacturers who continue to make trackball designs. Many different manufacturers also attempt to make "ergonomic" designs that each have a different approach to solving the issues associated with poor mouse design. Different mouse designs on the market can be seen in Appendix A.

Mice used in study

Five different computer mice were examined in this study. Four test designs were chosen, each with a unique shape or feature that made it “ergonomic”. A control mouse was also used, so that for each test performed the results for the test mice could be measured against a standard.

The first design chosen was the Logitech Trackman Marble (Figure 3a). This trackball mouse allows the user to control the translational motion of the cursor by rotating a speckled trackball. Its symmetric design, with redundant buttons on each side, is suitable for both left-handed and right-handed users. Online reviews praise the button positioning, as well as the way that the design reduces pressure on the wrist[48].

(a) (b)

Figure 3: Logitech’s Trackman Marble(a) and Evoluent’s VerticalMouse2(b)

The next design selected was Evoluent’s VerticalMouse2 (Figure 3b). This design rotates the orientation of the hand 90° compared to the traditional mouse. Doing this reduces both twisting of the arm and friction with the desk surface. This mouse was evaluated by UC Berkeley, and found to be successful in promoting a neutral position[49]. Reviewers of the design have supported its claim that the posture change promotes less painful computer use[50].

3M's Joystick Mouse was also included in the study (Figure 4a).. Shaped like a joystick, this mouse both shifts the resting position of the hand and changes the operating motions for clicking and translating the pointer. According to its creators, the mouse is designed so that its vertical grip reduces pressure on the median nerve[51]. The mouse has an "Ease of Use Commendation" from the Arthritis Foundation because of the neutral position that it is designed to promote[52]. There have also been several case studies done that verifies the design's success in reducing user fatigue, risk of shoulder and arm problems, and lost-time from work[53].


(a) (b)

Figure 4: 3M's Ergonomic mouse(a) and the Zero Tension Mouse(b)

The Zero Tension Mouse designed by Dr. Michael Leahy was the last ergonomic design included in the study (Figure 4b). Designed to reduce repeated strain injuries, the mouse has a similar shape to the Vertical Mouse, but the minor shape differences have a significant effect on user posture and activation motions. The mouse is designed so that the motions that the user goes through do not put excess tension on the tissues in the arm[54]. While this design was used for the consumer research portion of the project, it was not included in the laboratory testing as it is available in different sizes and testing each one would be impractical. Also, participants were randomly assigned test mice, making it difficult to test a single size without additional pre-screening.

The control mouse used in this experiment we the Dell 2-Button Optical Mouse with a scroll wheel (Figure 5). This mouse features a very traditional design that is similar to the default mice shipped with typical desktop systems. As this type of design is the standard for many work and academic settings, it should serve as a good standard with which to compare the different ergonomic designs.

Figure 5: The Dell 2-Button mouse

2.3 Past Studies: Market Research

Customer preference is an important component of product design. Redesigned mice that focus on user ergonomics and functionality, but ignore consumer preferences tend to be met with negative reviews and lower sales than expected[55]. There have been a variety of opinions on the exact cause for this disconnect between suppliers and consumers. Some have suggested that consumer purchase behavior is governed by house hold storage constraints reducing additional purchases[56]. Others have claimed that customer expectations for pricing are the most important factor in explaining poor sales[57]. In order to make sure that our final design guidelines included customer-based requirements in addition to technical requirements, we examined both of these ideas in greater detail.

Purchase Habits

Consumers have different purchase habits that influence how producers and vendors should sell ergonomic mice[58]. Understanding what might influence these habits can be very useful in identifying where and how to sell a mouse. For example, if customers only buy mice when purchasing a new computer, it would make more sense for an ergonomic mouse manufacturer to team up with a PC retailer than to attempt to sell their product at an office supply store. Knowing how customers purchase computer mice is also useful in figuring out how to successfully market a mouse. This would allow a producer to know whether they should focus promotion efforts on online stores or brick-and-mortar stores. Another useful piece of information is the type of research that consumers do before determining which mouse to buy. With this knowledge, a producer could understand what types of information they should make public, and where consumers would like to have information about their products. Understanding each of these components is useful for both the creation of an ergonomic mouse and in successfully marketing the mouse.

Pricing Expectations

Another important part of understanding consumer preferences when designing a product is being able to identify a reasonable target price. Based on the quality of their product, cost of production, and uniqueness of the good or service they provide, firms must identify a reasonable price for their products. For technology products, such as computer mice, this can be problematic. Clear differences in design have created a diverse market with many niches that have different pricing expectations. Further adding to this problem are issues with the adoption curve, which makes it clear that time is a significant factor in affecting if a customer is even willing to consider purchasing a new technology[59]. For ergonomic mice, these two factors work to reduce the number of users considering the product, but raise the expected price for the mouse.

The reality of this situation can be seen by taking a sampling of traditional mouse designs and comparing their prices of those of ergonomic mice. Most traditional designs retail for as low as $5, with more expensive mice based on connection type and optical sensor resolution[60]. However, looking at the prices for ergonomic mice, it is difficult to find a new mouse that is priced below $35[61]. Whether this discrepancy in prices is in tune with customer expectations or is purely driven by the market will be something that is explored through this project.

Technology Preference

Consumers have traditionally not been receptive to changes in technology. While there are some people willing to embrace new technology, this number is usually limited to around 2.5% of the total user group when the market for the product is mature[62]. If a new technology hopes to have a large, immediate following, it must make sure to be reasonably similar to existing technology. Alternatively, when the new technology is being used for a different purpose than the technology it is replacing, it is necessary to ensure that the new technology conveys that shift. In the case of this project, this means that an ergonomic design that does not convey a sense of its ergonomic nature will not be an effective design. These two conflicting preferences must be managed in an effective ergonomic design.

Focus Group and Survey Formation

Other studies were consulted in order to market our mouse to a larger number of consumers. These were extremely important because they offered a number of specific guidelines to follow while organizing these groups. Focus groups were used as method of gathering data to use to narrow design constraints. Specific analytical frameworks were applied to interviews to extract the most valuable information. Focus groups were useful for a variety of reasons. The target market depends heavily on relative individual user preference with small variation overall, meaning that qualitative information is key. As Krueger and Casey point out, focus group information is particularly useful at uncovering motivation and opinions, particularly when trying to expose the group to new ideas – in this case, new varieties of mouse design.

Krueger and Casey also place a great deal of importance on the size and selection restrictions, question design, and organization of focus groups. Size was kept to no more than five to six students per session to minimize the marginalization of participants while maintaining a large enough base for variation in the qualitative information. Participants were selected in both a narrow and broad fashion. Heavy users of computer mice were recruited for the focus groups because that subset of people would be most likely to participate in quality discussion. Within this cross section, emphasis was put on finding a variety of people from different backgrounds, in order to possibly isolate common threads between different users of mice. As Krueger and Casey advised, the questions were kept open ended and simple, moving from general to specific, while maintaining direction. These points were particularly important in keeping the focus groups on track and producing usable information.

2.4 Past Studies: Technology

The methods and processes of prior experiments and professional studies have heavily influenced our experimental methodology. Many studies separately used EMG testing, a motion analysis, a Fitts' test, or a button activation analysis to characterize mouse use. A few studies combined multiple analyses but no study fused all analyses together into one experiment. Using a wide variety of such sources, we incorporated and applied key aspects of these experimental designs to incorporate all four analyses into our experimental design.

Fitts' Test

Fitts' Law was devised to display the relationship in human motor tasks between the time taken to complete a movement task (MT), the distance traveled during the movement (A), and the width of the area where the movement was to terminate (W). The relationship is displayed in the equation:

$$MT = a + b \log2 (2A/W) \qquad (1)$$

In 1989, Scott MacKenzie explained the origins of this law. Fitts' Law was based upon Shannon's Theorem, a theorem that expressed the relationship in physical communication systems between the noise of a transmitted signal and the uncertainty of the amplitude of the signal. Fitts' Law was adapted from this theorem to apply to human motor tasks. MacKenzie proposed that a Fitts' Law equation directly derived from Shannon's theorem was the most accurate model of experimental data in human motor tasks. His equation was:

$$MT = a + b \log2((A+W)/W \qquad (2)$$

Many experiments deviated from this equation, and MacKenzie proposed that his equation boasted more accurate results than the equations used in other experiments.[63]

MacKenzie's study, however, was confined to one-dimensional motor tasks. This study is beyond the scope of MacKenzie's proposal, as the motor tasks completed by the experiment participants are two-dimensional; therefore, to evaluate the Fitts' relationship in the motor tasks of this experiment, a Fitts' equation adapted to two-dimensional motor tasks must be used.

In 1992, MacKenzie and Buxton began to explore Fitts' Law in two dimensions through target acquistion tasks (pointing and clicking) on a computer. The main issue with converting the original Fitts' equation to two dimensions was converting the width within which the movement was to terminate (W) to apply to two dimensions. When motor tasks are performed in two dimensions, the angle in which a human subject moves varies. In a one dimensional Fitts' Law, the angle does not vary, and therefore, W would not vary (Figure 6).

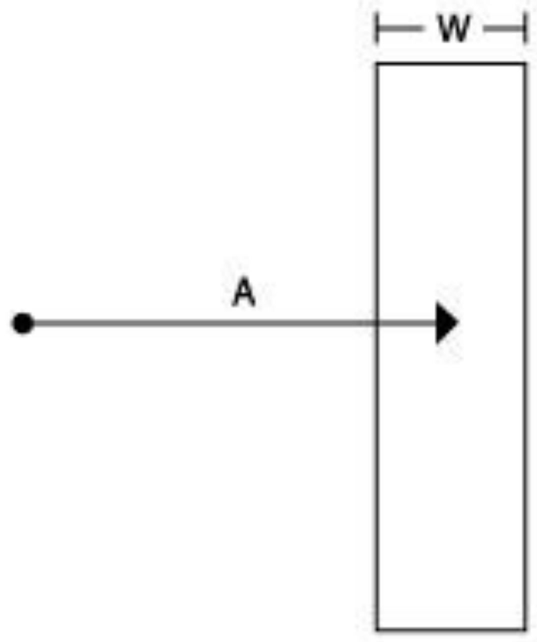


Figure 6: The arrow displays the amplitude (A) of the subject's movement and the termination width (W) from Equation 2.

MacKenzie and Buxton explored the different possible values for the target width, and proposed the most accurate value of W for two-dimensional pointing tasks. In two dimensions, they had to consider both the width and height of the target that their subjects had to click on with a mouse (Figure 7).

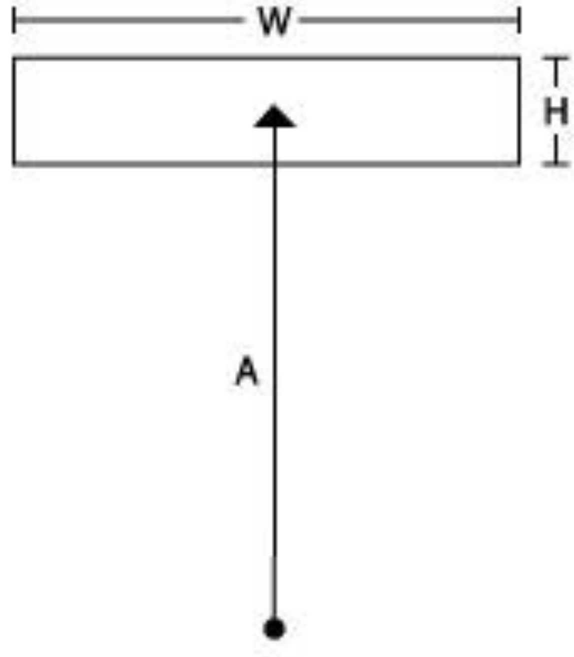


Figure 7: Two-dimensional pointing tasks introduce the role of the target height (H) in the target acquisition tasks.

MacKenzie and Buxton proposed different models of the target width, labeling them as STATUS QUO, W+H, WxH, SMALLER-OF, and W'. STATUS QUO used the original one-dimensional Fitts' equation's target width W as its model. W+H used the sum of the width and height of the target as the target width. WxH used the area of the target as the target width. SMALLER-OF selected the smaller of W and H as its target width. W' used the width of the target along the subject's line of movement as the target width (Figure 3). With each of these models, MacKenzie and Buxton had subjects perform a target acquisition task with a computer mouse.

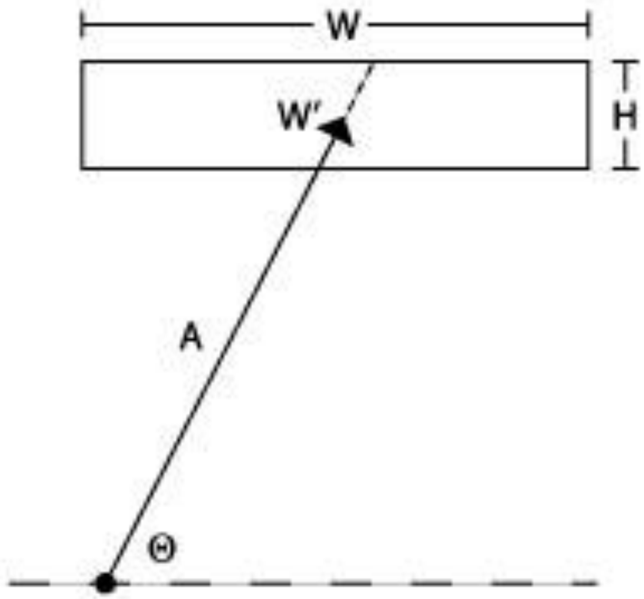


Figure 8: W' is the width of the target on the line of approach of the subject's movement.

MacKenzie and Buxton found the SMALLER-OF model to be the most accurate model, followed closely by the W' model. The original STATUS QUO model for one-dimensional target acquisition tasks proved to be the least accurate model after comparing how much the models varied as experimental parameters were changed. While this study concluded the accuracy of certain target width models over others, MacKenzie and Buxton encouraged further research into better models for two-dimensional target acquisition tasks.[64]

MacKenzie et. al. addressed the application of Fitts' Law in the comparison of different input devices in pointing and dragging mouse tasks. Their experiment is relevant to the context of this study because they introduce a way to normalize the target width, which will allow the comparison of the standard mouse and the different ergonomic mice in this study. In previous experiments, the Fitts' index of performance (IP) equation (3) was used to compare performance across multiple devices.

$$IP = 1/b, \text{ (see equation 2)} \qquad (3)$$

This application of the IP is invalid because the error rates differ among different input devices. MacKenzie et. al. proposed the concept of the effective target width, W_e, which was derived from the technique that Welford developed to normalize subject responses based on their error rate. With W_e, the error was explicitly set to 4 percent, and thus stated what the subject's performance would be with this constant error rate. This normalization allowed MacKenzie et. al. to compare the performances among their three input devices, a standard mouse, a tablet, and a trackball mouse. Their study concluded that the trackball had the worst performance in the pointing and dragging tasks. However, their study was only applied to one-dimensional mouse tasks; limiting the application of portions of their methodology into this experiment.[65]

To develop the methodology for this experiment, further research was needed in which the concept of normalization in Fitts' Law and two-dimensional tasks were combined. In 1999, Murata used two-dimensional probability distributions to translate the one-dimensional effective target width to two-dimensional pointing tasks.

In Murata's experiment, he had subjects move from the center of the screen to a square target across the screen, using an approach angle of 45 degrees. The targets had 4 different areas and were placed at 4 different distances from the target across the screen (resulting in 16 different combinations). Each subject had to complete 100 pointing trials for each combination. Murata calculated an effective target width in both the horizontal

(W_{xe}) and vertical (W_{ye}) dimensions. To calculate these widths, Murata used the two-dimensional joint probability density function B,

$$B = -2\,(1 - r)\ \ln(1 - A) \tag{4}$$

where r is the correlation coefficient between the x and y coordinates clicked during the target acquisition task and A is the explicitly stated error (used for normalization). From equation 4, the standard deviations of the x and y coordinates (SD_x and SD_y, respectively) were used to calculate the effective target widths in each direction:

For $SD_x < SD_y$,

$$W_{xe} = \sqrt{(\,2B/(1 - r^2)\,)} \quad \{SD_x^2 + SD_y^2 - \sqrt{(SD_x^2 - SD_y^2) + 4\,(SD_x^2)\,(SD_y^2)\,r^2}\ \}\,) \tag{5}$$

$$W_{ye} = \sqrt{(\,2B/(1 - r^2)\,)} \quad \{SD_x^2 + SD_y^2 + \sqrt{(SD_x^2 - SD_y^2) + 4\,(SD_x^2)\,(SD_y^2)\,r^2}\ \}\,) \tag{6}$$

For $SD_x < SD_y$,

$$W_{xe} = \sqrt{(\,2B/(1 - r^2)\,)} \quad \{SD_x^2 + SD_y^2 + \sqrt{(SD_x^2 - SD_y^2) + 4\,(SD_x^2)\,(SD_y^2)\,r^2}\ \}\,) \tag{7}$$

$$W_{ye} = \sqrt{(\,2B/(1 - r^2)\,)} \quad \{SD_x^2 + SD_y^2 - \sqrt{(SD_x^2 - SD_y^2) + 4\,(SD_x^2)\,(SD_y^2)\,r^2}\ \}\,) \tag{8}$$

The two dimensional effective target width calculations developed in Murata's study provided a metric for efficiency of the standard and ergonomic mice through the calculation of the effective index of difficulty and throughput. These calculations rely on the effective target width and their formulas will be introduced in this experiment's analysis.

Motion Capture

In 2007, J.N.A. Brown et. al. compared the posture of newly created input device to other commercially available mice. Poor posture has been shown to increase the likelihood of developing WMSDs such as CTS[66]. Brown et. al. created a new design to alleviate the strains of mouse use. To test their hypothesis, researchers recruited 24 participants to perform steering tests with the different mice while using a VICON optoelectric motion capture system to monitor the participant's posture. Six cameras were placed around the participants and thirteen markers placed on the forehead, wrist, elbow, shoulder, upper arm, and chair. Using the VICON motion capture system and the BodyBuilder software, the researchers created a model of the upper limb kinematics during testing.[67] Specifically, the researchers were looking for deviations from typical radio-ulnar pronation/supination and wrist flexion/extension. In general, Brown et. al. concluded that their new device did not yield more neutral postures than the current ergonomic mice.

Although their device did not show any substantial improvements, their experimental design proved very helpful. Marker placement was of key interest. Following their placement, we also chose to place markers on the shoulder, upper arm, elbow, and wrist, as these positions on the arm and hand help outline it from a camera view. We did not choose to place markers on the chair as back positioning was not an interest of our study. Also because of this, we placed our cameras not only to the right side of participants but also in front of them.

To verify that the Vicon motion capture system was a reliable system for studying the posture during mouse use, we consulted a 1996 study by J.R Williams et. al. The researchers assessed the system accuracy at a distance within 1 meter from the calibration object. The maximum error under the worst movement and marker combination was 32mm and was 2mm for the best marker and movement combination.[68] Williams et. al. also concluded that the analysis system is "predictable, remote, non-invasive, and does not itself interfere with the activities that are being recorded."[69] As this study was examining elbow movement, it is reasonable to conclude that the Vicon system would also perform well monitoring finger, wrist, and arm movement. The error described by Williams et. al., is small and we can thus be confident that the Vicon system will produce reliable results.

A 2009 study on shoulder muscle fatigue also used a Vicon MX40 motion capture system to model shoulder motion. As our motion capture system was also a Vicon MX40 model, this study was particularly of interest. Fourteen right-handed subjects were asked to perform a repetitive reaching task intended to fatigue the shoulder muscle. The researchers used EMG to measure the activation of certain muscles. The motion capture system used six cameras to monitor whole-body posture and characterize movement. Markers were placed on bony landmarks such as the head, shoulder, elbow, wrist, hand, pelvis, knee, and ankle. The researchers were interested in the center of mass of certain parts of the body, the shoulder flexion/extension angle, and the shoulder abduction/adduction angle.[70] Using the BodyBuilder software, these kinematic variables were determined. The researchers also determined the range of motion (maximum – minimum position) for each attempt at the reaching task.

Fuller, et.al. concluded that fatigue occurs in multiple segments of the arm, as well in multiple directions.[71] Fatigue was most evident in the medial-lateral direction of the shoulder, although no changes were observed in the abduction/adduction range of motion.[72] Thus, subjects varied their posture to compensate for fatigue.

From this study, we decided to focus on the range of motion of each participant during mouse use. This parameter helped best characterize subjects' motions. This study also showed proof of concept. We concluded that it is possible to use the Vicon MX40 motion capture system to characterize arm and hand positioning during mouse use. Since our proposed Fitts' test may introduce fatigue, we may see similar results of deterioration of arm and hand posture during mouse use.

A 2007 study on the recognition of sign language shows that motion capture can be used to model hand and finger movement.[73] The previously discussed studies focused mainly on whole body or upper arm motion capture. Because we want to focus on small changes in finger and wrist position, this study helps us understand such a possibility.

In the study, ten students were asked to perform hand gestures while a Vicon 250-optoelectronic motion analysis system recorded their movements. Eight cameras captured the movement of miniature 5mm diameter reflective markers which were placed on every knuckle of the hand and then on the wrist. The system sampled at a frequency of 120 Hz. An algorithm was then developed to take the marker positioning and determine which sign was produced.

The Vicon system and algorithm could correctly recognize hand gestures at a 96.58% rate.[74] This study is very important as it shows that the Vicon system can be used to track small changes in hand and finger positioning. As the different hand gestures in this study were unique and sometimes subtly different from other gestures, the Vicon system was able to differentiate between subtle differences in posture. Thus, monitoring changes in finger and wrist positioning during mouse use is possible.

Overall, these studies show that examining arm and hand positioning during mouse use with a Vicon MX40 motion capture system is possible. The system is very reliable and can easily track small changes in marker positioning. Thus, it will be possible to detect small changes in the positioning of the finger, wrist, elbow and shoulder during mouse use. This will allow us to characterize how participants positioning their arm and hand for different types of mice.

EMG Testing

Once we decided to focus on computer mice and WMSDs, the next question was how to examine the relationship between the two. One technique was the use of an electromyography (EMG) machine. EMG machines are designed to detect the action potentials generated by contracting muscles.[75] In surface EMG, two electrodes attached to the skin above the body of the muscle of interest detect the difference in electrical potential due to travelling action potentials. Needle-shaped electrodes are also used in EMG. This procedure is invasive, but it can provide more accurate readings. Because no members of the team were trained in needle EMG, the surface method was used. Because action potentials cause muscle contractions, EMG provides a good indication of when and how much a certain muscle is being used. The amount of muscle activity can be used to make inferences about the benefits or drawbacks of any activity, including computer mouse use.

EMG has been used to study computer mouse use in previous research. In most cases, the experimental design is similar. The subject performs some sort of standardized task with a computer mouse, while their muscle activity is measured with an EMG machine. The subject then repeats the task with some variable changed. One common variable to modify was the type of mouse used. Agarabi, Bonato, and De Luca,[76] Lee, et al.,[77] Hengel, et al.,[78] and Chen and Leung[79] all had their subjects perform the same test while using a different mouse. Using this technique, comparisons can be made by examining the EMG graphs produced by the same person doing the same task with different mice. Agarabi, Bonato, and De Luca also varied the way their subjects gripped the mouse,[80] while Dennerlein and Johnson changed the position of the mouse in relation to the user,[81] and Dennerlein and DiMarino introduced "force-fields" near targets for the mouse.[82] Søgaard, et al. did not use a mouse at all in their study, instead they had their subjects perform standardized tasks that simulated mouse use.[83]

When studying the computer mouse, it is important to examine muscles affected by mouse use. Finger, forearm, and shoulder muscles were often examined in computer mouse studies. Specifically, Agarabi, Bonato, and De Luca recorded electromyographic signals from the extensor carpi ulnaris (ECU), extensor digitorum (ED), pronator quadratus (PQ), flexor digitorum superificialis (FDS), and the first and second dorsal interosseus (FDI, SDI).[84] Lee, et al. examined the ECU, FDS, FDI, the extensor digitorum communis (EDC), and the extensor carpi radialis (ECR).[85] Dennerlein and Johnson used the ECR, ECU, flexor carpi ulnaris (FCU), flexor carpi radialis (FCR), anterior deltoid, medial deltoid, and the upper trapezius.[86] Dennerlein and DiMarino examined the ECU, ECR, FCU, and FCR,[87] the same muscles that we examined, while Hengel, et al. looked at the ECU, ED, FDI, and ECR.[88] Finally, Chen and Leung studied the ECU, ED, PT, and the trapezius.[89] The most commonly studied muscles were the

ECR and ECU, which extend the wrist, and the ED, which extends the fingers.[90] These muscles are used when operating a mouse, and are at risk of developing a WMSD.[91] We decided to measure these four muscles because previous research indicated they were the most used during mouse clicking.

EMG signals are highly variable. This can be due to a subject performing a task slightly differently, or it could be due to the random nature of action potentials. Further differences arise between subjects. The amount of muscle or fat present in a given subject's forearm will change the resulting EMG graph. In addition, underlying differences in the basic structure of a subject's forearm may change the EMG signal. To correct for differences between subjects, many studies use a maximum voluntary contraction (MVC). A MVC consists of the subject exerting a given muscle as hard as possible for a particular amount of time while being recorded by the EMG machine. This provides a baseline of what the subject's maximum muscle activity looks like. All subsequent activities can be compared to this baseline.[92] Lee, et al.[93] Dennerlein and Johnson,[94] Dennerlein and DiMarino,[95] Søgaard, et al.,[96] Hengel, et al.,[97] and Chen and Leung[98] all used MVCs to normalize their data. Where the MVC procedure was detailed, the subject was asked to exert maximum force with the muscle in question for five seconds, while the researcher manually restrained the subject in the appropriate direction. Subjects rested for a minute in between MVCs. Lee, et al. and Dennerlein and Johnson referenced Buchannen, et al.'s *Estimation of muscle forces about the wrist joint during isometric tasks using an EMG coefficient method*.[99] This paper details the directions in which the ECR, ECU, FCR, and FCU move the wrist.

EMG is vulnerable to noise. Sources of noise include motion of the electrodes, motion of the cables, potential buildup at the electrodes, and electromagnetic interference, especially from alternating current.[100] To reduce the noise, the skin is scrubbed to remove dead skin cells, which lessens the resistance between electrodes. Chen and Leung used alcohol soaked cotton balls to remove dead skin,[101] while Konrad recommends removing hair, then using specialized cleaning pastes, fine sand paper, or alcohol and a textile towel.[102] However, regardlesss of skin preparations, before the EMG data in analyzed, it is usually passed through a filter, so that only the relevant signals are left. Lee, et al. used a high pass filter at 5Hz to eliminate DC bias, and a notch filter to eliminate 60Hz AC noise.[103] Hengel, et al. used a bandpass filter between 20Hz and 450Hz.[104] Chen and Leung used a bandpass filter at the same frequencies as Hengel, et al., but they also eliminated 60Hz noise with a notch filter.[105]

Once the EMG data is filtered, it must be analyzed. Because the electrical potential alternates between positive and negative values, it must first be rectified.[106] Then the EMG data may be analyzed in many different ways. Usually, portions of the graph are averaged together to make a smoother chart. Agarabi, Bonato, and De Luca used RMS measurements, and compared the results between different mice, using five second periods of constant EMG signal amplitude.[107] Chen and Leung also used RMS as an measure of the EMG amplitude for their experiment.[108] Hegel, et al. [109] and Dennerlein and DiMarino,[110] Lee, et al.,[111] and Dennerlein and Johnson[112] all specified that they evaluated the RMS over a 0.2 second moving window. Konrad gives peak value and area under the curve measurements as additional ways to quantify EMG data.[113]

Force Testing

The forces used in common office work tasks have been considered a risk factor for WMSDs. In a study conducted by Jules G. Bloemsaat in 2004, WMSD patients put 10 g more force on a computer input pen than healthy study participants across the entire testing period (not just the peak selection force).[114] They also "raised the pen pressure with greater leaps (from 116 [waiting for the next command] to 137 [in reaction to the command] to 191 g [in movement])" … finally exceeding the controls by 41 g."[115] The healthy participants put pressure on the pen gradually, and exceeded the control activation force by a smaller amount. Bloemsaat argues that stiff, harsh movements like these are patterns that lead to WMSDs. He acknowledges that the disorders can cause increased stiffness and various situations can aggravate the behavior, but the behaviors exist before the disorder does.

This information is assumed in the study "Alternative Computer Mouse Design" by Lee[116]. Lee developed on this knowledge by comparing EMG amplitudes of finger muscles during mouse clicking activities, with both normal and ergonomic mice. While he did find significant differences between the EMG amplitudes, this information could not be quantified into measures of force. He concluded, "[The] finding support[ed] the idea that making it more difficult for inadvertent switch activations to occur may have resulted in users reducing their sustained muscle activity for the task's static muscle loading requirements." Again, this is hard to quantify into any particular mouse design. Developing from this, we can consider the actual force applied in ergonomic mouse designs.

Knowing the above information, it would be tempting to assume that if the activation force of a mouse button was decreased, users would exert less force. By this logic, measuring the force required to click a mouse button would be one approach to considering one mouse more ergonomic than another. However, the force required tends to be much less than amount of force actually used in a mouse click. In a 1999 study using keyboard keys, study participants used 0.75 N to press a key that only required 0.31 N to activate, and 1.10 N to press a key that required 0.71 N.[117] The force used to press a 0.71 key increased to 1.71 N when the distance that the key needed to travel to activate was increased to 1 mm.[118] This, amongst other similar data, led Radwin to conclude that key activation distance was also a factor in the amount of force actually used. In addition, other studies suggest that human psychology is also a compounding factor.[119] Because of these three factors, the amount of actual force used to press the buttons on the various mice used in this study could not be predicted using other measurements.

Even though human psychology is a compounding factor, it should not cause significant error in this study. A 2004 study by Visser found that a participants in a high stress environment used up to 40% more force to click a mouse than participants in a low stress environment. However, it should be noted that Visser's study does not define "low stress environment" or "high stress environment". During this study, participants were advised to click as close to the center of the target circle as possible, while being as quick as possible. Nothing else in the experiment was anticipated to create stress. It was intended to simulate mouse usage in a normal work environment for high frequency computer users. A normal work environment is full of stressful factors, as well as "computer work often comprises high precision and concentration demands and high time pressure."[120] Therefore, it is likely that the minimal mental stress imposed in this study does not exceed (if even approaching) that in a normal workplace, and thus should not cause the users to use excessive click force.

Chapter 3: Methodology

3.1 Consumer Research

Computers have become a standard household item in today's society, necessary for many to function every day. Unfortunately, while significant time may be spent deciding which computer is right for a particular consumer, computer mice receive significantly less attention as people are comfortable with classic, standard designs. It is this comfort with the status quo that posed a major obstacle for our team. Regardless of what we learned of the ergonomics of different computer mice and what design we came up with, our findings would be useless unless they were marketable. In order to attain this marketability, it was necessary to determine the aspects of mice that consumers found most desirable as well as which specific target markets our recommendations would be intended for. This was the task of the business subgroup: to learn consumer preferences in order to impose design constraints on potential mouse designs as well as to analyze potential niche populations for such ergonomic mice.

In order to determine these consumer preferences, we used both surveys and focus groups, the methodology of which will be broken down separately in following sections. We were able to attain tangible data from a variety of subjects, enabling us to see how users rated different computer mice. The breaking-down of mice into individual features allowed us to see which aspects of each mouse were popular and which were widely disliked, which aided us significantly in our design. Overall, this aspect of our research allowed us to create design constraints for an ergonomic mouse that could be successful on the market.

Focus Group Design

One of the two aspects of the methodology of the business subgroup was focus groups. Ten focus groups were conducted, varying in size from two to eight people. In the early stages of our research, we attempted to contact a number of local businesses to recruit participants; however, due to a lack of response, we turned our attention to the campus community. The primary method we employed to obtain participants was by passing out fliers and sign-up sheets in large classes around campus. We also advertised on various campus listserves and contacted various groups of graduate students. The only criteria subjects had to meet in order to participate in the focus group was that they had to be over the age of 18. The age limit was imposed to eliminate the issue of needing parental permission for participation. Participants were offered incentives of pizza and soda during the focus group to make their participation more enjoyable. Specific focus group sessions were then scheduled based on times that between 2 and 8 participants could attend as well as when at least two facilitators were available.

The focus groups were highly organized and were conducted in the same order and fashion each time. They were held in the basement of Ellicott Hall, largely in the evenings; focus group members were seated around large tables along with facilitators in order to create the best environment for group participation. Each focus group began with the distribution of refreshments, the incentive, allowing participants to relax and be satisfied before they began the focus group. After that followed consent forms. Each participant was asked to sign a consent form guaranteeing that they met the requirements. The next step was the pre-focus group survey, which will be detailed in the next section. We then conducted the focus group.

During the active focus group, two moderators were used to facilitate discussion, asking set questions and then using more probing questions to directly respond to participants' answers. See Appendices D and E. Subjects were given the opportunity to hold and mock-use each of the five types of mice: the Dell 2-button mouse, the trackball, the vertical, the joystick and the zero tension mouse. They were asked to discuss their feelings with the moderators and other participants, highlighting areas where their opinions changed after gaining hands-on experience with the equipment. Detailed notes were taken on the subjects' responses through each focus group. See Appendix F. The focus group ended with a post-focus group survey.

Survey Design

The focus group survey (See Appendix B) that we utilized was a very important aspect of our research. Because it was given both before and after the focus group, it demonstrated changes in opinion due to experience with the mice as well as changes in opinion due to the discussions participants had with other participants and with the facilitators. The survey consisted of 42 questions of different formats. Questions were designed to be easy to understand and unbiased. The survey evaluated participants on many levels, beginning with demographic data and including questions concerning their prior knowledge of computer mice, ergonomics and their individual assessments of the designs we were testing. Thirty-three total participants were surveyed.

The demographic data collected at the beginning of the survey gave us another aspect to analyze the data against, helping to determine potential niche markets as well as providing us with some points of comparison for our analysis. We were also able to determine features that were consistently determined to be highly desirable, setting design constraints that required certain features. At the end of each focus group, the section of the survey detailing individual assessments of the designs was re-administered. This allowed us to compare the preconceived notions of participants with their opinions after having experienced the various designs. Giving the entire survey again was unnecessary, as demographic information should not change over the course of an hour-long focus group. The survey allowed us to gather quantitative data, in conjunction with the qualitative data we gained from the focus groups. This mixed data set allowed us to view our findings more confidently, as the two types supported each other with consistently similar results.

In order to properly analyze our findings, we observed trends in the data. Simple rating systems were used by subjects in order to simplify comparisons and analysis. From this rating system we were able to analyze each subject individually as well as to calculate means and standard deviations for each type of mouse. We used coding to analyze suggested improvements, as well as problems in current designs. Responses in the pre- and post-focus group surveys were compared in order for us to see what sorts of misconceptions participants had and what sort of reactions they had after gaining firsthand experience with the different types of mice.

3.2 Experimental Methodology

During the laboratory testing, we ran four different experimental procedures simultaneously. Each of these procedures is detailed in the following sections. Twenty-seven participants for the experimental testing were recruited through listserves. The selection criteria were that the potential participant be at least 18 years old, be right-handed, have suffered no injury to the right arm, and average at least 20 hours of computer use per week. When a participant came in for a testing session, the non-technical aspects of the procedure were explained to him or her. Next, participants were asked to read and sign a consent form. All of the experimental methodology was approved by the IRB. The participants completed the course once with the control mouse and once with an ergonomic mouse. The type of ergonomic mouse was rotated between the joystick mouse, the vertical mouse, and the trackball mouse described in previous sections. We also alternated whether the control mouse or the ergonomic mouse was used first.

Fitts' Test

This section will explain the role of the Fitts' Test in analyzing current mouse designs. The target activation course that the experiment participants completed and the implementation of the course will be described, followed by an overview of the formulas used to measure the efficiency of each mouse design tested.

The Role of Fitts' Law in Evaluating Mouse Design

In order to evaluate the efficacy of current mouse designs, human performance must be compared among the usage of the different mice. The Fitts' test was used to evaluate the efficiency of the standard two-button mouse and each of the ergonomic mice. This metric, along with the focus group, survey, EMG, activation force, and motion capture results, was used to isolate ideal design concepts and features that should be incorporated into a new mouse design.

The experiment participants completed a course. While completing the target acquisition course, the EMG activity of the muscles exercised from mouse use, the movement of specific points on the arm, wrist, and hand, and the force exerted to click the mouse button was recorded. The course is designed according to Fitts' Law, meaning that the time taken to complete tasks will be analyzed with respect to the distance the mouse pointer has to travel and the size of the objects that must be clicked. The accuracy of the mouse is determined by the precision regarding the pixels crossed in order to achieve the task (De Sena and Moschini). The accuracy of a mouse is closely tied to the mouse's efficiency. A more accurate mouse often decreases the time needed to complete a task, as users do not have to spend time re-executing the task.

Target Acquisition Course

The target acquisition course is based on a Fitts' Test used for one-dimensional pointing tasks, modified for two-dimensional pointing tasks (Murata 138). The participants' goal is to move the mouse to targets across the screen with the greatest accuracy and speed possible. The two variables that were experimental factors where the movement distance, d, and the radius, rad, of the circular targets. The movement distances were 75, 100, 125, and 150 pixels. The different radius sizes were 25, 50, 75, and 100 pixels. The circles appeared around a center button at a randomly chosen multiple of 45 degrees (see figure 9).

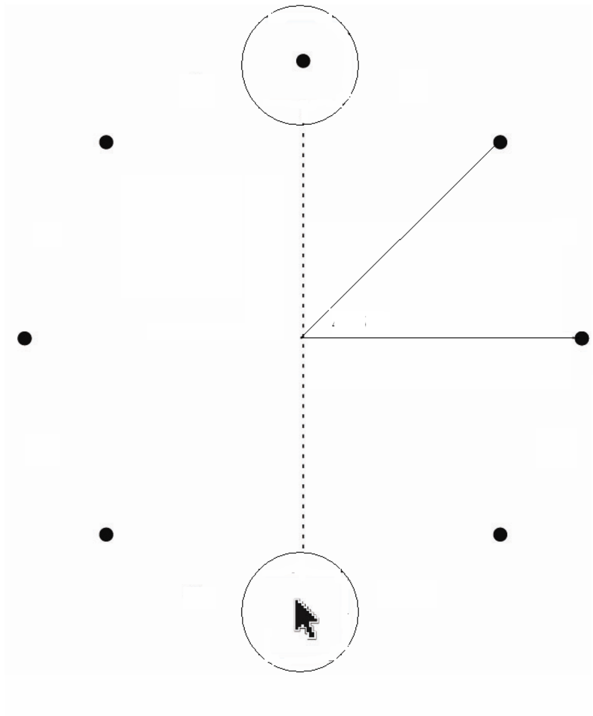


Figure 9: The target circles would appear around the center button at one of the randomly decided 8 positions above.

The subjects would click the center button to make the first circle appear. The subject would then move the mouse cursor as quickly and accurately as possible to the center of the target that appeared. After clicking the target, the subject would move back to the center button. Clicking the center button again would make the current target disappear and a new target appear (see figure 10).

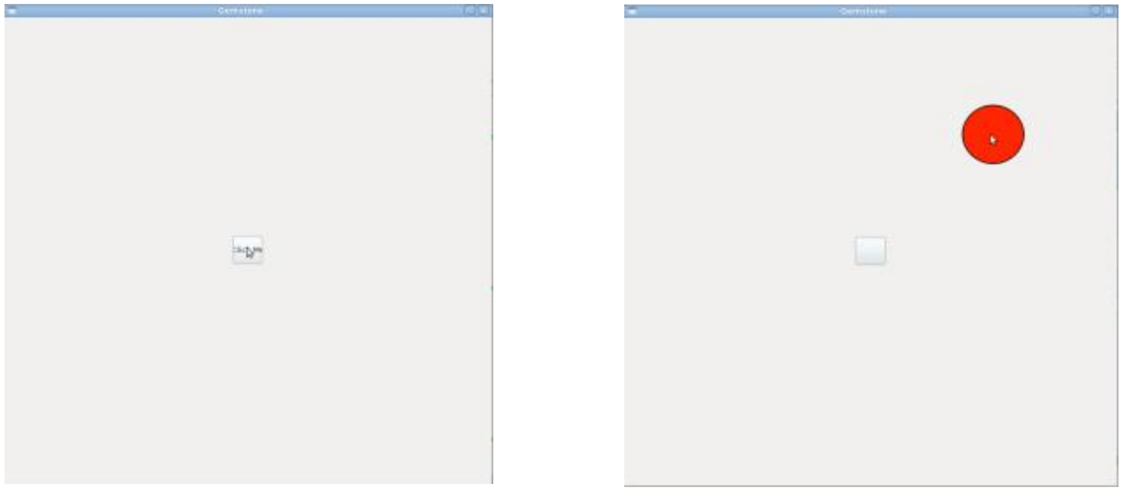


Figure 10: Subjects start at the center button. Upon clicking the center button, a target circle appears. Subjects move as quickly and accurately to the target as possible.

The permutations of the circle widths, circle diameters and angles results in 128 target acquisition clicks. The subject continued the course until all of the permutations were completed. For each click, the x-directional pixel, y-directional pixel, time taken to click either inside or outside the target circle, and the overall time were recorded.

Implementation

The target activation task was written in C++ using the C++ Qt libraries. Programming languages such as Java automatically perform garbage collection. The garbage collector stops the execution of the program; therefore functions that return the time elapsed for an action return inaccurate times because the time while the program is stopped is not recorded. C++ was chosen because the language allows the programmer to manually control garbage collection, resulting in accurate time records. The Qt libraries were chosen for their extensive user interface framework.

Fitts' Law

Using the x-directional pixel, y-directional pixel, the width of the target (w), and the distance of that was traveled to reach the target (d), the effective target width in the x and y directions and the effective index of difficulty was calculated. The effective target width is a measure of what the participant actually performed (Murata 138). The effective target width in the x direction is calculated using the mean x-directional pixel and its standard deviation:

$$We_x = 2u_x((1 - A)/2)\ SD_x \qquad (9)^{**}$$

The effective target width in the y direction is calculated using the mean y-directional pixel and its standard deviation.

$$We_y = 2u_y((1 - A)/2)\ SD_y \qquad (10)^{**}$$

*** A represents the probability that the user clicks inside the target square. This probability is derived from the experimental data.* The effective index of difficulty displays the performance of the mouse, based on the diameter and the minimum of the effective widths in the x and y directions:

$$ID_e = \log2(d / s + 1.0) \qquad (11)$$

$$Time = a + b \log (d/ s + 1.0) \qquad (12)$$

$$Time = a + b\ ID_e \qquad (13)$$

In Equation 11 and 12, s represents the minimum of the We_y and We_x .When the effective index of difficulty is combined with the time measurement, the mice can be compared for accuracy and efficiency (Cockburn and Brewster 1132). This measurement is the index of performance.

$$IP = \frac{Time}{ID_e} \qquad (14)$$

Data Processing

Murata's formulas for effective target width were used. From these target width calculations, the overall target size was determined with the equation:

$$s = \min(W_{xe}, W_{ye}) \qquad (15)$$[121]

From this equation the effective index of difficulty (ID_e) is calculated using the formula:

$$ID_e = \log_2((d / s) + 1) \qquad (16)$$

From this effective index of difficulty, the metric of efficiency, the throughput of the mouse, could be expressed with the following equation:

$$\text{Throughput} = ID_e / t_m \qquad (17)$$

where t_m was the average movement time taken for each target acquisition click.

From Equation 11, the throughput for each mouse was calculated for each of the 16 distinct target width and travel distance combinations. From the throughputs of each combination, the average throughput, the value ultimately used to rate each mouse's efficiency, was calculated.

Motion Capture

Setup and Capture

A motion capture system was used to reconstruct subjects' arm and hand positioning during the Fitts' test. The system consisted of four Vicon MX40 infrared cameras (Vicon, Los Angeles CA) running on Nexus software (Vicon, Los Angeles CA). The purpose of the motion capture analysis was to relate the other systems (EMG, Fitt's test, button activation) to the arm and hand positioning during mouse use. Elevated muscle activity seen from EMG results, less efficient Fitts' test scores, and increased button activation force could all be related to particular arm and hand positions. Therefore, the motion capture system related all systems to how the subject used the three ergonomic mice and control mouse.

Before subjects arrived for testing, the four infrared cameras were placed around a 3 foot tall table, with a surface area of 4 ft. by 2 ft. For all four computer mice, the infrared cameras were placed in front of and to the right side of the subject (see Figure 11). Because all subjects were screened to be right-handed, the right hand and arm of the subject needed to be fully visible to all cameras. This was especially true for the vertical mouse and 3M Joystick which required subjects to position their hand in a vertical resting position. When the hand rested in a vertical position, any infrared markers placed on the wrist or forearm could only be visible by cameras directly in front of or to the right of the subject. The cameras were adjusted to be approximately 5 ft in height, and were placed one foot from the edge of the table. All cameras were then aimed at the subject.

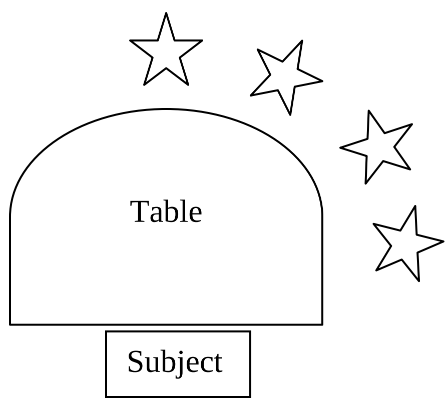


Figure 11: Camera Positioning

A wand, containing five infrared markers, was then set on the table in view of all the cameras. In the Nexus software, all cameras were adjusted to have a threshold of ~0.3 and intensity of ~0.7 as described by the user manual for the system. Adjustments to these parameters were made until each camera saw the markers as a white circle with gray edges, optimized for best capture.

The subjects were then asked to sit in an adjustable chair at the table and position themselves in a comfortable position to use the mouse. Using the 5-marker mini wand, the cameras were calibrated in the Nexus software. This was accomplished by moving the wand throughout the area where the subjects had their arm and hand positioned and the area where the subject could move during mouse use. This critical step ensured that the cameras would actually be able to see markers placed on the subjects, especially when the subjects would change their position. As described by the user manual for the system, a camera image error below 0.3 was acceptable. This camera calibration process sampled 100 initial points and 1900 additional points for a total of 2000 points per calibration. Calibration was repeated until the resulting image error for all cameras was below 0.3.

The 5-marker mini wand (Vicon, Los Angeles CA) was then placed on the table so that the edge of the wand laid flush against the edge of the table. In the Nexus software, the volume origin was set in relation to the wand. This ensured that for all captures, the xy-plane always corresponded to the plane of the table and that the z-axis was perpendicular to the plane of the table. Also, by placing the wand flush with the table edge, the xy-plane was always oriented in the same direction. Because of this, position calculations could be conducted for each marker with respect to the location of other markers.

Eleven 9mm retro-reflective infrared spherical markers (Vicon, Los Angeles CA) were then placed on the subject (see Figure 12). Markers were placed on the index finger (11), a T-square on the wrist (7-10), a triangle on the lower arm (4-6), the elbow (3), the middle upper arm (2), and the shoulder (1). Markers were placed directly on the subject’s skin or clothing with tape. Subjects were asked to wear short-sleeved shirts so that all but the shoulder and upper arm markers could be attached directly to the skin. Because the 3M joystick mouse required button activation with the thumb, the index finger marker was moved to the thumb for this mouse. The T-square provided a rigid model of the wrist. This ensured that the correct angle of the wrist was captured relative to the fingers and lower arm. The top three markers on the T-square were placed in a line to provide a model for the knuckles. The bottom marker of the T-square was positioned to form a perpendicular 'T'. The bottom marker of the T-square was used to determine how the wrist was being flexed. The triangle on the lower arm was used to determine the rotation of the lower arm. The three points formed a plane to determine the spatial locality of the lower arm. No triangle configuration was used on the upper arm because most mouse motions for the Fitts' test required pivots around the elbow. The elbow, upper arm, and shoulder markers were used to construct the upper arm with respect to the forearm, wrist and finger.

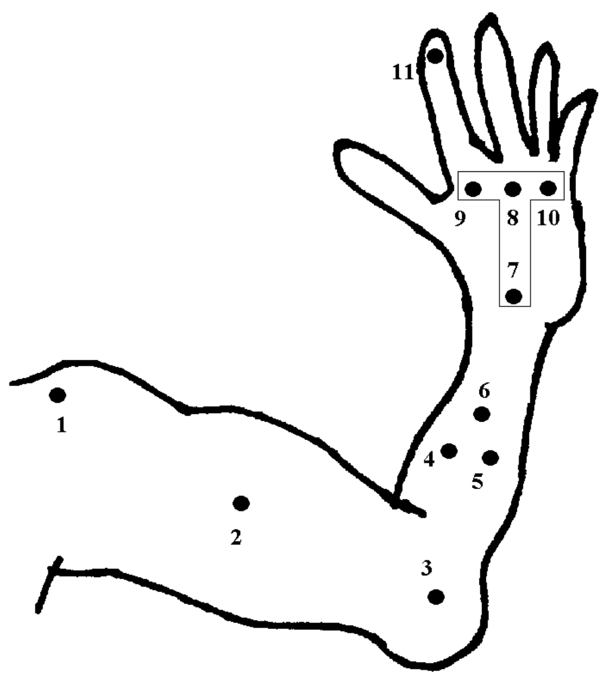


Figure 12: Position of Reflective Markers

After all other systems were calibrated, the force sensor was first started. Then concurrently, the EMG system and the Nexus data capture were started. Finally, the Fitts' test program was started and the subject was asked to begin the task. Marker coordinates were sampled at a rate of 50 Hz. When the subject finished the Fitts' test, the capture was stopped in the Nexus software. The Nexus software then automatically reconstructed the coordinates for all markers during the entire capture time.

After the coordinates were reconstructed, each marker was manually labeled with a unique text identifier at each time frame. This labeling was conducted for both tests for each subject. After this labeling, the xyz coordinates for each marker at each time frame were then exported as a .csv file to be processed in MATLAB.

Data Processing

Each marker xyz coordinate pair was treated as a 3-D vector from the origin previously set in the Nexus software. From these eleven vectors, four new vectors were created which represented the index finger, wrist, forearm, and upper arm. To form the finger vector, marker vector 9 was subtracted from marker vector 11, using marker 9 as the local origin. To form the upper arm vector, marker vector 3 was subtracted from marker vector 1, using marker 3 as the local origin. To form the wrist vector, marker vector 8 was subtracted from marker vector 7, using marker 8 as the local origin. Finally, to form the forearm vector, marker vector 3 was subtracted from maker vector 7, using marker 3 as the local origin.

These four vectors were calculated at each time frame of the capture. However, due to noise in each capture, some markers were not present at all time frames. This occurred if the subject moved so that a marker could not be seen by a camera, or if the marker was not in the capture volume set during calibration. Thus, to improve the reliability of the results, these vectors were only calculated if markers 1, 3, 7, 8, 9, and 11 (those used to calculate the four vectors) were all present at the particular time frame.

From these four vectors, the angle between adjacent vectors (finger and wrist, wrist and forearm, and forearm and upper arm) at each significant time frame was calculated using:

$$\theta = \cos^{-1} \frac{v_1 \cdot v_2}{\|v_1\|\|v_2\|} \tag{18}$$

These angles represented the angle at the index finger joint, wrist joint, and elbow joint, and will be referred to by these names henceforth. The range of angles for each of these joints was then calculated over the entire capture. This gave a measurement of which parts of the arm were most active during the capture. Then, the mean angle for each joint was calculated over the entire capture.

The mean angle and range of angle was calculated for each trial for each subject. Of the 27 subjects, the motion capture system failed for both trials for one subject. Of the 26 remaining subjects, two vertical mouse trials, one trackball trial, and two joystick mouse trials were excluded due to excessive noise and missing markers in the capture. This resulted in data for 26 control mouse trials, 7 joystick trials, 7 vertical mouse trials, and 8 trackball trials.

EMG Testing

Measurements with an electromyography (EMG) machine comprised an important part of our methodology. As the subject executed the modified Fitts Test, the EMG recorded electrical signals coming from various muscles in the subject's forearm.

We used these signals as indicators of the amount of muscle activity for each ergonomic mouse.

The EMG detects the difference in potential between two different points on the same muscle as the concentration of positive ions travels along the muscle fiber.[122] Two electrodes attached to the skin of the subject, over the muscle of interest detect this potential difference.

Procedure

In order to acquire accurate data from the EMG, the subject's skin must be prepared before the electrodes are attached. After the subject signed the consent form acknowledging that they understood the experiment, the subject was instructed to shave a section of their right forearm. A team member escorted the subject to the bathroom and provided them with a new razor and shaving cream with which they shaved the section from the top of the elbow down to about three-fourths of the forearm. This covered the area where the electrodes will be placed. Shaving the forearm reduced the amount of resistance detected by the EMG electrodes. It also allowed for better contact between the skin and the electrode. The subject's forearm was then rubbed vigorously with a textile towel or paper towel moistened with rubbing alcohol. This removed dead skin cells and other derbies, which would otherwise impede the electrical signal that travels from the subject's muscles to the EMG.[123]

After the skin was prepared, the electrodes were attached to the body of each muscle. A team member located each forearm muscle by feeling around the area and having the subject flex. Electrodes were placed about a half an inch apart on the body of each muscle to be measured. After attaching the electrodes to the subject, the electrodes were secured with tape in order to prevent them from becoming detached during the experiment.

Four muscle groups were examined in this experiment. They are the flexor carpi radialis, extensor carpi radialis, flexor carpi ulnaris, and extensor carpi ulnaris. The flexor carpi radialis flexes the wrist and helps the hand move away from the body; it also functions to help the elbow flex. The extensor carpi radialis helps the wrist extend and also helps to move the wrist away from the body. The flexor carpi ulnaris is a powerful wrist flexor and helps to move the hand towards the body; the muscle also stabilizes the wrist while our fingers are extended. The final muscle, the extensor carpi ulnaris, extends the wrist along with the extensor carpi radialis; it also helps to move the wrist toward the body. Humans use these muscles to move their wrists; therefore, these muscles are utilized during mouse use.[124] In addition, many work-related musculoskeletal disorders involve the wrist; especially those associated with large amounts of mouse use. The EMG will provide an indicator of the total amount of muscle use, since the more a muscle is used, the more action potentials it will produce. In addition, the more a muscle is used, the more likely it is to become injured.

In order to obtain optimal accuracy from the EMG, the electrodes used must be placed directly over the appropriate muscle. This reduces the amount of extraneous activity from other muscles that each electrode will detect.[125] The exact placement of the electrodes was determined by referring to anatomical diagrams in “Human Anatomy & Physiology Laboratory Manual” by Elaine N. Marieb and Susan J. Mitchell.[126] The experimenter pressed lightly on the subject’s forearm to confirm exactly where the widest part of the muscle is located. This is known as a test palpitation.[127] The subject was then taken into the room where the experiment will take place and is hooked up to the EMG machine.

Normalization

In order to compare Fitts' Test data between different subjects, all of the information acquired by the EMG must be normalized. Therefore, the subject performed a set of four maximum voluntary contractions (MVC), one for each muscle, before each Fitts Test. In total, a subject performed two sets of maximum voluntary contractions during their time in the laboratory. The second set of MVCs was necessary to account for muscle fatigue while performing the Fitts' Test for the first mouse. A maximum voluntary contraction consists of exerting the appropriate muscle to the greatest extent possible. This measurement allowed us to compare sets of data between different subjects. Without maximum voluntary contractions or some similar normalization procedure, it would be impossible to compare data from different subjects. This is because each subject will generate a unique EMG signal even when undertaking a pre-formulated task. This is due to variables such as the amount of body fat on the subject's forearm, the subject's muscle mass, and underlying physical differences between different subject's forearms.

In order to perform a maximum voluntary contraction it is important to be certain that the subject is flexing the appropriate muscle. Because it is unclear which muscle is being used when extending the wrist in a given direction, it is necessary to direct the subjects to attempt to flex their wrist in a particular direction, thereby contracting the correct muscle. This direction is determined using the diagrams from T.S. Buchanan, et. al.'s work "Estimation of Muscle Forces About the Wrist Joint During Isometric Tasks using an EMG Coefficient Method."[128] The subject was directed to exert as much force as possible in this direction using their wrist, while the experimenter manually restrains the subject's hand. Each maximum voluntary contraction lasts for about five seconds. The muscles were tested in the following order: first the extensor carpi radialis, then the extensor carpi ulnaris, third the flexor carpi radialis, and finally the flexor carpi ulnaris. During the actual Fitts Test, the electromyography machine passively collected data, while the subject completed the modified Fitt's test.

Equipment and Software

The Noraxon Telemyo was the electromyography machine used in this experiment; it consists of two units: a receiver and a transmitter. The transmitter receives information about the electric potential between each of the four pairs of electrodes that have been placed on the appropriate muscles. The electrodes used were GS27 Pre-gelled Disposable sEMG Sensors. The transmitter is powered with nine-volt batteries. The information is relayed wirelessly to the receiver, which then sends the information to a computer through a National Instruments SCB-68 shielded I/O connector into a NI Data Acquisition Card. The computer uses National Instruments LabVIEW to write the data to comma separated value files, where the information is stored for further analysis. The LabVIEW program must be prepared before the actual experiment by running it through without taking any data. This allows LabVIEW to store the data properly. The results of the experiment were stored in five different files; one for each of the four maximum voluntary contraction tests, and one for the Fitts Test. These files were labeled with the subject's identification code and the test being performed. Therefore, for each Fitts' test, the electromyography machine produces an ID-ECR.csv, an ID-ECU.csv, an ID-

FCR.csv, an ID-FCU.csv, and an ID-test.csv. These comma separated value files were processed afterwards using the procedure detailed in the analysis section.

Data Processing

The data from the electromyography machine was analyzed in several steps. First, alternating current noise was filtered out. Then, the data was processed to produce mean, peak, and area measurements. Finally, these measurements were compared to reach conclusions.

When examining the Fast Fourier Transform of any set of data, it was apparent that noise from 60 Hz power supplies dominated the frequency spectrum. Spikes existed at 60 Hz and all of its higher harmonics. To remedy this situation, several band stop filters were created in MATLAB and the data was processed. These filters removed frequencies in 10Hz bands around 60Hz, 120Hz, 180Hz, and 240Hz. The band stop filters were combinations of low and high pass filters. For example, to filter out the 60Hz noise, the data was passed separately through a 55Hz low pass filter, and a 65Hz high pass filter. Then, the two sets of filtered data were added back together. In addition, any frequencies above 300Hz were removed entirely. This was done because frequencies above 300Hz were not of interest for this experiment, since the information which would be gathered from such high frequencies would not be relevant for this project.[129] Figure 13 shows the Fast Fourier Transforms for an unfiltered and filtered set of data.

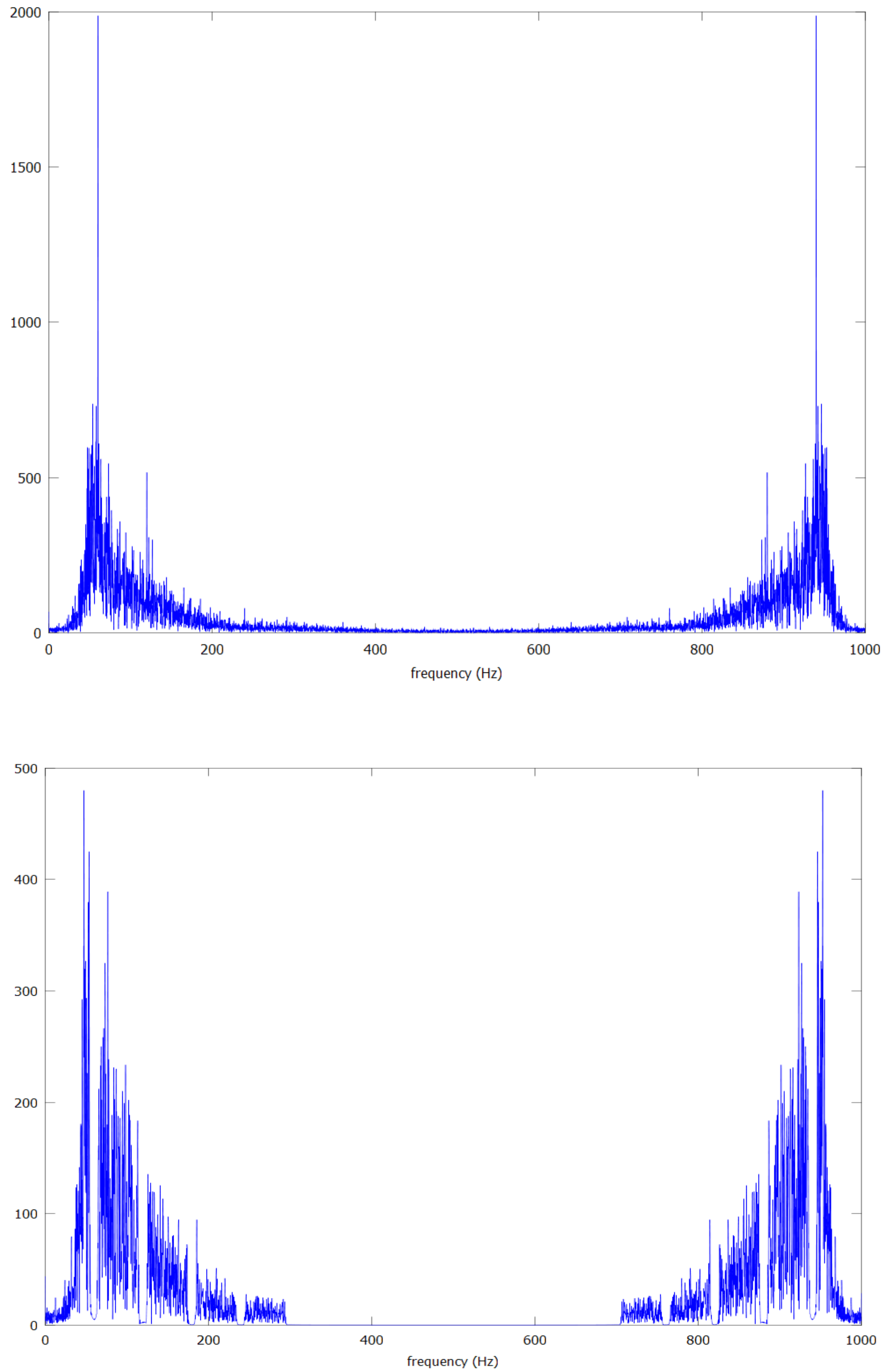
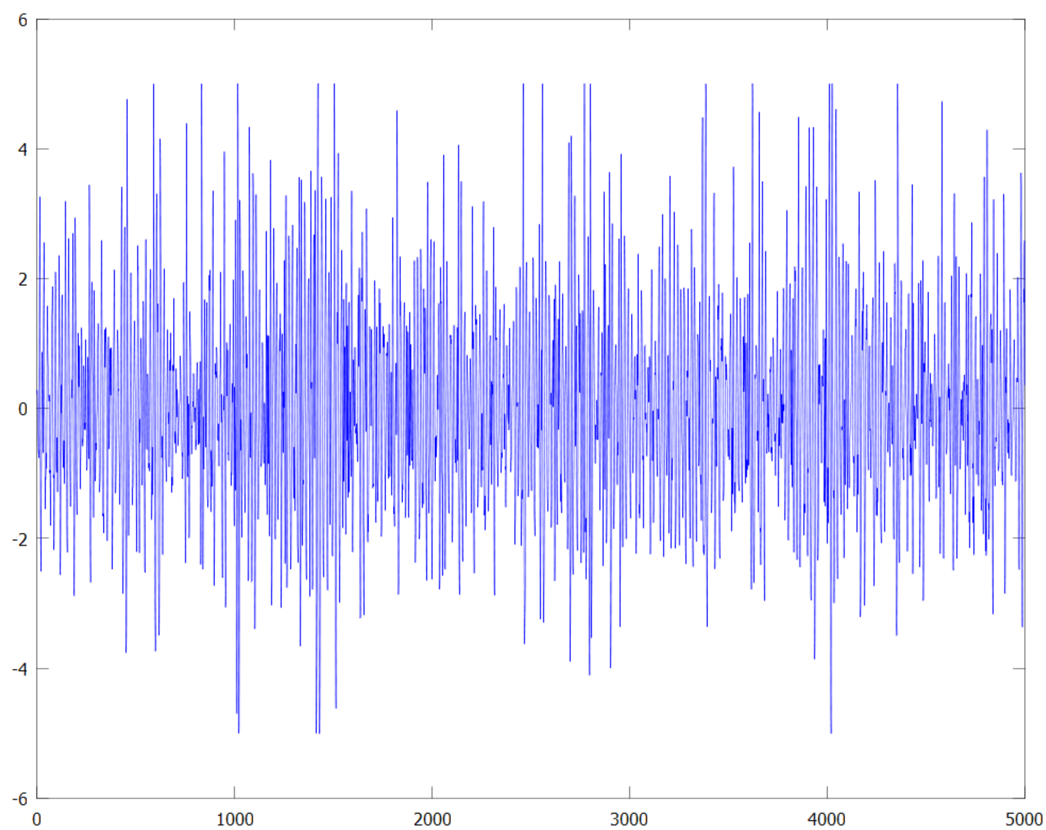


Figure 13: A comparison between an unfiltered data set (top) and the same data set after being filtered (bottom)

The filtering process produced an interesting byproduct. For every single subject, approximately the first 2.5 seconds of data were removed by filtering. Therefore, for every Maximum Voluntary Contraction (MVC) and Fitts' Test for every subject's muscle, these first 2.5 seconds appear to be entirely noise from the power source. Because of the uniformity of this dead period, it is likely that this delay is indicative of the time it takes for the Noraxon Telemyo to begin taking data after the LabVIEW program is activated. Therefore, when analyzing this data, the first 2.5 seconds were ignored. Figure 14 shows the zero line produced by filtering.



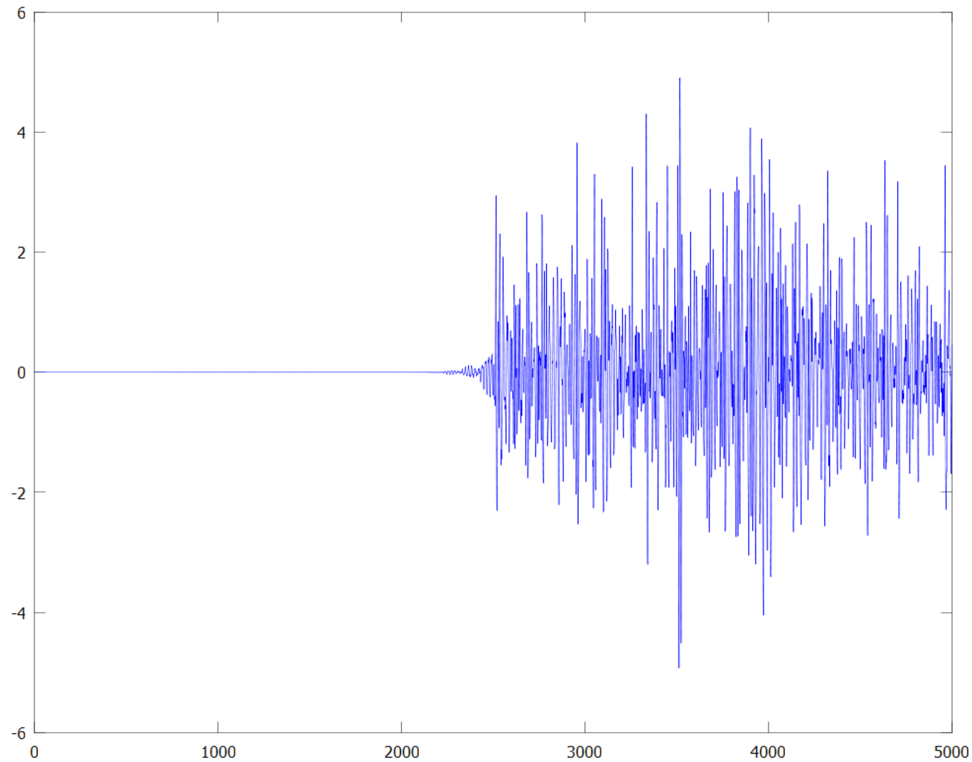


Figure 14: Five seconds of unfiltered (top) and filtered (bottom) data. Note the zero line in the filtered data.

Three measurements were taken from each data set. These measurements are mean, peak value, and area. Because the EMG signal is centered about the zero line, all filtered data was rectified before undergoing analysis. Since the MVCs consisted of a single sustained contraction, only one measurement was taken in each category for each MVC. Therefore, each data set contained mean values for all four muscles, average peak values for all four muscles, and values for the area under the graph for all four muscles, for twelve measurements for each MVC. On the other hand, since muscle activity during the Fitts' Test was more complex, all data from the Fitts' test was divided into 0.5-second time intervals before undergoing analysis. Because mouse movements and clicks took about this long to complete, intervals much smaller than this are not of significant interest to our research. Mean measurements were obtained by taking the average of all filtered data points within the given time interval. Because EMG graphs tend to randomly produce high spikes, the average of the ten highest peaks in a given time interval was used in place of the true peak value. This kept the peak value data from being skewed by abnormally high, random EMG values. The area measurements were taken by using a trapezoidal integration method. If two data points were given by (t_1, y_1) and (t_2, y_2), then the four corners of the trapezoid were (t_1, y_1), (t_2, y_2), (t_1, 0), and (t_2, 0). All analysis was done using GNU Octave 3.2.3.

Force Testing

A force sensor system was used to measure the force exerted in each mouse click. This section will detail how this system was planned, implemented, and utilized in testing procedures.

Measurement System

To measure the force used in each mouse click, a simple circuit interfaced with a computer program via a converter board. A force sensor in the circuit varied the voltage input to the converter board. The converter board then translated this voltage into a number, and communicated this number to a computer via a USB port. A program running on the computer then recorded this number.

Force Sensor

The force sensor was an eight inch long FlexiForce Resistive Force Sensor Model A201, chosen for its sensitivity, precision, accuracy, size, and flexibility. Sensitivity range was 0 to 1 pounds, which fully encompassed the anticipated force range for a mouse click while providing more precision than other models. Other sensitivity ranges would have offered absolute certainty that any mouse click would be within the range of the sensor, but also would have significantly reduced the precision available. Flexiforce sensors also had a reputation of being accurate. Error within the resistor's response to force is less than five percent, and drift (change in the sensor reading when the applied force does not change) is less than five percent per logarithmic time scale. Finally, the FlexiForce A201 was extremely thin while providing ample sensing area. The thickness was only eight thousands of an inch, while sensing area was three eights of an inch in diameter circle. This was thin enough that users will hardly notice the extra thickness of the sensor on the mouse button, while the sensing area was large enough to effectively measure the force applied by a single finger.[130]

The force sensor was sufficiently thin for this testing because it measured force using pressure sensitive ink. This force sensitive ink was layered between substrate and conductive silver. This conductive material "extend[ed] from the sensing area to the connectors at the other end of the sensor, forming the conductive leads… terminated with male square pins."[131] The two pins of the sensor that connected to the conductive leads were also connected to the voltage divider circuit. As the force on the sensing area increased, the pressure sensitive ink caused the resistance through the conductive material to decrease. Essentially, the force sensor behaved as a variable resistor.

The FlexiForce sensor, as its name implied, was extremely flexible. For this reason, the sensor was gently taped down on the mouse button, then the remaining length of the sensor was draped around the mouse in such a manner that it did not interfere with the user's experience with the mouse. Specially, the center of the sensing portion of the force sensor was attached to the center of the mouse button by a single piece of masking tape placed over the sensor. After this was done, the rest of the length of the sensor, which was connected to the voltage divider circuit, was draped around or over the mouse. This positioning did not interfere with any functionality of the mouse, nor the user's experience.

Voltage Divider Circuit

Earlier, it was mentioned that the force applied to the force sensor was inversely proportional to the voltage difference across the sensor. To measure the voltage difference across the sensor, a voltage divider circuit was used. The voltage divider circuit, shown in Figure 15, used a known constant resistor and the force sensor connected in series to implement the voltage divider rule, which states that "total voltage is proportionately divided between impedances [resistors] in series."[132] By knowing the source voltage and impedance of the constant resistor, and measuring the voltage across the across the sensor, the impedance of the variable resistor could be calculated using the following equation:

$$V_{sensor} = V_{source} \frac{Zsensor}{Zsensor + Zconst} \tag{19}$$

This solves to:

$$Z_{sensor} = -\frac{Vsensor \times Zconst}{Vsource \times (\frac{Vsensor}{Vsource} - 1)} \tag{20}$$

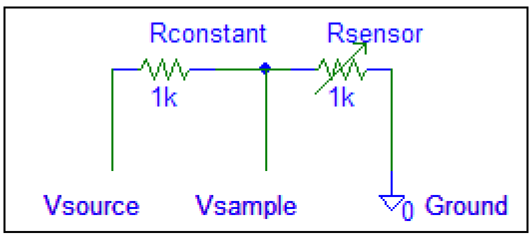


Figure 15: An electrical diagram of the voltage divider circuit.

A/D Board

The analog to digital conversion board (A/D board) was responsible for measuring the voltage across the sensor and transmitting this information to a PC. This was particularly useful because it automated this portion of the testing process, saving the researchers' time during the testing process, and allowed the recording of several data points each second, allowing the more accurate representation of the force used in clicking a mouse. Specifically, a Phidget InterfaceKit 8/8/8 was used. This board provides eight analog signal connections, each of which contains a 5V source voltage, a ground, and an input for sample voltage. This sample voltage is measured relative to ground at a high frequency by the board, and interpreted as a value between 0 and 1000. Within this range, 0 represents 0V, and each unit over 0 represents 5 millivolts. The interpreted value is transmitted to the computer via USB, where it was received by a computer program.

Software

Phidgets provided a programming library for the A/D board in several languages with examples coded in each. This library only required that a lightweight Phidgets driver run in the background to handle low level communication with the board. One of the examples, InterfaceKit-full, provided most of the functionality that recording force data required, as well as a user interface that showed real time data from the A/D board. This example was altered to meet the needs of this testing.

Software for recording the force data was coded in the Visual C# language. This language was chosen because it allowed event driven programming and easy creation of a graphic user interface, and quick creation of installation files. Event driven programming was a crucial part of the coding process. Data from the A/D, with a timestamp, was recorded whenever it changed (in practice, many times per second), which was considered an event that occurred in the driver. Other events, such as creation of a data file and closing of that data file depended on mouse clicks within the user interface, another example of an event.

The graphic user interface from the sample was easily adjusted using the editor in Visual Studio. The provided interface was too intensive for the testing application, and mostly unnecessary. So, some of the features were scaled down or removed with very little need for alterations in the code. A pop up window with a prompt for a participant ID and a textbox was added.

When the code had been tested and confirmed to function perfectly, installation files were created using the one click publisher in Visual Studio. These created an installation program, which could be used on any Windows machine. These files were used to install the program onto a computer dedicated to the force sensor data acquisition in the testing laboratory. While this computer was used for other tasks in the laboratory, no other programs ran on this computer during testing.

The end result was a program that was easy to understand and required minimal interaction. On launching the program, a window prompted for the user to input the participant's ID, which was then used for naming the data file. It immediately began data collection, and saved the data to a file in a comma separated values format, while displaying the data on the screen so that the user could see that the program was functioning. It ceased data collection and closed the data file when the program was closed.

Procedure

After the EMG and the motion capture system were prepared, the force sensor system was setup. First, all programs running on the computer dedicated for the force sensor program were closed. Next, the Phidgets driver program was started, and the Phidgets A/D board was connected to the computer via USB port. The force sensor was taped flush to the left (if there were multiple) mouse button, and the wires were moved into a position to minimally interfere with the test participant's experience. Just before the Fitt's test program was started, the data recording program was opened, and a pop up window prompted for the participant's identification number. Once the OK button was pressed, data recording began, and all data was saved to the hard drive. When the Fitt's test program ended, the program was manually exited, and data recording ceased.

Calibration

Tekscan and Trossen Robotics provide resistance and conductance data for a model of Flexiforce sensor with a higher sensitivity range. As shown in Figure 16, the resistance of the force sensor is inversely proportional to the applied force. The conductance of the force sensor (defined as the inverse of resistance) is approximately linear in relationship to the applied force. Applying Ohm's Law (Voltage is proportional to resistance and inversely proportional to conductance[133]), force must be inversely proportional to the voltage difference across the force sensor.

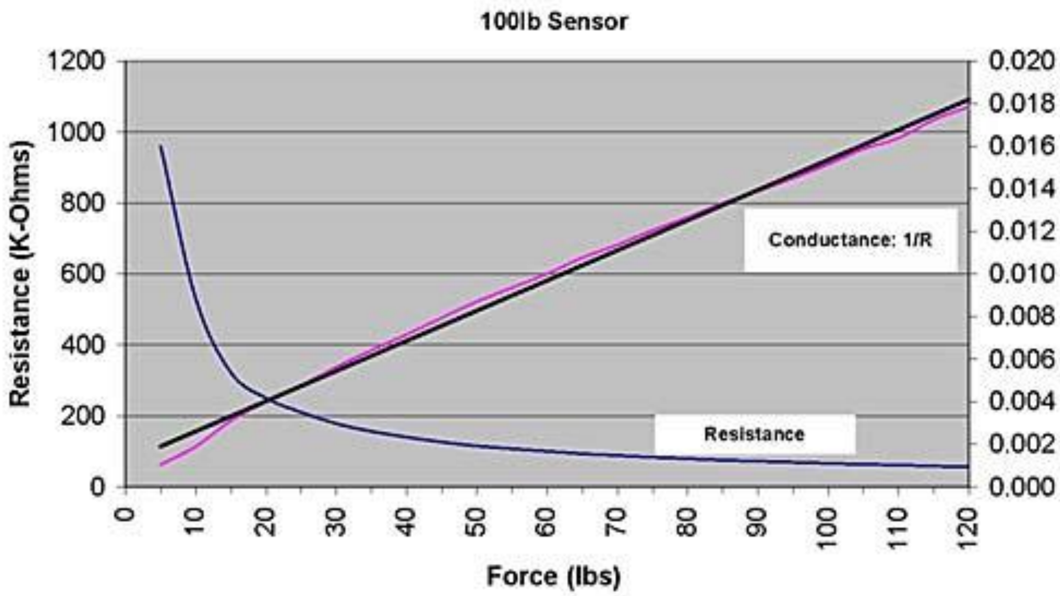


Figure 16: Resistance and Conductance Data for 0 to 100lb sensor. Blue resistance curve and pink conductance curve represent the measured data. Blue conductance curve is the line of best fit for the conductance curve.[134]

While one approach to equating the number received by the computer program from the converter board to a force applied on the sensor would involve creating resistance versus force curves as shown in the graph above, it is much simpler to directly equate the digital reading to the force applied. Knowing that force is related to voltage, and that the digital readings are related to the voltage, means that force can be related to the digital readings. To find this relationship, small weights were placed on top of the force sensor. The weights were incrementally increased from zero pounds to 1.2 pounds. At each weight interval, the digital output from the computer program designed for this study was recorded. The data was graphed, and the line was best fit was determined to be: force in lbs= (digital reading)/965.

Chapter 4: Results and Discussion

4.1 Consumer Research

Survey Results and Analysis

Survey Results: Demographics

The survey began with a selection of questions aimed at evaluating basic demographics. In addition to summarizing the demographic characteristics of the population, the data gathered from these questions would later be applied in correlation research.

While 64% of the surveyed participants were male, 36% were female. Participants' ages ranged from 17 to 40, with a mean age of 20.06. Participants were asked to provide their profession or major. Almost half of the participants had chosen a science as their major, while a significant portion had chosen some form of engineering alone. The rest had jobs or majors that fell in other, non-technical fields.

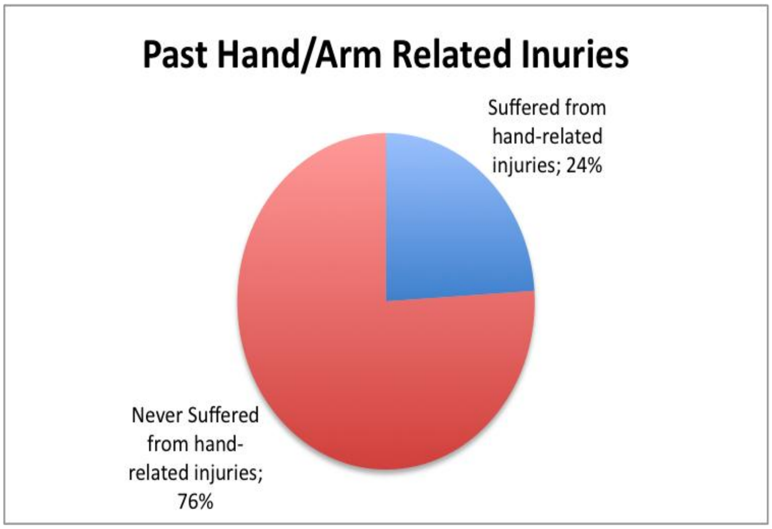


Figure 17: Percentage of Past Hand/Arm Related Injuries

94% of the sample indicated a dominant use of the right hand, while the other 6% were left-handed. When asked whether they had suffered from hand-related injuries in the past, nearly one quarter of those surveyed indicated that they had. (Figure 17)

Respondents were asked to provide the amount of hours, on average, that they used a computer mouse on a given day. They selected from a distribution, which ranged from 0 hours to 13 hours or more. In general, their responses, which are illustrated in Figure 18 suggest a negative relationship between the population's relative frequency and daily mouse use.

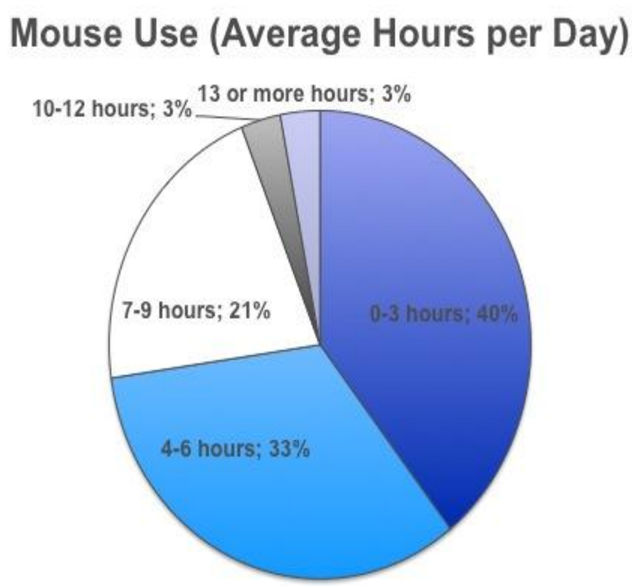


Figure 18: Average Hours of Mouse Use per Day

Once users had specified the extent of their mouse use, their actual mice were examined. For example, they were asked to indicate the input used to connect their mice to computers. While the majority of the survey population used mice connected by a USB, a significant portion admitted to not knowing their method of input.

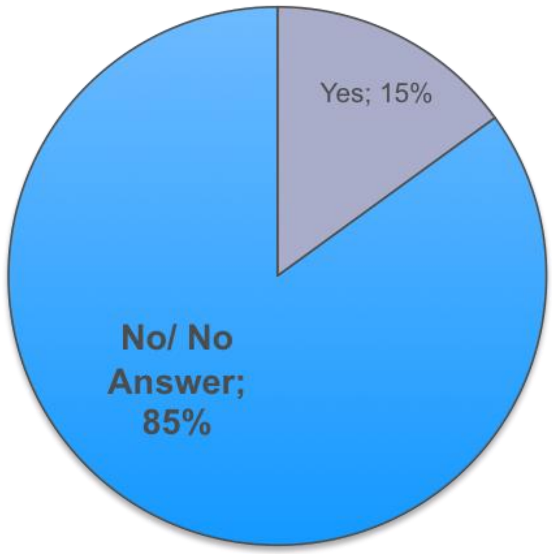


Figure 19: Considered purchasing ergonomic mouse

Respondents were then asked to indicate whether their computer mice were wireless, with 56% saying yes and 44% saying no. 81% of the sample had optical mice, while 19% had those that were mechanical. Finally, 81% indicated owning mice with extra features of some sort, such as programmable buttons or a scroll wheel. Respondents were then asked whether they had ever purchased an ergonomic mouse. According to our findings, which are illustrated in Figures 19, the majority of our survey population had never purchased an ergonomic mouse, or even considered doing so. The majority of our survey population indicated purchasing new computer mice fairly frequently, as indicated in Figure 20.

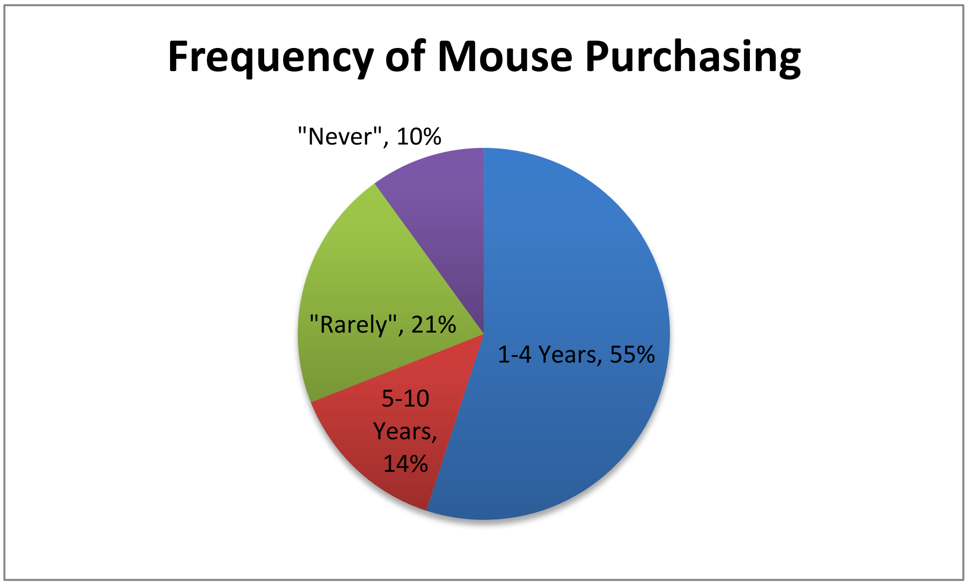


Figure 20: Frequency of Mouse Purchasing

Respondents were then asked what events might prompt this purchase. The majority of users identified the breaking of their current mice as the leading cause. Other prompting factors consisted of the purchase of a new computer increasing technological developments, and other assorted factors.

The survey delved deeper into purchasing preferences, asking users to rank a selection of features in order of importance. Ease of use was indicated as the most important, followed by cost, the presence of a scroll wheel, and general comfort. Only after these preferences were taken into account did users indicate consideration of an ergonomic design. This was followed by users' need for additional and programmable buttons.

The population's general knowledge of current computer mice was examined in part by asking them to list the names of companies within the market. Their answers varied, consisting of lists ranging from 0 to 11 companies. The most commonly identified companies were Logitech, Microsoft, Dell, and Apple. Others, including Hewlett Packard, Gateway, and Razor, were identified, but by fewer respondents. Finally, only a few users identified other companies like Sony, Acera, Bluetooth, IBM, 3M, Targus, and Kensington.

Respondents' technological preferences were assessed when they were asked how much they cared about having the latest technology in their lives, and specifically in their mice. Their responses are illustrated in Figures 21 and 22. The majority of respondents indicated caring about having the latest technology only "a little," both in their computer mice, and in their lives in general. Despite this similarity, the distributions of responses to these two questions differed. This suggests that having the latest technology in computer mice is generally not a top priority, even to those that consider technology generally important.

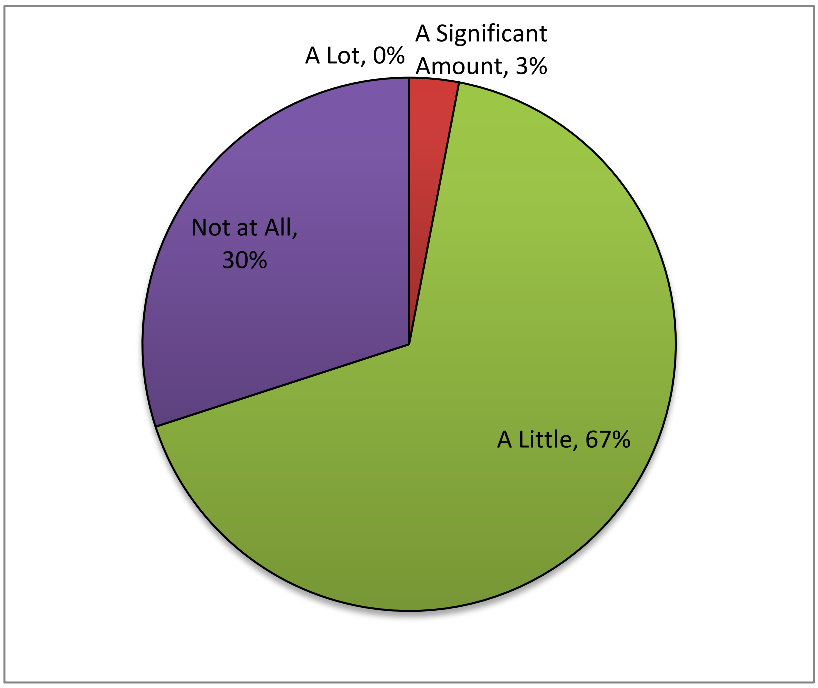


Figure 21: How much users care about having the latest technology in their lives

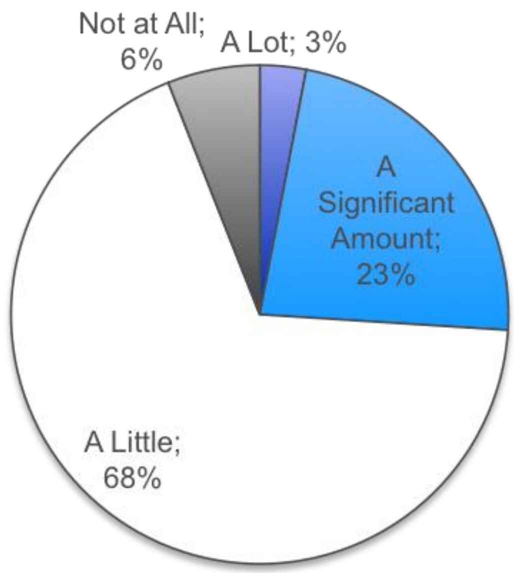


Figure 22: How much users care about having the latest technology in their mice

Users were asked whether it might bother them to have different mice at work and at home. A majority answered that this would not be a problem.

We had successfully identified those specific features that might lead users to either choose or dismiss a particular mouse design. Next, it was necessary to expand upon this, asking users to identify specific conditions that might make them more likely to purchase a computer mouse. The most common identified circumstance was the creation of a new mouse that allowed users to complete tasks faster. However, this was identified by only one quarter of respondents, suggesting that, at least within the survey population, there is no single factor of overwhelming importance to users. However, results demonstrate a positive relationship between users; likelihood to purchase a mouse with how long the mouse in question has been available. Also, according to the survey, users would be more likely to choose a specific computer mouse, if they had heard about it before, whether from a friend, online, or on the news.

When asked about computer mice and WMSDs, some users said they would be more likely to purchase a mouse if it looked like it would reduce the likelihood of the conditions, or was advertised to do so. A larger portion said they would be more likely to purchase a mouse if it was *proven* to do so.

This question led to the portion of the survey that addressed WMSDs directly. The survey asked respondents whether they believed WMSDs to be a major problem. Responses to this question were split almost equally. Similar results were found when users were asked whether they had ever experienced discomfort from mouse use. However, respondents' descriptions of their pain illustrate a negative relationship between relative frequency of suffering users and severity of pain. Those who had suffered were also asked whether they ever made any changes to their mouse use habits due to their discomfort. Only a small percentage had done so.

Correlation Testing

Once the initial data was gathered, findings were examined using correlation tests, specifically the chi-square test for independence. To test for a significant association, the team went through findings and chose data sets to apply, such as testing for an association between a person's gender and their likelihood to purchase an ergonomic mouse. In contrast, the alternative hypothesis indicates that the value of one variable *can* be used to predict another.

Gender vs. Likelihood to Purchase an Ergonomic Mouse

Table 1: Observed Values

	Males	Females
Have Purchased an Ergonomic Mouse	6	0

Have NOT Purchased	15	12

Table 2: Expected Values

	Males	Females
Have Purchased an Ergonomic Mouse	3.84	2.16
Have NOT Purchased	17.28	9.72

P=.04

In the case of gender versus likelihood to purchase, the test yields a p value of .04. This indicates a 4% chance of getting the sample results, given that the two categorical variables are actually independent. According to the rules of the test, a p value this small allows us to reject the null hypothesis and rule that these two variables are not independent.

WMSDs a problem vs Hand Discomfort

For this chi-squared test, the observed and expected findings are listed in Tables 3 and 4, and are illustrated in relation to each other in Figure 23.

Table 3: Observed Values

	Yes	No
Yes	11	4
No	3	14

Table 4: Expected Values

	Yes	No
Yes	6.58	8.46
No	7.42	9.54

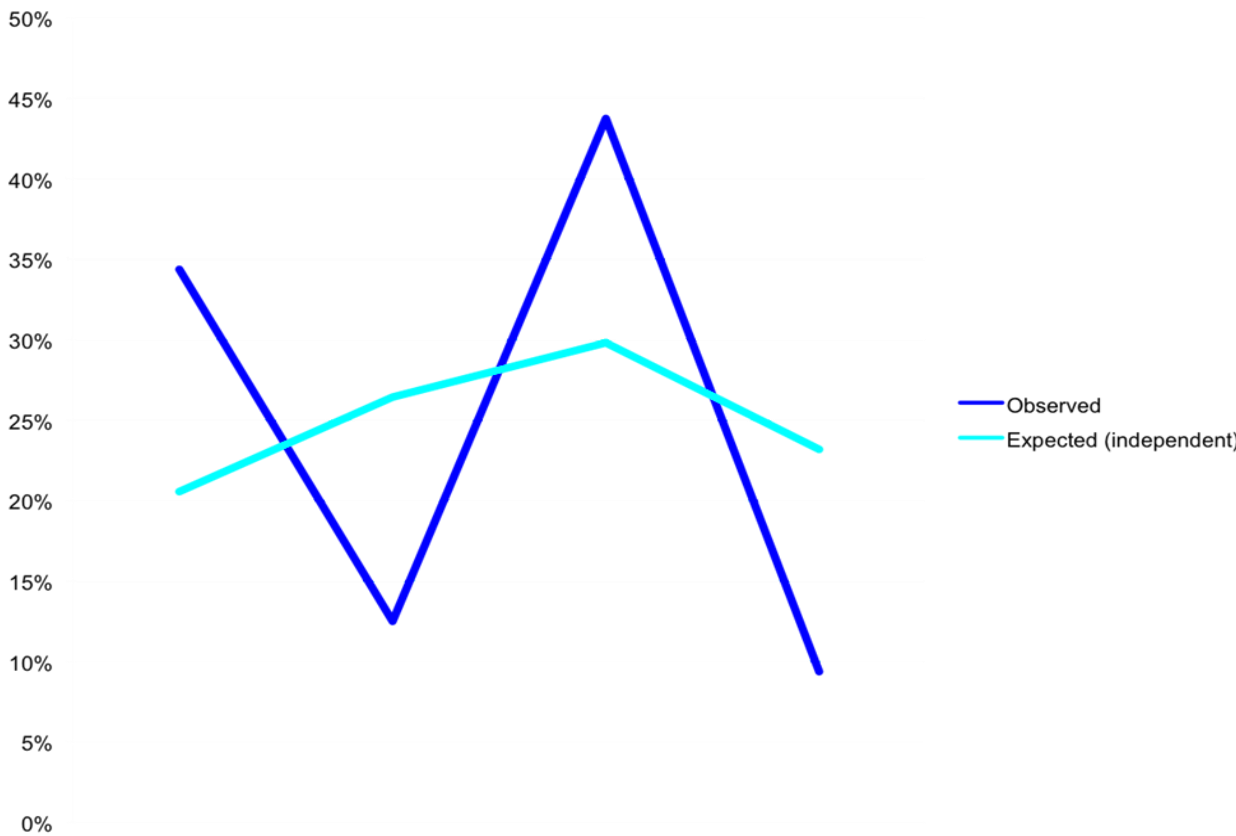


Figure 23

The test yields a p value of .0015, or a 00.15% chance of getting the sample results if these variables were independent. With such a low probability, the null hypothesis can be rejected, indicating that the two variables are not independent of each other.

Pre-Survey and Post-Survey Ratings

The pre-survey and post-survey rating for the different mouse designs were analyzed by using a Kruskal-Wallis analysis of variance. Before this could be done, the data had to be ranked, and the data from the two sample groups had to be separated. The raw rating data can be seen in Appendix # and the ranked data can be seen in Appendix #. Calculations were done assuming an alpha of .1.

The first analysis that was done was comparing the ergonomics rating of the control mouse before and after the subjects were given the mice. Calculating an ANOVA gave a p-value of .055 meaning that doing a comparison of means was appropriate. Using the Kruskal-Wallis test (seen Figure 24), it was clear that the two groups appeared to come from different populations. This meant that users thought that the control mouse was more ergonomic after getting to use it and the other mice. This seems to indicate that people take the ergonomic features of the mice that they use daily for granted.

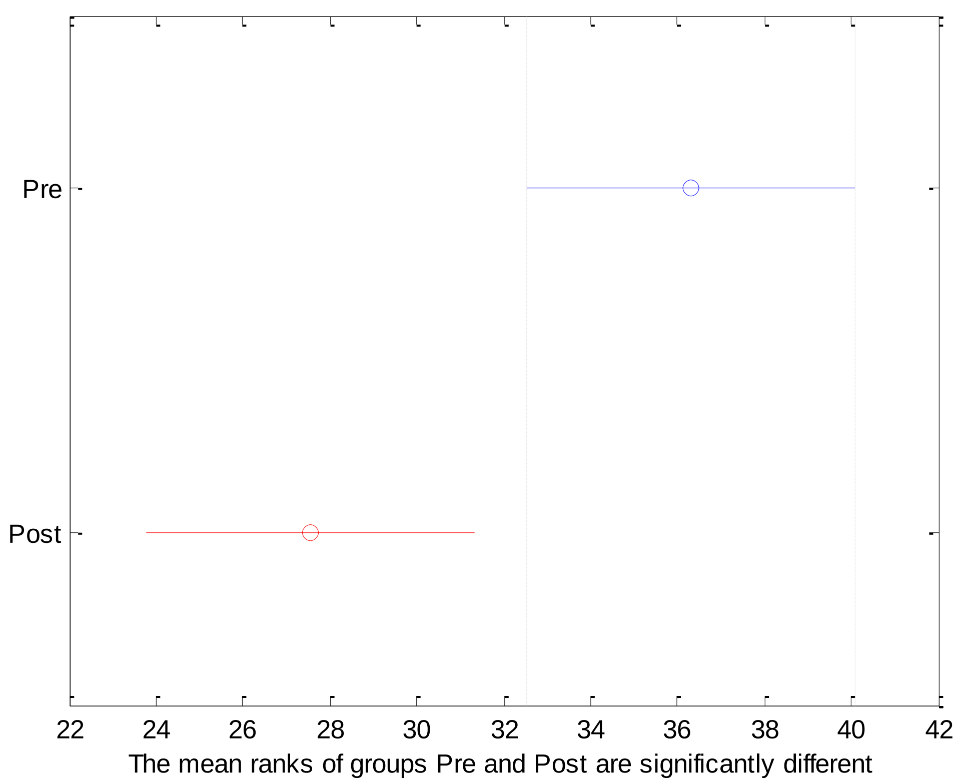


Figure 24: Comparison of Means for Control mouse ergonomics

The second test that was done with the rating data was an examination of the pre-survey and post-survey overall ratings for the vertical mouse. Calculation an ANOVA gave a p-value of .027. Based on this, that Kruskal-Wallis test was completed to compare the means of the samples. Looking at the results in the figure below, it is clear that the users had a more favorable impression of the vertical mouse after being able to use the mouse. This indicates that users, once they are able to use the vertical mouse, like the mouse more than they do when they only see the mice.

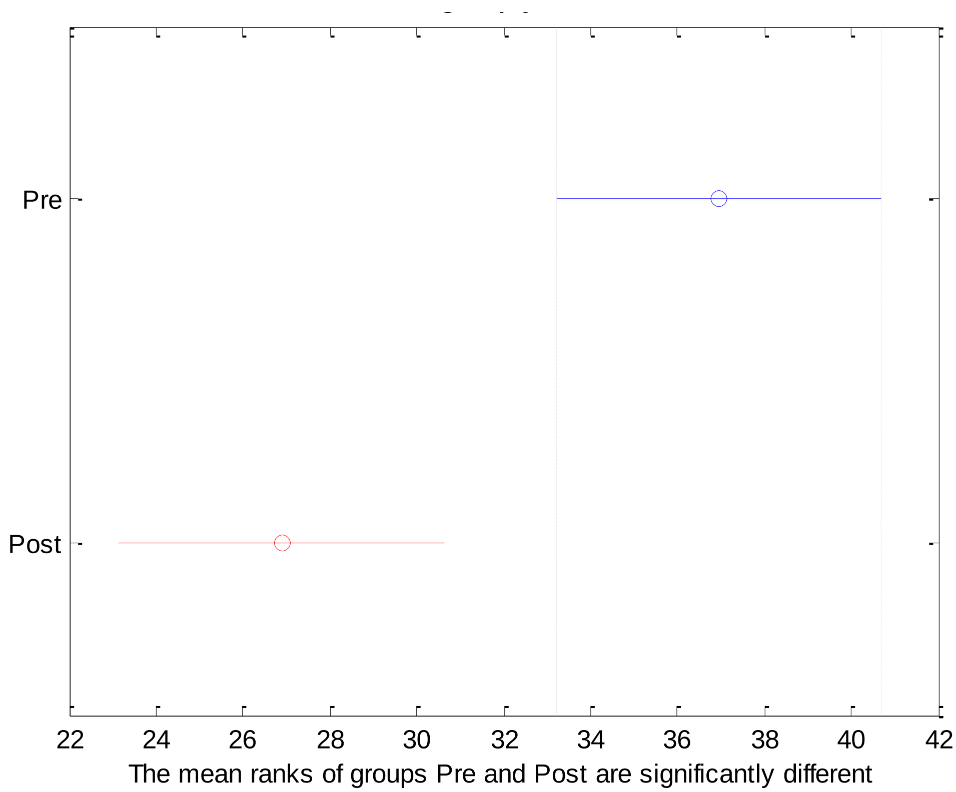


Figure 25: Comparison of Means for overall rating of Vertical Mouse

The last test that was done was a comparison of user ratings for the trackball design's usability. The ANOVA resulted in a p-value of .0658. The comparison of means below showed that the user post-survey impression of how easy it is to use the trackball mouse was lower than the pre-survey impression. This indicates that being able to use the trackball mouse reduces how well people believe they can use the mouse on a daily basis. This may indicate that users tend to over-estimate their abilities to use unfamiliar designs.

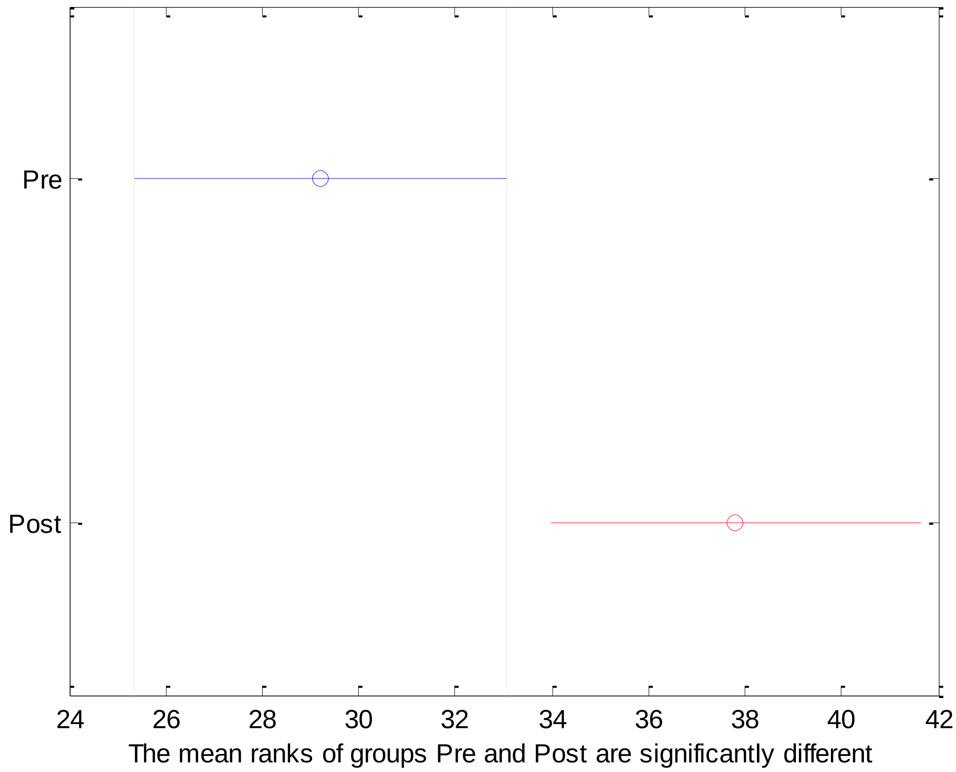


Figure 26: Comparison of Means for Usability of Trackball

Focus Group Results and Analysis

To record and analyze the information from the focus groups, notes were taken throughout the sessions by the members of the team that were not addressing the participants. The information was aggregated and analyzed. We focused on words and phrases that indicated approval or disapproval of a mouse, as well as the details participants gave about their own personal mouse use. Major importance was placed on the pricing and desired (or unwanted) features of the mouse. Lesser focus was put on purchasing influence and overall ergonomic knowledge of the participants.

The prompting factors for purchasing a mouse were fairly unvaried throughout the focus groups. At least one person in every focus group – often more than one – stated that their reason behind purchasing a new computer mouse would be if the old one stopped working. This was by far the most common response to the question. They rarely mentioned dissatisfaction with their old mice – this happened in two focus groups, and emphasis was placed on a dislike of using a laptop touchpad. It was also rare that the participants needed a new mouse because their previous one was inadequate for a task. One focus group mentioned the need for a specialized mouse, specifically for playing online games. This implies that our participants, on the whole, are satisfied with general mice as computer interfaces – perhaps implying a lack of WMSD effects among our target population, or simply a lack of knowledge.

Table 5: Reasons for purchasing new mice

Prompting Factor responses from Focus Groups "What prompts you to purchase new mice?"	Individual responses
Focus Group 2	"…Just got my first laptop and the touch pad is too annoying"
Focus Group 5	Lack of a mouse from a broken mouse or broken touchpad
Focus Group 6	"… need a gaming mouse for top performance"

The purchasing influences that participants talked about had a larger extent. Most focus groups gave two specific answers; either price or personal recommendations were the deciding factors in their purchase. In two focus groups, participants mentioned disliking mice made by the manufacturer Apple, and at least one focus group had a participant who liked those mice. Manufacturers were often important in purchasing a mouse, but on a largely superficial level. Most focus groups believed that a recognized name-brand mouse would be of higher quality than an off brand, but the brand itself was not important. Online reviews of mice were cited in about half of the groups, and specific mouse features were also deciding factors. Low price was also a factor, with one participant specifying that they would start with the lower end of the quality mice while searching for one to purchase.

Table 6: Responses on Importance of Manufacturers

Influence responses from Focus Groups “How do you decide?” And “What manufacturers do you know of? Are manufacturers important?”	Individual responses
Focus Group 3	Influenced by reputation and word of mouth “…manufacturers are a little important if I recognize the name”
Focus Group 4	Influenced by a friend’s recommendation of a mouse Mouse brand doesn’t matter
Focus Group 8	Influenced by “what I’m used to” Mouse brand doesn’t matter, although “maybe Logitech”

Both expected and optimum price ranges of specific mice were requested from the participants. Most participants believed that a two button optical mouse should cost them under 20 dollars, with the scroll wheel potentially adding up to five dollars in cost. Often, this price was placed at 15 or even 10 dollars. However, most participants expected to pay much more for “different” mice, like the vertical mouse or the Zero-Tension mouse. These ranged from 30 to around 50 dollars. We also asked the participants to describe their hypothetical “perfect” mouse and the price they would expect to pay for it.

Participants gave wide ranging prices, from 20 dollars all the way to 100. Features of these mice also varied from a comfortable mouse with two buttons (with programmable additional buttons) and a scroll wheel to a mouse that was Bluetooth-compatible and made of a gel substance. A mouse made of gel (or just simply a comfortable mouse) seemed to come up the most often. At least one participant specified that the mouse needed to look like a “regular” one.

Table 7: Responses on price range of mice

Price range of mice	Individual responses
Focus Group 3	Control Mouse - $5-10, $15 Perfect Mouse - $30-60
Focus Group 7	Control Mouse - $8-15 Perfect Mouse - $25-50, $100
Focus Group 8	Control Mouse – $3-10 Perfect Mouse - $20, $40-60

The participants were also asked to give their opinions on each of the individual mice. We gave them five to choose from – the “normal” mouse, a trackball mouse, a joystick mouse, a vertical mouse, and the “Zero Tension” mouse. The “normal” mouse was the one most often rated favorably. Many participants focused on the familiarity with the mouse as a positive aspect, as well as the mouse’s general shape that more or less conformed to their hands.

The trackball mouse received an overall unfavorable review. Participants disliked the change from moving the arm to manipulate an entire mouse to moving their fingers to manipulate the ball interface. Complaints ranged from unfamiliarity to awkward design, as well as more everyday worries such as the loss of the exposed ball itself. Participants felt as though the ball movement would be imprecise, and their fingers would become tired much faster than with another mouse. However, previous experience seemed to improve the participants' opinion of the mouse.

Table 8: Responses on trackball mouse

Trackball Mouse	Individual responses
Focus Group 3	"[The trackball mouse is] too much work, I don't like it."
Focus Group 4	I've always thought it was weird, but it's not that bad, I have used it before –it's better and more accurate."
Focus Group 8	"[The mouse] was pretty uncomfortable." "Hand movement is better."

The joystick mouse received a mediocre rating. The joystick appendage of the mouse was not articulated, which initially confused participants. When they realized that the mouse was meant to be moved completely, they felt as though there was no good resting position for their hand, meaning that their arms would have to be continually supported. Some found it unstable, and the button placement was unintuitive. There was also no scroll wheel, which some participants found bothersome. Some participants had used joysticks before, and after the initial movement confusion they found that they enjoyed the shape of the mouse and felt that it was comfortable. These participants seemed to be the minority, however.

Table 9: Responses on Joystick Mouse

Joystick Mouse	Individual responses
Focus Group 4	"[The mouse] doesn't support your hand." "[It] might be an advantage in Counterstrike."
Focus Group 5	"[My hand] is not in a resting position"
Focus Group 6	"[The mouse] is comfortable but needs a scroll wheel."

The vertical mouse was slightly more popular overall. Most participants found that it was an interesting concept to change the orientation of the hand while manipulating the mouse. There were complaints about the mouse size and button size, although these were not universal. The most common problem was that there was no platform to rest the user's hand on – participants felt as though after a period of use, their wrists would be tired or that their smallest finger would be caught underneath the moving mouse. There was also the problem of support while clicking the mouse – because the mouse's buttons were at a perpendicular angle to the mouse itself, the user would have to support the mouse as they depressed the buttons. They did find the mouse comfortable, however, and many thought that with use they could adapt to the positioning.

Table 10: Responses on Vertical Mouse

Vertical Mouse	Individual responses
Focus Group 6	"My fingers drag on the table, it needs a ledge." "Stabilizing [my hand] is hard."
Focus Group 8	"[The mouse] is comfortable, but the side is awkward." "I could learn to like it."
Focus Group 2	"It would take some getting used to, but it's kind of cool"

The Zero-Tension mouse received mixed reviews. Some thought that the mouse was too small, and due to the grooves in the mouse, their fingers were shifted into uncomfortable positions. This may not have been an inherent problem of the mouse – the product is available in three different sizes, so complaints like these may have been alleviated by addressing the participant's personal specifications. Some disliked the orientation of certain features, like the thumb-based scroll wheel. Other participants thought that the mouse features were actually positioned well, and they found scrolling and button activation much easier than on the vertical mouse, which also changed the orientation of the user’s wrist and hand. In general however, the participants who disliked the Zero-Tension mouse tended to have a difficult time mapping their fingers to the grooves, whereas those who did like it tended to have hand sizes that fit the mouse well.

Table 11: Responses on Zero-Tension Mouse

Zero-Tension Mouse	Individual responses
Focus Group 3	“[The mouse] is spectacular.” “I think the third [finger] slot should have a button.”
Focus Group 4	“I don’t like to scroll with the thumb” “The most intuitive way to hold it would be to wrap your hand around it completely.”
Focus Group 5	“[It has] something to do with size – it might be easier if it were larger.” “The scroll wheel is inconveniently placed.”

Overall, the mouse that was liked the least was the trackball mouse. Participants disliked the mouse on the whole, aesthetically and in use. The Zero Tension mouse was often a favorite, but also had some participants who disliked it the most. The vertical mouse received generally favorable reviews, without a lot of participants voicing distaste for it. However, both the Zero Tension and vertical mouse were often thought to be elaborate or hard to transport. The normal mouse received the most support of the five mice, most likely because it was familiar and known to meet the needs of the participants while staying within their perceived price range.

In terms of ergonomic knowledge, the participants possessed at least a basic understanding as to what caused WMSDs and how ergonomic computer mice were designed to alleviate conditions leading to them. They had a fairly strong conceptualization of the consequences of WMSDs, but usually related it to a loss of ability to use the computer for entertainment, as opposed to loss of productivity at a job. Most participants had seen either ergonomic mice or keyboards before, but very few indicated that they had used them. Some indicated that they found the ergonomic keyboards that they had used or seen to be uncomfortable, and the mice to be complicated. There was no personal experience of WMSDs among the participants, but a few did know other individuals who had developed conditions. However, they believed that the conditions were primarily developed by older people and people who performed repetitive tasks or worked in computer-centric jobs. It is possible that this lack of concern may influence their purchasing decisions, as ergonomic mice may seem unnecessary and costly when the problems that WMSDs cause are not prevalent in a consumer's everyday life.

Table 12: Knowledge of WMDSs/Ergonomics

Knowledge of WMSDs/Ergonomic knowledge	Individual Responses
Focus Group 5	What causes it? – "Having your wrist at unnatural angles for long periods of time. That's the reason for using gel pads while typing." Who gets them? – "Older people," "office workers," "computer programmers." Personal experience? (None) What does it do? "Trouble gripping," "loss of movement in wrist and possibly fingers"
Focus Group 6	What causes it? – "Worn down cartilage," "movement of wrist," "repeated motion," "awkward posture" Who gets them? – "Secretaries," "older people" Personal experience? (None) What does it do? – "Everyday tasks are harder," becomes difficult to play video

	games
Focus Group	What causes it? - “Repeated typing,” “ computer use,” “things like tennis,” (response from participant to participant – “I thought it was only from typing”) Who gets them? – “Musicians,” “tennis players,” “people who type for 8 hours a day” Personal experience? – “My mother,” “my mother’s friend,” “a friend of mine” What does it do? - [Causes] pain,” “[you] have to stop using your wrist, it’s like arthritis,” “[you] have to go to physical therapy, possibly have to get surgery.”

4.2 Experimental Research

Fitts’ Test

The throughput for each mouse was calculated for each of the 16 distinct target width and travel distance combinations. (see Equation 11) From the throughputs of each combination, the average throughput, the value ultimately used to rate each mouse’s efficiency, was calculated (Figure 27).

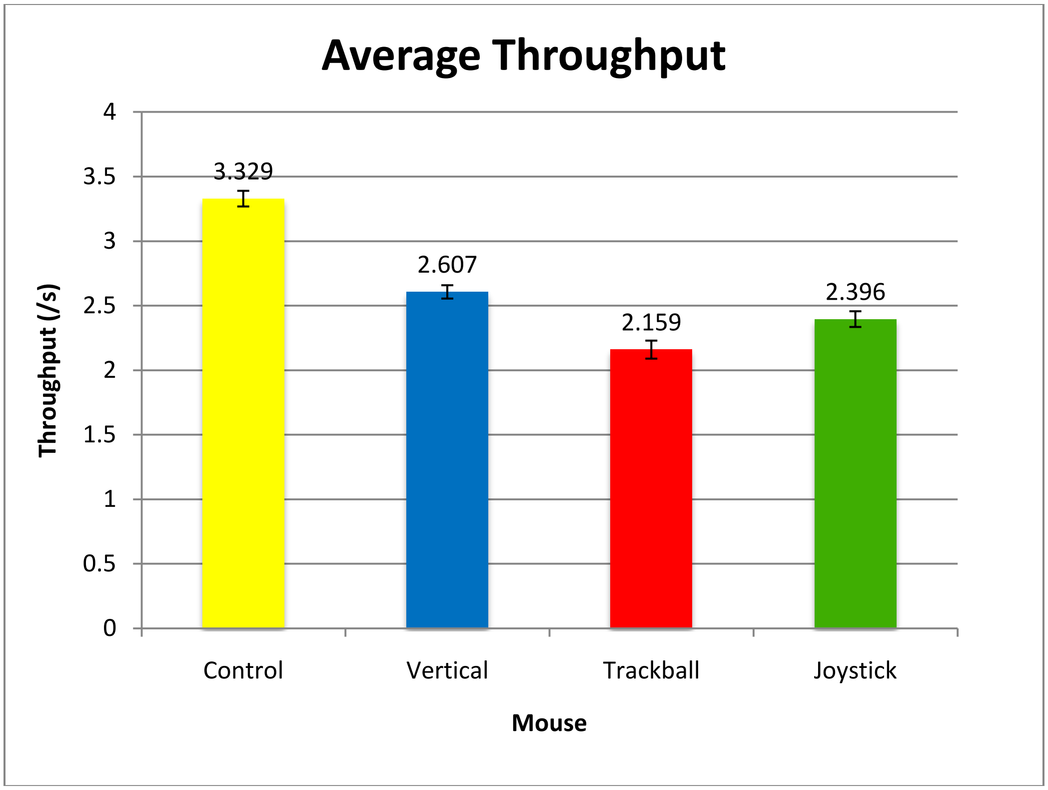


Figure 27: Average Throughput

The calculations show that the control mouse was most efficient. The vertical mouse followed the control mouse, performing the best out of the three ergonomic mice. The joystick mouse and the trackball mouse followed the vertical mouse, respectively. The standard error calculations and p-values display that the results are statistically significant. To determine statistical significance, each ergonomic mouse was compared to the control mouse using a t-test. The mice were also compared to each other ergonomic mouse. All of the p-values yielded were less than 0.01; therefore, the throughput can be attributed to the type of mouse used (Table 13).

Table 13: p-Values between each mouse throughput

Relationship	p-Value
Control, Vertical	2.72198E-10
Control, Trackball	9.95983E-14
Control, Joystick	3.32518E-12
Vertical, Trackball	9.41642E-06
Vertical, Joystick	0.006540264
Trackball, Joystick	0.008090512

The average throughput values for each mouse directly corresponded to the average time the mouse user took to complete the target acquisition task. In speed performance, the control mouse was the fastest, followed by the vertical mouse, the trackball mouse, and the joystick mouse, respectively (Table 14).

Table 14: Average Time Taken Per User to Complete Mouse Activation Task

Mouse	Average Time (seconds)
Control	128.7784074
Vertical	140.939
Trackball	155.4094444
Joystick	163.1191111

Similarly to the throughput calculations, the vertical mouse's performance was most comparable to that of the control mouse, and the trackball and joystick mice had the worst speed performance.

Overall, an analysis of the results derived from the modified Fitts' test and the users' performances shows that the control mouse is the most efficient. Of the ergonomic mice, the vertical mouse yielded results most comparable to the control mouse; therefore, a new ergonomic mouse should implement features of the control mouse and vertical mouse to maximize its efficiency. This conclusion will be combined with the conclusions made from the EMG, activation force, and motion capture data to isolate ideal features of a mouse design.

Motion Capture

The range of motion and average angle for each joint for each mouse were first averaged across subjects and them compared by type of mouse. The results are shown in Figures 28 and 29 respectively. Then, for each subject who had a both a measurable ergonomic and control mouse trial, the difference was calculated between measurements of each trial. Only 22 subjects had measurable trials for both the ergonomic and control mouse (7 joystick, 7 vertical, and 8 trackball). These differences in average angle and range of motion were then averaged across subjects and compared across ergonomic mouse types. The results are shown in Figures 30 and 31 respectively. All graphs also report the circular standard error for each angle measurement.

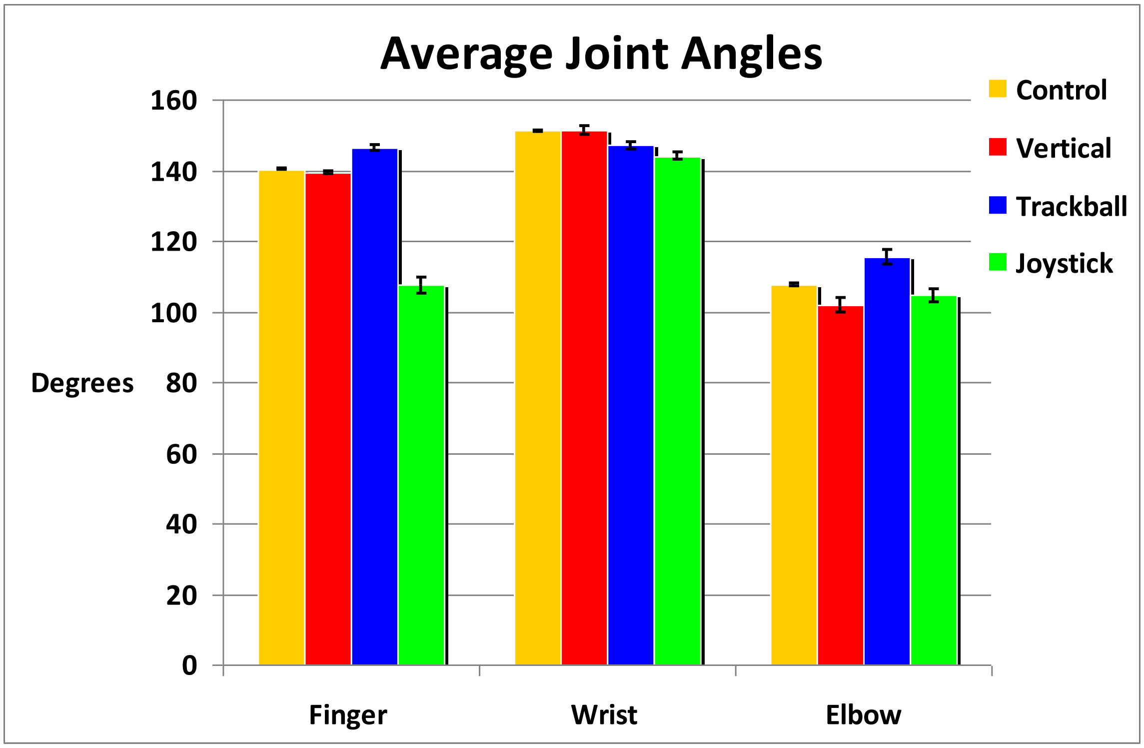


Figure 28: Average Joint Angles

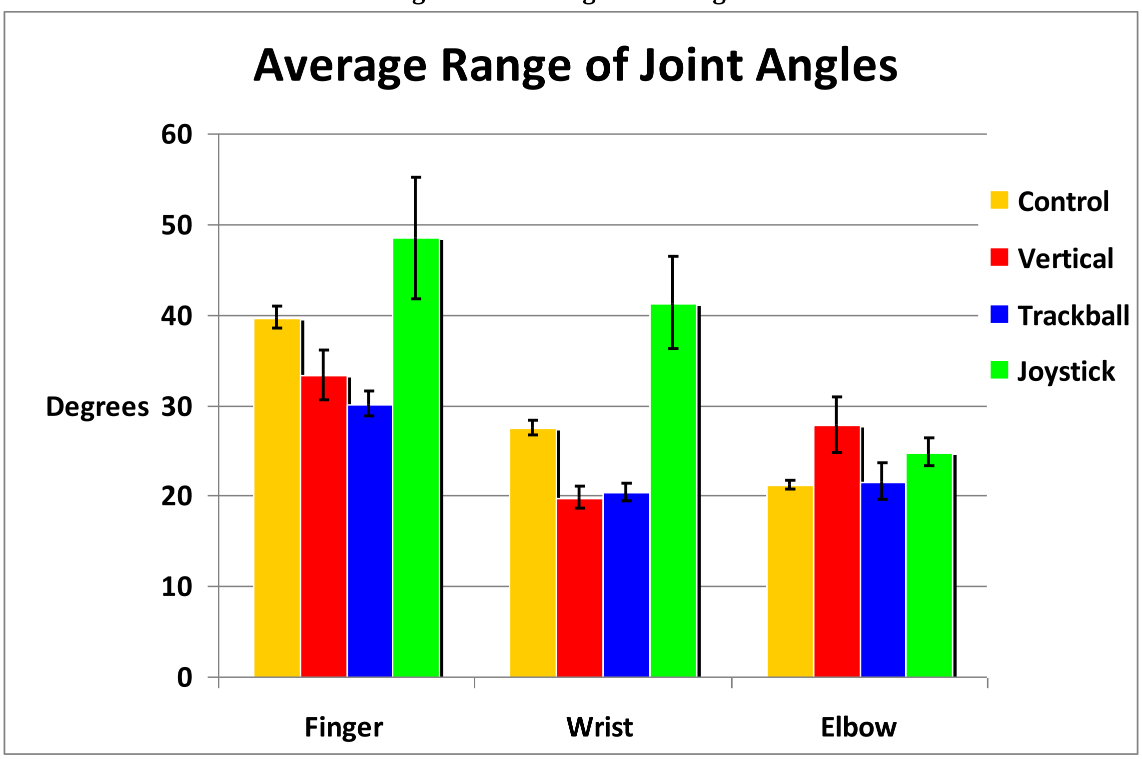


Figure 29: Average Range of Motion

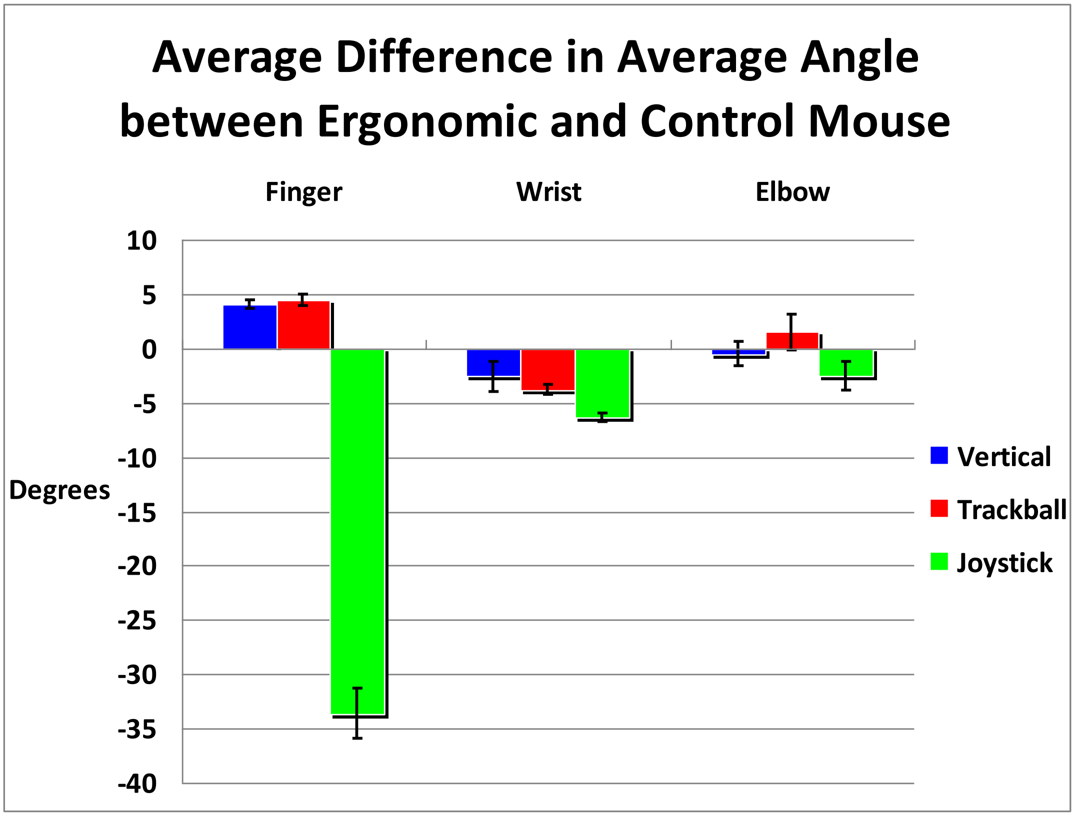


Figure 30: Average Difference in Average Angle

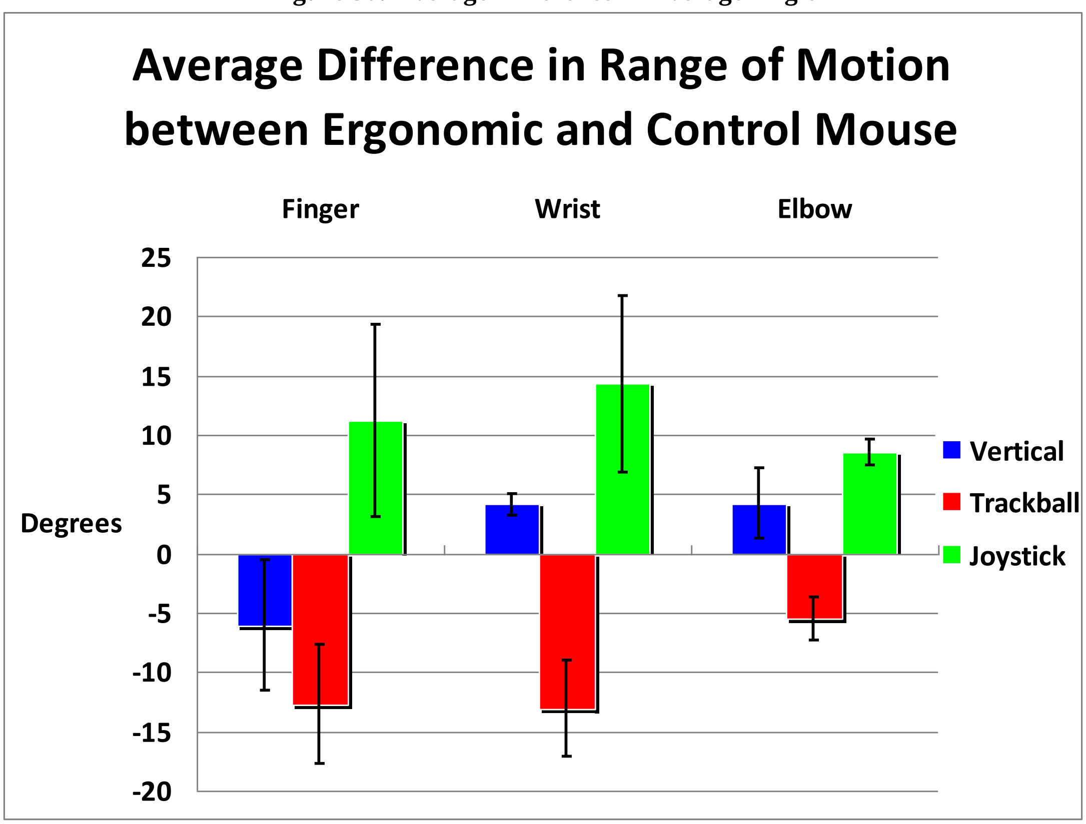


Figure 31: Average Difference in Range of Motion

As evident in Figure 28, the average wrist and elbow angles for all four mice are very similar. The average wrist angles are all within 7.19 degrees of each other, while the average elbow angles are all within 13.67 degrees of each other. Thus for all mice, the subjects positioned their wrist and elbow generally in the same position. However, for the average angle of the finger joint, the control, vertical, and trackball mice all have a similar position, while the joystick mouse has a significantly lower angle. This stems from the fact that for the control, vertical, and trackball mice, subjects clicked with their index finger with their hand resting in a position similar to that of the control mouse. However, when using the joystick mouse, subjects clicked with their thumb in a motion very dissimilar to that of the other three mice. This difference in finger angle shows that the joystick mouse required the most different posture from that of the control mouse. All average joint angles have a very small standard error, evident in Figure 24. We can be very confident that the average angle for mouse is significant.

An analysis of Figure 29 shows which mice required the most motion during mouse use. Looking at the finger joint, it is evident that joystick mouse required the greatest range of motion. The vertical mouse and trackball mice both show a decrease in the range of motion as compared to the control mouse. Examining the standard error, the joystick mouse significantly increases the range of motion of the finger joint as compared to that of the control while the trackball and joystick mice significantly decrease range of motion for the finger joint as compared to that of the control. Similarly for the wrist joint, users of the joystick mouse had a statistically significant higher range of motion than users of the control mouse. Again, the vertical and trackball mice both show a statistically significant decrease in the range of motion as compared to the control mouse. The elbow joint, however, does not follow this trend. The control and trackball mice have very similar ranges of motion and the vertical and joystick mice both show a greater range of motion than the other two mice. From these results, in terms of overall range of motion as compared to the control mouse, the trackball mouse showed a statistically significant reduction in the operational range of motion, the joystick mouse significantly increased the operational range of motion, and the vertical mouse both increased and decreased the operational range of motion. Thus, in terms or range of motion, the trackball mouse is an improved design, the joystick mouse is a worse design, and the vertical mouse offers little benefits or drawbacks.

Figure 30 shows the difference in average joint angles between the control mouse and ergonomic mouse, averaged across subjects. A positive change indicates the ergonomic mouse induced a larger average angle during mouse use, while a negative change indicates the control mouse induced a larger angle. From these results, it is evident that the joystick mouse most drastically changed the average angle of each joint. For all three joints, the joystick mouse has the statistically significant largest relative change as compared to the trackball and vertical mice. This shows that the joystick mouse required subjects to change their arm and hand positionings the most from the positionings used with the control mouse. Also, for all three joints, the joystick mouse decreased the average joint angle. This result is statistically significant because the error bars for all three joints lie below the 0 degree mark. This represents an arm and hand positioning that is more compact and closer together. The trackball and vertical mice only altered the average joint angles by less than 4.5 degrees and these changes were both increases and decreases from the joint angles of the control mouse. Thus, the vertical and trackball mice had very little effect on the average arm and hand positioning as compared to the control mouse.

Figure 31 shows the average change in range of motion for each of the three joints for each ergonomic mouse. A positive change indicates the ergonomic mouse increased the range of motion while a negative change indicates the ergonomic mouse decreased the range of motion. It is clearly evident that the joystick mouse increased the range motion for all three joints, as the change in range of motion is greater than 8.5 degrees. This increase in range of motion is statistically significant because the error bar for each joint for the joystick mouse lies above the 0 degree mark. On the other hand, for all three joints, the trackball mouse decreased the range of motion as compared to the control mouse. This decrease was greater than 5.48 degrees for each joint. This decrease in range of motion is statistically significant as the error bar for all three joints for the trackball mouse lie below the 0 degree mark. The vertical mouse decreased the range of motion for the finger joint, but increased the range of motion of the wrist and elbow joints. These changes however were all less than 6.05 degrees for all joints. This indicates that the vertical mouse was able to keep the same range of motion as that of the control mouse.

In conclusion, an analysis of the motion capture data shows that the trackball mouse design improves upon the control mouse design, the joystick mouse design performs worse than the control mouse design, and the vertical mouse design performs very similarly to the control mouse design. The trackball and vertical mice keep the same arm and hand positioning as the control mouse. The joystick mouse, however, alters the arm and hand positioning of the control mouse, most evident in the finger joint. This is caused by the joystick mouse requiring button activation with the thumb instead of the index finger. In terms of range of motion, the joystick mouse significantly increases the range of motion for all joints. On the other hand, the trackball mouse decreases the range of motion for all joints. The vertical mouse shows little change in the range of motion compared to the control mouse.

EMG Testing

When analyzing the results, it became apparent that the ECR data from subject E1, the control Fitts' Test data from subject F1, and the control Fitts' Test data from subject J3 was faulty.

In order to compare results between subjects, Team MICE intended to give Fitts' Test results as a percentage of the corresponding MVC. This course of analysis produced a surprising result. The average and peak values from MVCs were not significantly greater than the corresponding values from the Fitts' Test. MVC and Fitts' Test comparisons were done using mean and average peak values from the data, since area measurements depend on the time over which the area is measured. For the Fitts' Test data, the average of all 0.5-second intervals was taken, so that single values from corresponding MVCs and Fitts' Tests could be compared. The following chart shows the average Fitts' Test value as a percentage of the corresponding MVC value.

Table 15: The average test value as a percentage of the corresponding MVC value

	ECR-Avg	ECU-Avg	FCR-Avg	FCU-Avg	ECR-Peak	ECU-Peak	FCR-Peak	FCU-Peak
Average	2207.87	56.08	45.33	42.80	3298.19	54.23	37.58	39.54
St. Dev.	1682.26	59.44	80.54	33.11	2323.84	76.93	48.56	30.19

From these results, it is possible to deduce either that the procedure for the ECR MVC was faulty, or that the ECR electrodes were not placed in the correct place. In addition, the Fast Fourier Transforms of the ECR MVCs were significantly different from other MVCs. Regardless, the numbers for the other muscles seem suspect as well. Does a person really exert thirty-seven to fifty-six percent of their maximum muscle force when moving a computer mouse? Furthermore, in the lowest case, FCU-Peak, one standard deviation lies at sixty-nine percent, and in half the cases, one standard deviation is over one hundred percent. The standard deviation should not be miniscule, as different subjects will use different amounts of their maximum strength when taking the Fitts' Test. However, values of over one hundred percent should never occur, and should certainly not be within one standard deviation of the average. Data from both the MVC and the Fitts' Test was taken using the same experimental setup, and the MVC procedure was designed using accepted scientific literature.[135] Therefore, it is likely that the MVC test was not administered correctly, resulting in values below the subject's true maximum voluntary contraction. Perhaps the subjects did not exert their maximum force. If this is the case, then the MVC results are invalid, as it is impossible to tell what level of effort each subject attained.

An alternative way to compare data between subjects is to compare their results with their alternative mouse to their results with the control mouse. Again, to produce a single result for each muscle in each Fitts' Test, all of the 0.5-second data slices were averaged together to produce twenty-four numbers for each subject. The twelve numbers from the test with the alternative mouse were divided by the corresponding value from the control, to give the muscle activity for each alternative mouse as a percent of the muscle activity for the standard mouse. The results are shown in figures 28-30.

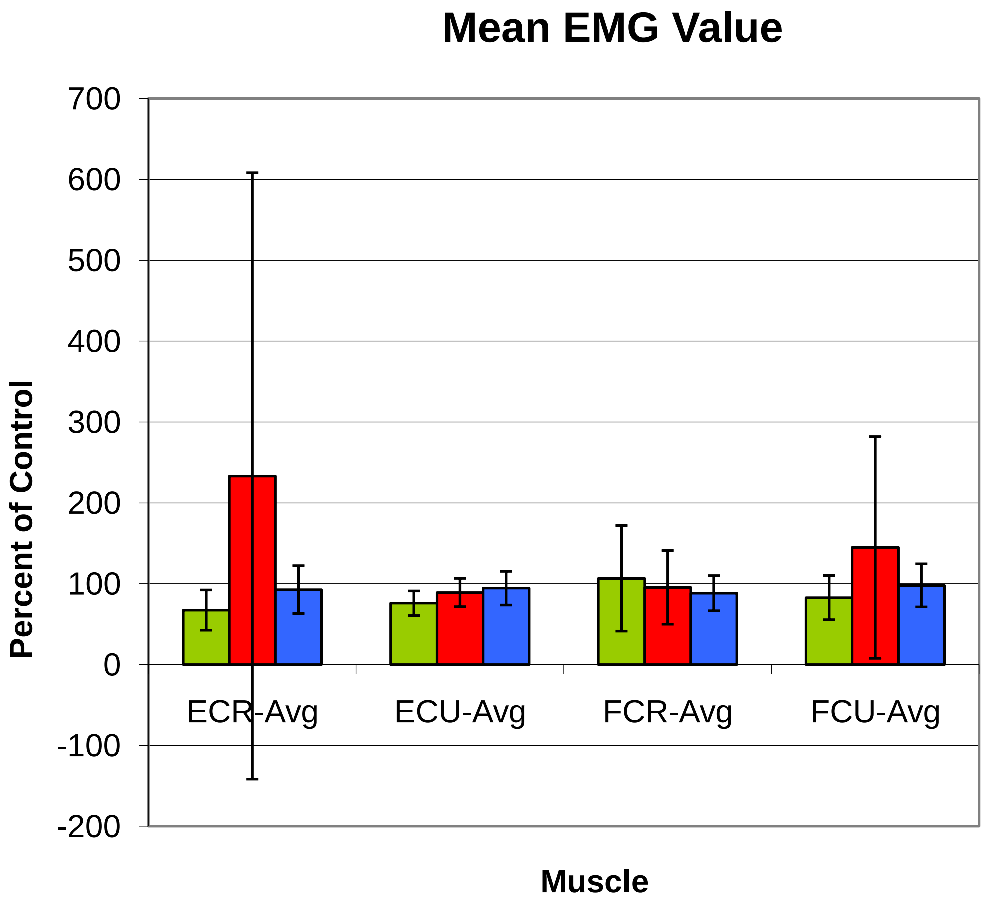


Figure 32: The average mean for the various alternative mice as a percentage of the control mouse

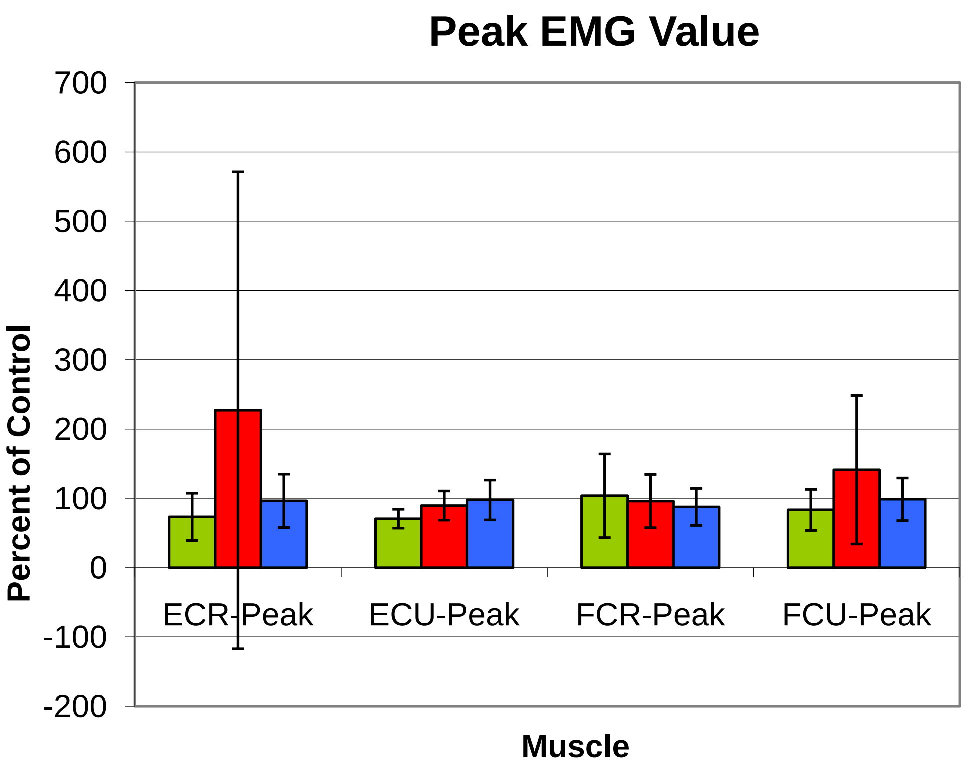


Figure 33: The average peak for the various alternative mice as a percentage of the control mouse

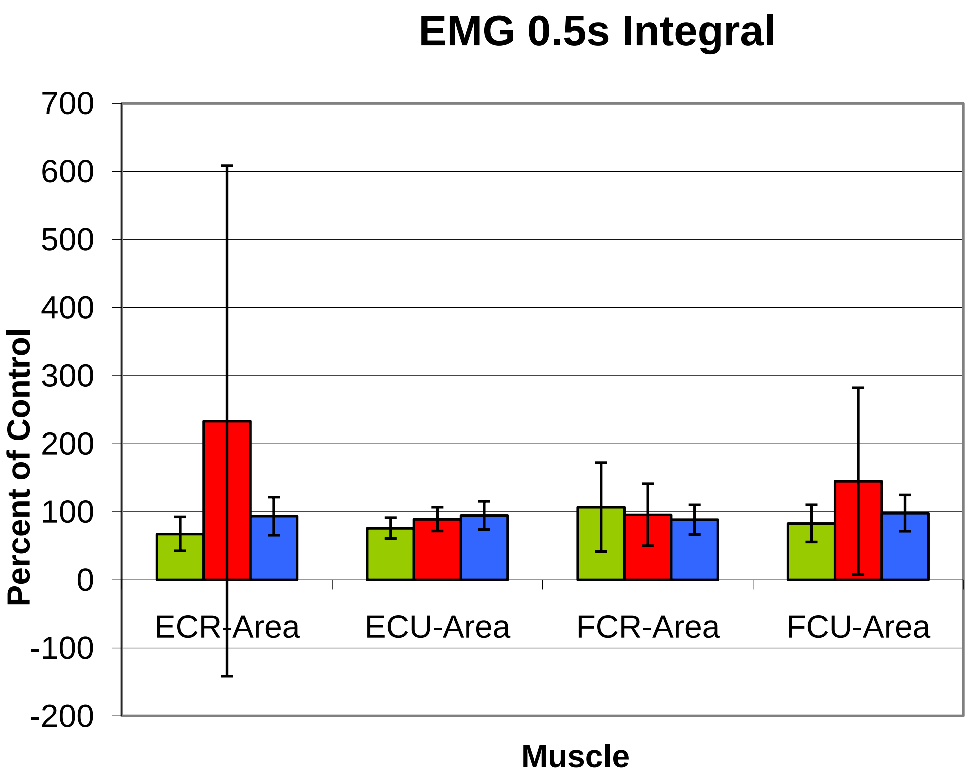


Figure 34: The average 0.5s integral for the various alternative mice as a percentage of the control mouse

As seen in these figures, the results for each muscle and alternative mouse are similar. The vertical mouse shows a slight decrease across all four muscles, while the joystick has larger decreases offset by a slight increase in FCR activity. The trackball shows a large increase in ECR and FCU activity, and a slight decrease in other areas. The trackball's increase in ECR activity is to be expected, as the ECR connects to the index finger, which is used to manipulate the trackball.[136]

Unfortunately, the standard deviation as seen in the error bars was extremely large. This could be attributed to differences between test subjects. As subjects were not instructed to use the mice in a particular way, this could have led to large differences in which muscles participants used to move the mouse during the Fitts' test. The ridiculously large uncertainties in the trackball mouse for the ECR and FCU muscles can be reduced if one outlying data point is ignored. The Fourier transform of these points for those muscles does differ from the normally seen Fourier transforms, but this is not sufficient grounds to reject these data points. The graph without outlying points can be seen below.

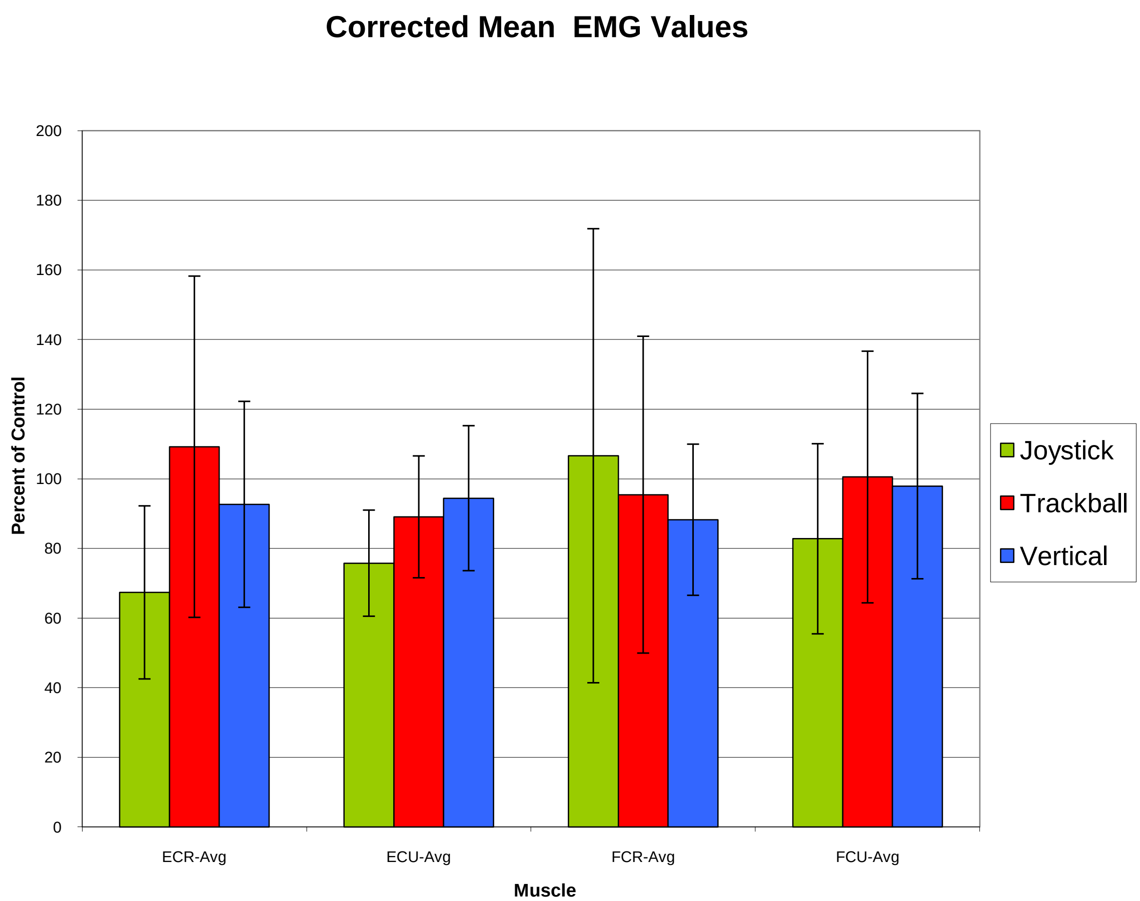


Figure 35: The Mean EMG Values without outlying points for the ECR and FCU trackball

Whether or not outlying data points are removed, the only statistically significant conclusion that can be drawn from this data is that the joystick mouse tends to reduce muscle activation in the ECR.

Force Testing

The mouse click force measuring procedure previously explained yielded a comma separated value file containing time and a numeric digital representation of click force. First, each data file (trial) was analyzed individually. Information retrieved was grouped with information from trials using the same mouse, and groups were statistically analyzed and compared.

There was one data file for each trial. Each data file contained several thousand data points (the total amount depended on how long it took the participant to finish the trial), each including the system time, with a resolution of seconds. Although C# allows the programmer to request system time from the computer, the computer that the force sensor program was run on had some errors providing time in milliseconds. To combat this, all times were rounded to the closest second. Because the force was measured on change, rather than a certain time interval, the number of data points per second was inconsistent. Regardless, the data points were saved to the file in the order that they were received from the sensor; other than order, time was unimportant for the analysis algorithms. A small sample of a raw data file, shown by the order that the data points were recorded, rather than time, is shown in figure 31. The large peaks indicate mouse clicks, while the very small peaks are variations in the resting force.

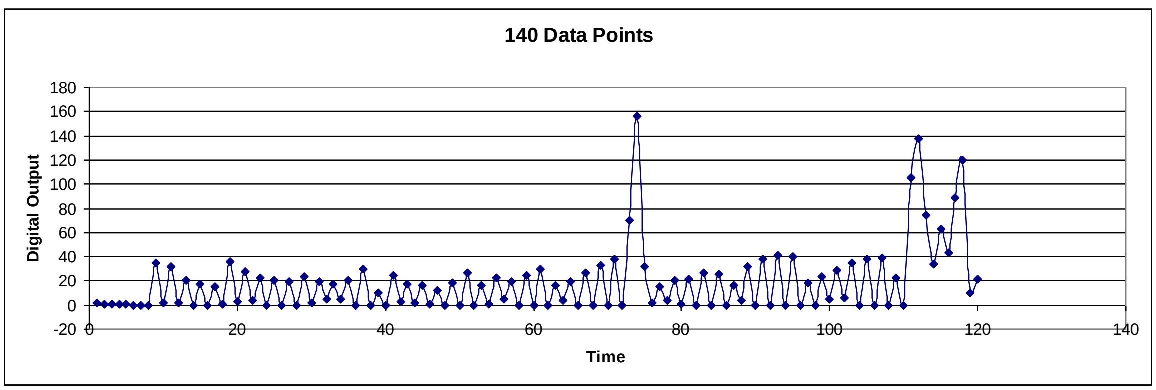


Figure 36: 140 Raw Data Points, shown in order that they were taken.

Several interesting pieces of information were retrieved from the raw force data for each trial using a Matlab script and algorithms designed by this team. These algorithms determined maximum force used overall, the peak force used in each mouse click, the number of mouse clicks recorded, and the average peak click force used across all mouse clicks. For statistical analysis, standard deviation of peak click force was also recorded. It is emphasized that these algorithms found this information for each trial, and did not produce summary information. Also, these were calculated for the raw data received from the computer program. This information was calibrated to actual force units, instead of the raw data, to reduce the amount of error in the calculations.

Most of the algorithms were very simple. The maximum force algorithm used a local maximum and a scan through every data point to find the overall maximum. The local maximum was initially set to zero, and every time a value larger than the local maximum was found, the local maximum was set to that value. Other points that had not been scanned yet were compared to this new local maximum, until a larger value was found or all data points were scanned. The number of mouse clicks recorded counted the number of peaks within the data resembling a mouse click, and average peak force summed the peak forces and divided by the number of mouse clicks.

In contrast, the mouse click finding algorithm was much more complicated. A mouse click was indentified in the data set as any maximum that had a steep curve on either side of it. A local maximum finding algorithm was too simple, as it found much more noise than actual mouse clicks. In short, this algorithm used a threshold value to sort out the data, and then used an adjusted local maximum finder. For every point above the threshold, it looked for a few values less than it nearby, both before and after the point in question.

The information retrieved from the individual trials was grouped by the mouse used in the trial. A basic statistical analysis was done on each group to help characterize each group for comparison to other groups. This analysis included averages and standard deviations of similar data, such as the maximum force and click force. After all of these algorithms were run on the original data, the results were converted to actual force units using the calibration scheme previously explained. This was done to reduce error in the analysis data.

Analysis data included 18 control trials, seven joystick trials, five trackball trials, and eight vertical mouse trials. Although more trials were completed, some data sets were unusable because the test subject did keep their finger on the force sensor, data acquisition was interrupted, or the voltage divider circuit was broken (it was physically pulled apart, and repaired by the next testing session). These are still sufficiently large sample sizes for the purposes of this experiment.

Overall, the standard Dell mouse (control) trials yielded the lowest mean click exertion force, and the joystick mouse trials yielded the highest mean click exertion force. The control mouse users exerted a mean click force of 0.4540 lbs, with a standard error of plus or minus 0.0218 lbs. Trackball mouse trials were very similar, with a mean click force of 0.4830 lbs and error of plus or minus 0.0487 lbs. Vertical mouse users exerted slightly more force; mean click force was 0.5006 lbs and standard error was plus or minus 0.0240 lbs. In the joystick mouse trials, users exerted a mean click force of 0.5346 lbs with an error of plus or minus 0.0477 lbs.

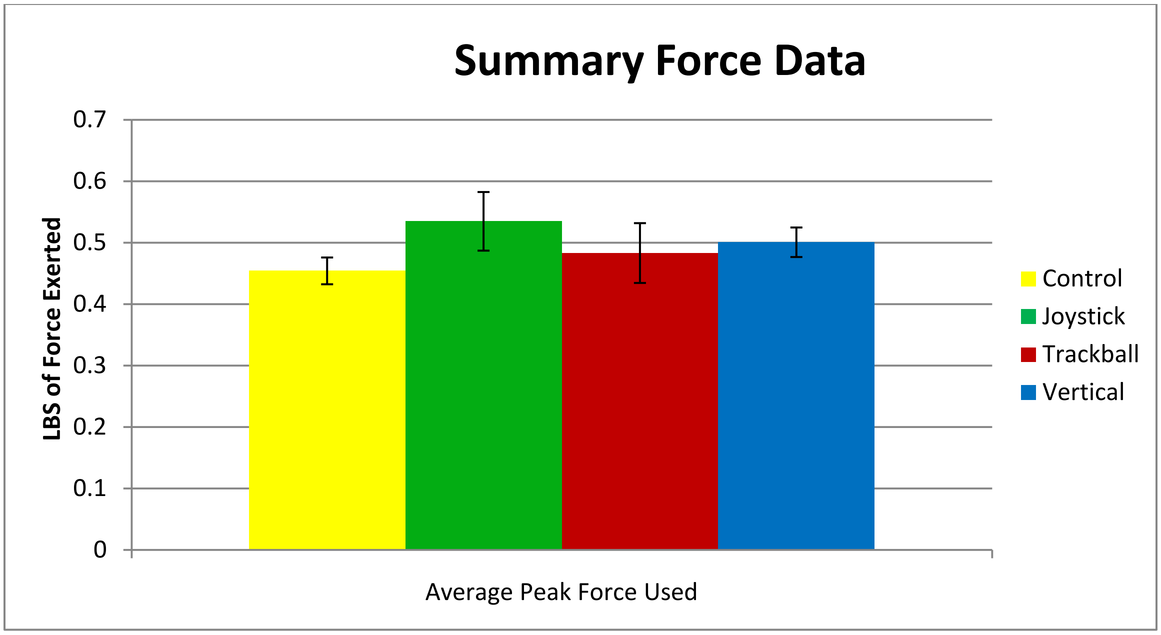


Figure 37: Mean Peak Clicking Force

The mean maximum force applied was calculated by finding the maximum force exerted in each trial, then taking the mean of the found maximums. Vertical mouse users exerted the smallest maximum force, 0.6665 lbs, plus or minus 0.0280 lbs. Control mouse users exerted slightly more force, 0.7090 lbs, with an error of 0.0245 lbs. Joystick users exerted a comparable amount of force when accounting for error, 0.7392 lbs, plus or minus 0.0406 lbs.

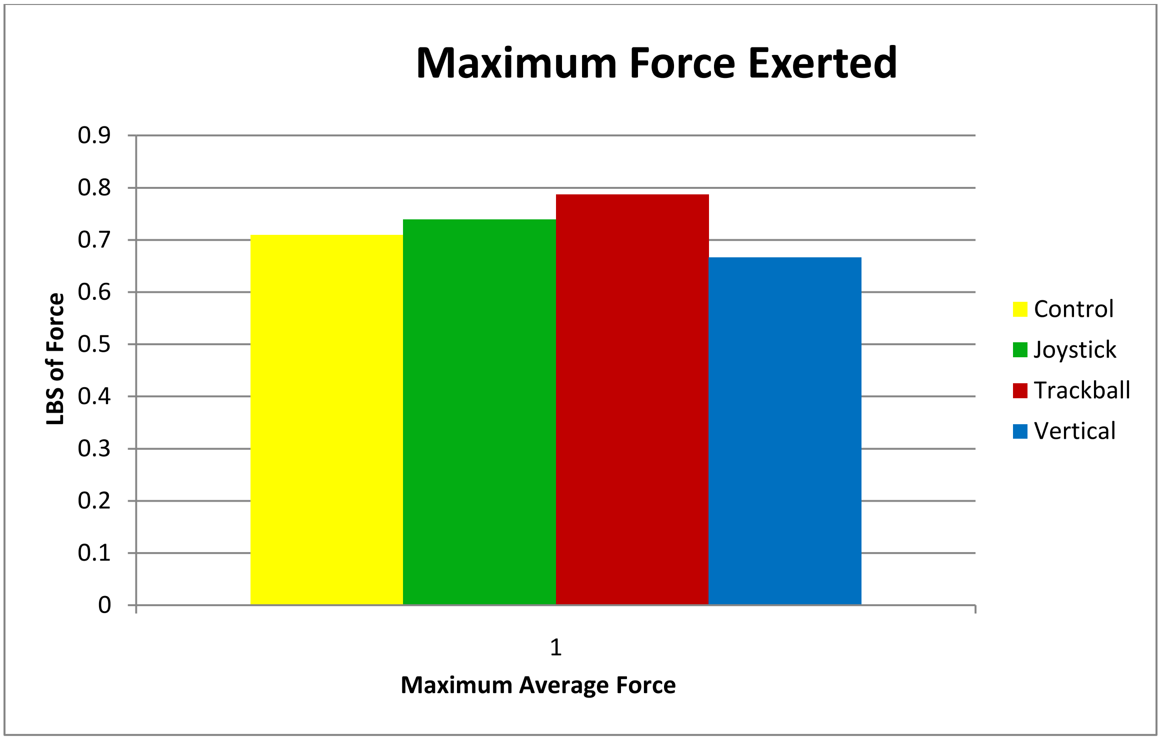


Figure 38: Maximum Force Exerted

Next, the consistency of the exertion force in each trial was considered. Specifically, this statistic asks if the user consistently applied the same force in each mouse click across a single trial. This was calculated using standard deviation of the exertion forces. The mean of these standard deviations was used to define the statistic. Users clicked the most consistently with the vertical mouse- mean standard deviation was 0.0483 lbs. Users were much less consistent with the control, joystick, and trackball mouse, with mean standard deviations of 0.0814 lbs, 0.8000 lbs, and 0.1016 lbs respectively.

Chapter 5: Conclusions

Throughout this study, several aspects of mouse design were tested both from the business and technological perspectives to determine features that would make a mouse design more ergonomic while maintaining efficiency and meeting customers' expectations and needs. As shown in chapter two, there has been extensive research linking heavy computer mouse usage with WMSD's; as such, there are many "ergonomic" mouse designs on the market. However, these mouse designs had not been compared in a multi-displinary approach before. The business group utilized focus groups and surveys to examine the issue, while the technological group used motion capture, Fitts' test, EMG, and exertion force measurement. After analyzing data from each measurement method individually, the measurements were considered as a whole. The recommendations below resulted from this whole.

5.1 Business Conclusions

After comparing the results from both the surveys and the focus groups, the team identified several recommendations for the manufacturer of a future mouse. While some of these recommendations focused on the design of the mouse, several of them focus on the promotion surrounding an ergonomic mouse.

In terms of mouse shape, a design that looks similar to the traditional design is preferable. Participants in the focus groups labeled the trackball mouse "a spaceship" and were not sure how to click with the joystick mouse. The vertical mouse, with a two button design similar to the traditional mouse, was the mouse that people needed the least instruction in using. Looking at the results of our survey, it is easy to see that the traditional mouse (6.45) and the vertical mouse (6.44) were thought to be the most comfortable designs.

Looking at the design of the mouse, it is clear based on both the surveys and the focus groups that users only cared for a limited amount of features. In the focus groups, the scroll wheel was quickly identified as the only “must-have” addition to a two button mouse. While users said it was fun and interesting to have additional buttons, most agreed that those buttons were more of a novelty than a necessity. In the survey, the scroll wheel easily topped the list of other features that a mouse should have, and problems with the scroll wheel was the third most common reason for disliking a mouse design. With strong customer feedback supporting its inclusion, the scroll wheel, is one of the most important features a successful mouse design should incorporate.

Another recommendation resulting from a closer examination of our work is that any new ergonomic mouse should attempt to have a reasonably low cost. While this would be done anyway, in an attempt to improve the bottom line, the necessity for a low price in order to compete at all in the market for computer mice makes this an important point to address. In the focus groups, customers were right in identifying that the ergonomic designs they were shown cost $25 to $30 more than the traditional mouse. In the team’s survey it was clear that price was the second most dominant factor in the purchase decision. In a market where the main customer concern is cost, even a product attempting to function as a differentiator has to have a reasonable price.

One very interesting result of the survey was the finding that user consideration of ergonomic mice was not independent of whether the use had experienced hand discomfort. This, together with the discussions that occurred during the focus groups, hints to the idea that people never think of themselves as at-risk for developing WMSDs. During the focus groups, people tended to identify groups that they excluded themselves from, such as "old people" and people at "desk jobs for 40 years of their life". This sort of mental separation makes it so that while people are aware of the negative impacts of mouse overuse, they do not even consider that something could impact them. To this end it is necessary for the maker of an ergonomic mouse to make sure, through promotions and placement, that their consumers understand the consequences of continuous mouse use.

The survey also made it clear that most people only buy their mouse when they buy a new computer. This means that an ergonomic mouse manufacturer should try to team up with a larger distributer. While it may be easier to have their product sold online or in technology stores, having their product available during the purchase of a new computer would be greatly beneficial. As people in the focus groups tended to only buy a new mouse when their old mice broke, there are a limited number opportunities after a computer is bought during which a person would consider an ergonomic mouse. Because of the limited sale opportunities, working with a PC distributer is the best way for a mouse manufacturer to sell their product.

5.2 Technology Conclusions

After comparing the results from all technological experiments, the joystick mouse performed the worst across all tests. It had the highest clicking force of all mice and on average, participants took the longest to complete the Fitts' test with the joystick mouse. The Fitts' test also showed that the joystick mouse had the worst throughput of any mouse. The motion capture analysis revealed that for all joints, the joystick mouse had the largest range of motion. Also, compared to the control mouse, the joystick mouse increased range of motion. EMG results showed that muscle activations were kept constant as compared to the control mouse. Thus, overall, as the joystick mouse did not improve any statistical category as compared to the control mouse, it is the least ergonomic, in terms of muscle activation, range of motion, and click force exerted, and efficient, defined as clicking speed and accuracy as measured with the Fitt's Test.

The trackball mouse, on the other hand, showed improvement in some areas. In two of the muscle groups, EMG results showed a decrease in muscle activation, while in the other two muscle groups, the EMG results showed an increase in muscle activity as compared to the control mouse. Participants using the trackball mouse took the second longest time to complete the Fitts' test. The Fitts' test also revealed that the trackball mouse had the third worst throughput, only slightly better than the joystick mouse. As compared to the control mouse, the trackball mouse had a slightly higher average clicking force. Motion capture data indicated that the trackball mouse reduced the average range of motion of the trackball mouse. In conclusion, the trackball mouse was able to reduce some muscle activation and the range of motion during mouse use, but accomplished this by reducing ease of use and efficiency.

The vertical mouse showed the greatest improvement compared to the control mouse. Although participants still took longer on average to complete the Fitts' test as compared to the control mouse, it was the fastest of the three ergonomic mice. Similarly, the Fitts' test showed that the average throughput decreased slightly compared to the control mouse, but was still the greatest of the three ergonomic mice. The motion capture analysis showed that the vertical mouse kept the range of motion very similar to that of the control mouse. Also, participants used a similar clicking force as the control mouse. The EMG results showed that in general, the vertical mouse required less muscle activation. In conclusion, the vertical mouse offered similar performance to the control mouse but required less muscle activation.

Based on these results, we can speculate why certain mouse designs performed better in certain statistical categories. The vertical mouse was nearly as efficient as the control mouse. This fact can be accredited because the vertical mouse required the same clicking motion as the control mouse. The vertical mouse is simply the control mouse but turned 90 degrees in a vertical direction. Thus the vertical mouse had the look and feel of the control mouse and users were able to use it almost as efficiently as the control mouse. The vertical mouse also lowered muscle activation as compared to the control mouse. We can attribute this difference to the vertical position of the hand when using the vertical mouse because the main difference between the control and vertical mouse is the orientation of the hand. Thus, we can speculate that a vertical orientation of the hand may reduce muscle activation.

The trackball mouse reduced muscle activation in certain groups and also reduced range of motion. The design of the trackball mouse allowed the user to keep their arm in a stationary position. However, this reduction in range of motion came at the cost of an increase in finger activity. Participants had to use their index finger more to move the mouse pointer. This was evident in higher muscle activation in the finger muscle groups, and lower muscle activations in the elbow muscle groups. We can therefore conclude that the use of a trackball reduces range of motion.

From these results, an ideal mouse would incorporate these features to maximize improvements to the control mouse. A vertical design would reduce muscle activation while the use of a trackball would reduce the range of motion. By keeping the same shape of the control mouse, a new design could maintain the ease of use and efficiency. Thus, an ideal mouse would incorporate a trackball onto a vertical mouse. Using these features would maintain efficiency, reduce muscle activation, and reduce range of motion.

5.3 Limitations to Our Research

Throughout our research we faced a number of limitations, in both the consumer and technological aspects of our study, which had various but minor effects. One of our main overarching limitations was our budget. All of our funding came from the Gemstone program at the University of Maryland, and while these funds were sufficient, we could have expanded and intensified our research with more money. For example, we would have benefited from more precise equipment in our EMG and motion capture tests, however the equipment we used did give us enough detailed information to draw our conclusions. Additionally, with greater funds we could have provided participants with greater incentives. This could have allowed us to recruit a greater number of older participants; such variety would have been particularly beneficial in the focus groups and surveys because it would have allowed us greater ability to compare experiences and age with opinions. However, we were able to get several participants from a variety of age groups without greater incentives, so our research was not greatly hurt by this limitation. This leads to another overarching restraint, a lack of diverse participants. In both aspects of our study, subjects were predominantly college-age students because that is the age group that we had access to. We attempted to gain older participants through local businesses by sending out letters offering free lunch in exchange for several partakers; however, we received zero responses and thus had to turn our attention to students and other members of the campus community that were more willing and able to aid in our research. However, this lack of diversity in age is not overly important, as we did have a variety of participants between the ages of 18 and 22, as well as several older participants to allow us to make wider observations.

In terms of the focus groups and surveys specifically, we faced several unique limitations in this aspect of our research. Scheduling was at times an issue, because we the moderators as well as our subjects had to work around busy schedules in order to meet, which sometimes limited our participants. However, we were still able to obtain a significant number of participants over the ten focus groups. Additionally, time was a restraint that we had to deal with. A main part of the focus group was allowing participants to hold each mouse and marginally test it out, giving them some hands-on experience with the ergonomic mice so that they could better form opinions. Had we been able to extend this experience to several days of actual mouse-use, or even several hours, we may have found more exaggerated or possibly entirely different results. However, we believe that the experience we did give the participants with the mice was sufficient to draw preliminary conclusions about preferences due to the continuity across focus groups and subjects.

The technological testing aspect of our research also faced specific limitations. Because this was undergraduate research, we had little to no dedicated lab space, as we borrowed all of the space we used from graduate programs. Due to this restraint we had to set up and take down equipment frequently, possibly causing slight variations in our results each time the equipment was manipulated. However, because we had a very systematic way of setting up and taking down equipment, we believe that any variations were minor enough that they did not affect our general observations and conclusions. Additionally, we had some minor issues with equipment during these tests simply due to a lack of sophisticated tools. During a few tests the sensors or markers fell off of the participant during the test, and while this may sound significant, they were replaced immediately and in the exact same position; any minor variations were not significant enough to change our results. Another limitation in our technological testing that was cause for some discrepancy between the two subdivisions of our research was our inability to perform EMG and motion capture tests using the zero-tension mouse. This mouse was used in the focus groups and typically had rather positive reviews. However, because this mouse comes in three sizes, we were unable to use it in our technological testing. It would have been significantly more expensive to purchase all three sizes, which would have been necessary to fit various participants. We also would have had to add another ten participants to our study had we added another mouse; this was simply not feasible due to the time and lab space constraints that we faced.

While our research was clearly not perfect due to several factors beyond our control, we found that these limitations did not significantly detract from the validity and importance of our results. However, these restraints do allow for further studies to be done to expand upon our findings; some suggestions for such research can be found in the next section.

5.4 Recommendations for Future Research

To properly address some of our study's limitations, more research needs to be done in several areas. Our qualitative data had parts that could later be addressed by future studies. Our focus groups were primarily concerned with the immediate perception of the ergonomic mice, since a purchasing decision would be made mostly on an initial reaction to the mouse. Participants also reacted strongly towards familiarity, and seemed to dislike things that were not immediately intuitive. A future study may want to address opinions of mice if participants had been given several days to become accustomed to them. This may adjust the participants' opinions of mice that they initially liked or disliked. A future study may also address individual requirements of mice. We used mice that were considered "standard," and at least a few participants disliked the size of the mouse in comparison to their hands. We had to leave the Zero-Tension mouse out of the experimental study because proper use was dependent on the participant hand size, meaning we could not compare the mouse quantitatively to the others. A future study with more funding may want to address this by purchasing other sizes to fit a wider range of participants. It would also be beneficial to increase the sample size and range of participants. We primarily drew from college students, and while they are often exposed to mice, it was shown that they did not have a strong understanding of work related musculoskeletal disorders. It would be interesting to learn if this was due to the participants being primarily college students, or whether this lack of knowledge was common throughout a larger section of the population.

Our technological studies could also see benefits from further research. One of the mice we used – the trackball mouse – was oriented in such a way that much greater force was used to move the trackball as opposed to actual clicking. We did not consider this force in our studies, but for a more complete understanding it would be beneficial to look into it in order to determine its effects on the user. There was also a regular appearance of noise within our digital systems from both mechanical issues and possibly an improper setup. This noise required effort to work through, and at times made some of the measurements difficult to properly read. Reducing this noise would make any future test more accurate and reduce the workload in trying to analyze the data. As with our focus groups, an increase in trials would have given us a wider and more complete picture of our data. Some trials had to be thrown out for logistical reasons, as well as mechanical – sometimes the setup did not work, or the participant did not understand our directions. Increasing the number of trials could improve the study's accuracy and create more data points to analyze.

Appendices

Appendix A: Images of Various Mouse Designs

(All Images taken from Manufacturers' Websites)

Traditional-Wired		
		
Microsoft's SideWinder X3	Logitech's Optical Mouse USB	Razer's Diamondback Mouse

Trackball		
		
Logitech's Cordless Optical Trackman	Kensington's SlimBlade Trackball Mouse	Logitech's Trackman Marble Mouse

Presentation		
		
Hillcrest Labs' Loop Pointer	Kensington's SlimBlade Bluetooth Presenter Mouse	Logitech's Wireless Presenter R400

Laptop-Wireless

		
Microsoft's Wireless Mobile Mouse 4000	Dell's 5-button Bluetooth Travel mouse	Razer's Mamba Gaming Mouse

Ergonomic

		
Evoluent's VerticalMouse 2	Quill's Ergonomic Mouse	3M's Ergonomic Mouse
		
Leahy's Zero Tension Mouse	Waawoo's WOW-Pen	Mogo's Mouse BT

Appendix B: Focus Group Script

We will begin by introducing ourselves.

(Moderator #1): "Hi, my name is [Moderator #1] and this is [Moderator #2]. We would like to begin by thanking you all very much for joining us today to help us with our research, as we know what busy people you are."

We will then move onto outlining the focus group's parts.

(Moderator #2): "Before we begin the focus group, we are going to give you an overview of our project, describing to you the research we are doing, why, and how you relate to it. We will then distribute a survey to evaluate your prior experience with mice and knowledge about ergonomics and ergonomic mice. We will then conduct the focus group, giving everyone a chance to talk about their experiences and opinions. We will end by giving out a post-focus group survey to analyze any changes."

After that, we will briefly summary of out project.

(Moderator #1): "Team M.I.C.E. stands for Modifying and Improving Computer Ergonomics. Through an extensive preliminary literature review that we have conducted, we have determined that Work-Related Musculoskeletal Disorders are becoming a more and more serious problem in our country. This syndrome can cause severe pain in the hand, wrist and forearm do to repeated motions and movements, such as clicking or moving a mouse. Through our literature review we have found a correlation between WMSDs and mouse use. Because computers are so prevalent in today's society and only becoming more so, we want to create a mouse that will be more ergonomically efficient, decreasing the chances of getting WMSDs. However, we also know that it is very important for this mouse to be user-friendly, something that people will be willing to spend their money on."

We will then outline their involvement in the project.

(Moderator #2): "That is where you come in. Through these focus groups we want to gain insight into what you think are important aspects to have in a mouse, what you could do without, and what you simply do not like. Throughout the focus group we urge you to be open and honest. Everyone will have equal opportunity to participate and we hope you will join in as much as possible. We would like to add that your identities will be protected. You will each be assigned an identity composed of a letter and number that be used both during the focus group and in all data summaries hereafter. Please fill out the pre-survey that is being passed around, if you have any questions please see one of the moderators."

(Pre survey distribution, completion, and collection)

We will have reminders before the focus groups start:

(Moderator #1): "Please remember to be respectful to other participants, and if at any time you feel uncomfortable you may leave to focus group. Again, thank you for your participation."

Appendix C: Sample Data

1. Age:

   Range of 17-40 years
   Mean: 20.06 years

2. Gender (circle one): M or F

   Male: 64%
   Female: 36%

3. Profession/Major:

   Scientific: 46%
   Engineering: 17%
   Non-Technical: 37%

4. Handedness (circle one): Left Right No Preference

   Left: 6%
   Right: 94%

5. Previous hand/arm related injuries? If so, please explain:

   Yes: 24%

6. Frequency of mouse use (per day):

39%: 0-3 hours **33%:** 4-6 hours **21%:** 7-9 hours **3%:** 10-12 hours **3%:** 13+ hours

7. Tasks performed in mouse use (eg: web browsing, e-mail, word processing, etc):

   Browsing: 91%
   Email: 73%
   Word: 76%
   Gaming: 48%
   Data Entry: 12%
   IM: 6%
   Programming: 6%
   Itunes: 3%
   WoW: 3%
   File Sorting: 3%
   Graphic Design: 3%
   CAD: 3%

Matlab: 3%
Power Point: 3%

8. Input used to connect to computer:

   <u>0%:</u> PS2 **<u>81%:</u>** USB **<u>6%:</u>** Bluetooth **<u>0%:</u>** Other **<u>13%:</u>** I don't know

9. Is your mouse wireless?
   Yes: 56%
   No: 44%

10. How much did your mouse cost?

    Range: $0-$60
    Average Cost: $24

11. Does it have programmable buttons/scroll wheel/shortcut buttons? Y N

    Yes: 81%
    No: 19%

12. Is this mouse optical or mechanical?

    <u>81%:</u> Optical(has a light sensor) **<u>19%:</u>** Mechanical(has a mouse ball)

13. Have you ever purchased an ergonomic mouse? Y or N

    Yes: 18%
    No: 82%

14. If no, have you ever considered it? Why or why not?

    Yes: 15%
    No: 67%
    No Response: 18%

15. Rank the following features in order of importance when considering a mouse purchase:
    Average Rating:
    _____Cost: 2.77
    _____Ergonomic design: 5.27
    _____Ease of use: 2.61
    _____Comfort: 2.88
    _____Scroll wheel: 2.85
    _____Additional buttons: 5.79

_____Programmable buttons: 6.68
_____Other feature: ______________

16. What features do you dislike in mouse designs? Specify the severity of dislike as Minor, Moderate, or Severe.

Uncomfortable- 28%
Unusual/Awkward- 13%
Dysfunctional scroll wheel- 13%
Dysfunctional ball- 10%
Difficult to use- 8%
Too many buttons- 8%
No buttons- 8%
Dysfunctional sensors- 5%
Too sensitive- 3%
Short battery life- 3%
Wires- 3%

17. What features do you need to have in a mouse?

Scroll Wheel- 38%
Left/Right clicking- 23%
Wireless- 9%
Comfort- 8%
Sensitivity- 6%
Ease of use- 6%
Programmable- 3%
Separate on/off switch- 2%
Plug and play- 2%
Bluetooth- 2%

18. When considering purchasing a mouse, how much preparation goes into your decision?

36%: Comparing designs in store **13%** Researching latest designs online

25%: Asking friends **23%:** Asking family **4%:** Other

19. How often do you purchase a new mouse?

1-4 years-55%
5-10 years- 14%
"Rarely"- 21%
"Never"- 10%

20. What prompts this decision?

Current mouse stops working- 57%
New computer- 22%
New technological developments- 14%
Impulse- 5%
My father- 3%

21. How would you go about purchasing a new mouse?

    See Question 18

22. Name as many companies as you can that you know make mice and comment on what you know about the mice they make:

    a. **Number of People to Identify Specific Companies**
       Logitech- 31%
       Microsoft- 25%
       Dell- 10%
       Apple- 8%
       HP- 4%
       Gateway- 4%
       Razor- 4%
       Sony- 2%
       Acera- 2%
       Bluetooth- 2%
       IBM- 2%
       3M- 2%
       Targus- 2%
       Kensington- 2%
    b. **Amount of Companies Named**
       0- 37%
       1- 20%
       2- 23%
       3- 10%
       4- 7%
       5- 3%

23. How much do you care about having the latest technology in your life in general?

    6%: Not at all **68%:** A little **23%:** A significant amount **3%:** A lot

24. What about specifically in your mouse?

    30%: Not at all **67%:** A little **3%:** A significant amount **0%:** A lot

25. Would/does it bother you to have different mice at work and at home?

Yes: 29%
No: 65%

26. What do you consider a reasonable price range for a mouse?

    Range: $0-$100

27. What do you think the actual price range for a mouse is?

    Range: $0-$160

28. What types of mice have you tried using in the past? How did you feel about those mice?

    Responses Varied

29. Would you be more likely to purchase an ergonomic mouse if (Check all that apply):

It was recently released- 3%
It was on the market for 3 months- 1%
It was on the market for 6 months- 2%
It was on the market for a year or more- 7%
It looked like it would reduce the chance of causing WMSDs- 4%
It was advertised to reduce the chance of causing WMSDs- 4%
It was proven to reduce the chance of WMSDs- 18%
It allowed you to complete tasks faster- 25%
You had heard about it on the news- 5%
You had seen favorable online reviews- 13%
You had heard about it from a friend- 19%

Current knowledge of ergonomics:

30. Do you consider WMSDs a major problem?

    Yes: 47%
    No: 53%

31. Have you ever experienced discomfort from mouse use?

    Yes: 48%
    No: 52%

32. How serious was this discomfort?

Not severe- 79%
Mildly severe- 21%
Severe- 0%
Very severe- 0%

33. Did you make any changes in your mouse use due to this discomfort?

    Yes: 16%
    No: 84%

Evaluation of Current Ergonomic Designs:

34. Rate the following mice based on the picture provided and your past experience/knowledge

    Average Ratings:

	Dell Mouse	Marble	Vertical	Joystick	Zero Tension
Overall	6.34	5.45	5.09	5.15	5.13
Comfort	5.94	5.85	4.94	5.27	5.58
Usability	7.56	4.85	4.59	4.52	4.42
Ergonomics	4.81	6.24	5.91	5.45	6.42

35. Rate the following mice based on your experience with them during this session:

    Average Ratings:

	Dell Mouse	Marble	Vertical	Joystick	Zero Tension
Overall	6.71	5.00	6.19	5.52	4.94
Comfort	6.45	5.52	6.44	6.09	4.78
Usability	7.74	3.94	5.63	4.88	4.81
Ergonomics	5.90	5.97	6.66	5.94	5.75

Appendix D: Sample Survey

Pre-Focus Group Survey

36. Age:

37. Gender (circle one):   M   or   F

38. Profession/Major:

39. Handedness (circle one):   Left   Right   No Preference

40. Previous hand/arm related injuries? If so, please explain:

41. Frequency of mouse use (per day):

___0-3 hours   ___4-6 hours   ___7-9 hours   ___10-12 hours   ___13+ hours

42. Tasks performed in mouse use (eg: web browsing, e-mail, word processing, etc):

43. Input used to connect to computer:

    _____PS2   _____ USB   ____Bluetooth_____Other   ____ I don't know

44. Is your mouse wireless?

45. How much did your mouse cost?

46. Does it have programmable buttons/scroll wheel/shortcut buttons?   Y   N

47. Is this mouse optical or mechanical?

    _____Optical(has a light sensor)   _____Mechanical(has a mouse ball)

48. Have you ever purchased an ergonomic mouse?   Y   or   N

49. If no, have you ever considered it? Why or why not?

50. Rank the following features in order of importance when considering a mouse purchase:

_____Cost
_____Ergonomic design
_____Ease of use
_____Comfort
_____Scroll wheel
_____Additional buttons
_____Programmable buttons
_____Other feature: _______________

51. What features do you dislike in mouse designs? Specify the severity of dislike as Minor, Moderate, or Severe.

52. What features do you need to have in a mouse?

53. When considering purchasing a mouse, how much preparation goes into your decision?

____ Comparing designs in store ____ Researching latest designs online

_____Asking friends ____Asking family ____Other______________

54. How often do you purchase a new mouse?

55. What prompts this decision?

56. How would you go about purchasing a new mouse?

57. Name as many companies as you can that you know make mice and comment on what you know about the mice they make:

58. How much do you care about having the latest technology in your life in general?

_____Not at all _____A little _____A significant amount _____A lot

59. What about specifically in your mouse?

_____Not at all _____A little _____A significant amount _____A lot

60. Would/does it bother you to have different mice at work and at home?

Y N

61. What do you consider a reasonable price range for a mouse?

62. What do you think the actual price range for a mouse is?

63. What types of mice have you tried using in the past? How did you feel about those mice?

64. Would you be more likely to purchase an ergonomic mouse if (Check all that apply):

_____It was recently released?
_____It was on the market for 3 months?
_____It was on the market for 6 months?
_____It was on the market for a year or more?
_____It looked like it would reduce the chance of causing WMSDs?
_____It was advertised to reduce the chance of causing WMSDs?
_____It was proven to reduce the chance of causing WMSDs?
_____It allowed you to complete tasks faster?
_____You had heard about it on the news?
_____You had seen favorable online reviews?
_____You had heard about it from a friend?

Current knowledge of ergonomics:

65. Do you consider Work-related Musculoskeletal Disorders(WMSDs) a major problem?

Y N

66. Have you ever experienced discomfort from mouse use?

Y N

67. How serious was this discomfort?

_____Not severe _____Mildly severe _____Severe _____Very Severe

68. Did you make any changes in your mouse use due to this discomfort?

Y N

Evaluation of Current Ergonomic Designs:

69. Rate the following mice based on the picture provided and your past experience.

Overall Impression:
1 2 3 4 5 6 7 8 9 10

Comfort:
1 2 3 4 5 6 7 8 9 10

Usability:
1 2 3 4 5 6 7 8 9 10

Ergonomics:
1 2 3 4 5 6 7 8 9 10

Overall Impression:
1 2 3 4 5 6 7 8 9 10

Comfort:
1 2 3 4 5 6 7 8 9 10

Usability:
1 2 3 4 5 6 7 8 9 10

Ergonomics:
1 2 3 4 5 6 7 8 9 10

Overall Impression:
1 2 3 4 5 6 7 8 9 10

Comfort:
1 2 3 4 5 6 7 8 9 10

Usability:
1 2 3 4 5 6 7 8 9 10

Ergonomics:
1 2 3 4 5 6 7 8 9 10

Overall Impression:
1 2 3 4 5 6 7 8 9 10

Comfort:
1 2 3 4 5 6 7 8 9 10

Usability:
1 2 3 4 5 6 7 8 9 10

Ergonomics:
1 2 3 4 5 6 7 8 9 10

Overall Impression:
1 2 3 4 5 6 7 8 9 10

Comfort:
1 2 3 4 5 6 7 8 9 10

Usability:
1 2 3 4 5 6 7 8 9 10

Ergonomics:
1 2 3 4 5 6 7 8 9 10

70. Rate the following mice based on your experience with them during this session:

Overall Impression:
1 2 3 4 5 6 7 8 9 10

Comfort:
1 2 3 4 5 6 7 8 9 10

Usability:
1 2 3 4 5 6 7 8 9 10

Ergonomics:
1 2 3 4 5 6 7 8 9 10

Overall Impression:
1 2 3 4 5 6 7 8 9 10

Comfort:
1 2 3 4 5 6 7 8 9 10

Usability:
1 2 3 4 5 6 7 8 9 10

Ergonomics:
1 2 3 4 5 6 7 8 9 10

Overall Impression:
1 2 3 4 5 6 7 8 9 10

Comfort:
1 2 3 4 5 6 7 8 9 10

Usability:
1 2 3 4 5 6 7 8 9 10

Ergonomics:
1 2 3 4 5 6 7 8 9 10

Overall Impression:
1 2 3 4 5 6 7 8 9 10

Comfort:
1 2 3 4 5 6 7 8 9 10

Usability:
1 2 3 4 5 6 7 8 9 10

Ergonomics:
1 2 3 4 5 6 7 8 9 10

Overall Impression:
1 2 3 4 5 6 7 8 9 10

Comfort:
1 2 3 4 5 6 7 8 9 10

Usability:
1 2 3 4 5 6 7 8 9 10

Ergonomics:
1 2 3 4 5 6 7 8 9 10

Appendix E: Discussion Sheet

1. Mouse Purchasing
    a. Purchase Decision
        i. What prompts?
        ii. How do you decide?
        iii. Influences
        iv. Manufacturers
            1. Importance of Brand
            2. Importance of Uniqueness
            3. Importance of Functionality
    b. Features
        i. Ease of use
        ii. Comfort
        iii. Scroll wheel
        iv. Additional buttons
        v. Programmable buttons
    c. Pricing
        i. Importance of differing product lines
        ii. Reasonable Price
        iii. Default features
        iv. Features and Pricing
            1. Ease of use
            2. Comfort
            3. Scroll wheel
            4. Additional buttons
            5. Programmable buttons
2. Designs
    a. Favorable/Unfavorable designs
    b. Individual breakdown/pricing
        i. Normal mouse
        ii. Trackball Mouse
        iii. Vertical Mouse
        iv. Joystick
        v. Zero Tension Mouse
    c. Features preferred
3. Ergonomics Knowledge
    a. Work Related Musculoskeletal Disorders
        i. What is it?
        ii. What causes it?
        iii. Who is affected? Personal Experience?
        iv. How does it affect people?
    b. Ergonomic Computer Input devices
        i. Mice
        ii. Keyboards

Appendix F: Rating Data Means

		Means
Control(Pre)	Overall	6.34375
	Comfort	5.93548387
	Usability	7.5625
	Ergonomics	4.8125
Trackball(Pre)	Overall	5.45454545
	Comfort	5.84848485
	Usability	4.84848485
	Ergonomics	6.24242424
Vertical(Pre)	Overall	5.09375
	Comfort	4.9375
	Usability	4.59375
	Ergonomics	5.90625
Joystick(Pre)	Overall	5.15151515
	Comfort	5.27272727
	Usability	4.51515152
	Ergonomics	5.45454545
ZTM(Pre)	Overall	5.12903226
	Comfort	5.58064516
	Usability	4.41935484
	Ergonomics	6.41935484

			Diff
Control(Post)	Overall	6.70967742	0.37
	Comfort	6.4516129	0.52
	Usability	7.74193548	0.18
	Ergonomics	5.90322581	1.09
Trackball(Post)	Overall	5	-0.45
	Comfort	5.51515152	-0.33
	Usability	3.93939394	-0.91
	Ergonomics	5.96969697	-0.27
Vertical(Post)	Overall	6.1875	1.09
	Comfort	6.4375	1.50
	Usability	5.625	1.03
	Ergonomics	6.65625	0.75
Joystick(Post)	Overall	5.51515152	0.36
	Comfort	6.09375	0.82
	Usability	4.875	0.36
	Ergonomics	5.9375	0.48
ZTM(Post)	Overall	4.9375	-0.19
	Comfort	4.78125	-0.80
	Usability	4.8125	0.39
	Ergonomics	5.75	-0.67

Appendix G: Ranked Data

Control - Ergonomics

Subject	Ranking	Pre	Post	Ranking
A1	12	7	7	12
A2	21	6	7	12
B1	12	7	7	12
B2	40	4	5	29
B3	40	4	4	40
B4	29	5	7	12
B5	1	10	9	4
C1	61	1	4	40
C2	50	3	5	29
C3	29	5	8	5
C4	29	5	7	12
D1	40	4		
D2	29	5	5	29
D3	5	8	8	5
D4	21	6	6	21
E1			8	5
E2	61	1		
E3	29	5	8	5
E4	21	6	5	29
E5	60	2	3	50
F1	50	3	5	29
F2	21	6	6	21
F3	40	4	4	40
F4	5	8	7	12
G1	40	4	3	50
G2	61	1	3	50
G3	21	6	7	12
G4	29	5	4	40
G5	1	10	10	1
L1	40	4	6	21
L2	29	5	8	5
L3	61	1	4	40
L4	50	3	3	50

Vertical - Overall Rating

Subject	Ranking	Pre	Post	Ranking
A1			5	38
A2	13	7		
B1	25	6	8	4
B2	25	6	3	54
B3	48	4	6	25
B4	56	2	10	1
B5	59	1	8	4
C1	54	3	8	4
C2	13	7	9	2
C3	13	7	7	13
C4	13	7	4	48
D1	48	4	6	25
D2	59	1	6	25
D3	25	6	5	38
D4	25	6	6	25
E1	38	5	4	48
E2	59	1	1	59
E3	56	2	2	56
E4	4	8	8	4
E5	38	5	7	13
F1	25	6	4	
F2	13	7	9	2
F3	38	5	6	25
F4	13	7	5	38
G1	48	4	6	25
G2	4	8	8	4
G3	38	5	5	38
G4	25	6	7	13
G5	38	5	5	38
L1	48	4	7	13
L2	25	6	8	4
L3	38	5	7	13
L4	13	7	8	4

Trackball - Usability

Subject	Ranking	Pre	Post	Ranking
A1	58	1	1	58
A2	15	6	5	21
B1	44	3	3	44
B2	21	5	4	31
B3	44	3	3	44
B4	31	4	9	1
B5	58	1	1	58
C1	44	3	3	44
C2	2	8	6	15
C3	7	7	5	21
C4	2	8	5	21
D1	21	5	1	58
D2	21	5	1	58
D3	7	7	7	7
D4	44	3	2	54
E1	31	4	4	31
E2	31	4	3	44
E3	15	6	2	54
E4	15	6	7	7
E5	31	4	4	31
F1	21	5	4	31
F2	15	6	7	7
F3	7	7	4	31
F4	7	7	8	2
G1	58	1	1	58
G2	21	5	8	2
G3	21	5	1	58
G4	21	5	4	31
G5	31	4	2	54
L1	31	4	2	54
L2	7	7	6	15
L3	2	8	3	44
L4	44	3	4	31

Appendix H: Focus Group Raw Data

Overall

Wireless – 2
Not Wireless - 1
Scroll Wheel – 6
Comfort – 2.5
Cheap - 5
Additional buttons - .5
Programmable buttons – 1 (Gaming is only connotation)
Optical - 1.5
Manufacturer – 1 (referred to as not important multiple times)

Distinct opinions for manufacture – “whatever’s at the apple store” compared to “not a mac mouse”
Price is extremely important!
Mentioned liking basic mice several times
Perfect mouse is often described as two buttons and scroll

Regular – 7
Trackball – 2.5
Vertical – 5.5
Joystick – 3.5
ZTM – 4.5

Trackball isolated as “least favorite”

Vertical and Regular isolated as “favorite”

Regular mouse described as familiar and easy to use – no negatives listed

Trackball is hard to use with dexterity, and seems to be less than aesthetically pleasing

ZTM has poor orientation – worried about mobility/transportation, and the ledge and scroll wheel are physically difficult

Vertical mouse is comfortable but hard to stabilize, difficult to relax hand on

Joystick requires arm stabilization – maybe only used during video games. Liked because it can be gripped, but button placement and distracting construction are negative

Focus Group #2 (Nov. 24, 2008)

Prompts – not wanting to use the laptop pad
Decides – small, stylish, certain features (see below)
Likes – Optical, wireless
Manufacturers – unimportant
Features – Small, larger buttons, scroll wheel. Additional buttons are optional, but not necessary. Programmable buttons are unnecessary. Neither are worth extra money.
Pricing – Not listed
Mice designs

Normal mouse - like it because im used to it, I would scrunch my fingers if I used it, but it's pretty comfortable, after using it for awhile my hand starts to ache a little bit

Trackball Mouse- not a fan, difficult to get exact location, nice not having to move arm, but finger might get tired- not optimal for video games- big = comfortable

Vertical Mouse- would take getting used to, but kind of cool, think it would be fun

Joystick- lifting arm up more, uncomfortable

Zero Tension Mouse- too small, grooves dictate exactly where you have to put your fingers and that's not the most comfortable, my fingers feel scrunched together- maybe make buttons big enough so you can vary the placement of your fingers

What they know –

Having a laptop is bad for posture, typing is probably not good, mouse hasn't so much been a problem especially since I haven't been playing games too often- when I do my hand gets kind of dull- it's never been a serious problem but I could see how it could happen

Have seen ergonomic keyboards but I don't know the difference, mice I haven't really and I wouldn't recognize

Difference in button heights- I like it now that im used to it, I don't know that it really helps or hurts, I would choose one without if I had never used it before- a little more comfortable, not much easier to use

Favorite – Zero Tension, normal mouse
Least favorite - track ball

Prompts – Mouse breaks, dislike current mouse
Decides – looks best in price range, possible mouse functions
Likes – Price range (cheapest), scroll wheel
Manufacturers – unimportant
Features – Scroll wheel, not tiny mouse (good fit for hand), hard plastic (not deformable)

Normal mouse

Trackball Mouse-
1- too much work, I don't like it
2- ok, but not usable at all

Vertical Mouse-
1- this would not work for me at all!
2- pretty cool, kindof like a regular mouse just sideways

Joystick-
2- I could see myself using this but ehhh
1- I feel like the stick should move, but it doesn't, which bothers me

Zero Tension Mouse-
1- I actually like this one
2- I like when I put my hand in it, its really comfortable, easy scrolling too, the corner here is uncomfortable- combine zero tension and vertical

What they know -

Don't think mice will have negative effects on body- maybe it will effect people who use them all the time, like graphic designers and stuff- probably wont ever effect me

Had never seen any ergonomic mice- at least have never used them

Ergonomic keyboards- yes have seen them- wrist support, divided in half

Favorite- zero tension, but it depends what I'm using it for- gaming I need to be used to it

Least favorite- track ball

Prompts – New computer, broken old mouse
Decides – knowledgeable friends
Likes – whatever comes with computer, whatever is cheapest
Manufacturers – unimportant, but perhaps a better known brand (example given: Apple)

Features – scroll wheel, not trackball, mixed opinion on wireless (one for, one against), proper sensitivity is important

Mice –
Normal mouse
3- pretty good, doesn't force my hand in any certain position, mostly I like it cause im used to it
4- what I need and use

Trackball Mouse
3- ive always thought it was weird, but its not that bad, I have used it before- its better and more accurate
4- does anyone actually use this?

Vertical Mouse
3- I kindof like it, its kindof nice
4- its pretty comfortable, if you got used to it it could be really good

Joystick
4- don't know what I would use this for, it is comfortable though
3- really comfortable, but I feel like I would use it less often

Zero Tension Mouse-
3- doesn't fit my hand, feels like a weird position
4- not a fan

3&4- No ridiculous price range, its so necessary its well worth it

3- vertical mouse is my favorite, but I don't like how your 4^{th} finger is left out
4- regular mouse is favorite

4- zero tension is my least favorite
3- zero tension is my leat favorite

Harmful effects of mice?
4- hasn't happened yet- people who work with them are probably more effected
3- not that worried, but I have thought about it- mostly people who use it at work, also maybe intense gamers, I don't really know anyone like that though

Ergonomic mice and keyboards?
4- yeah ive seen them- my mom buys them all
3- haven't seen ergonomic keyboard, have seen ergonomic mice

Focus Group #3 – (date not listed)

Prompts – broken mouse
Decides – price range, reputation (word of mouth, reviews)
Likes – molded mice, scroll wheel (important), comfort (important)

Unsure – programmable buttons received mixed review, could be useful or confusing (ultimately unnecessary)

Manufacturers – not particularly important
Pricing – Average of $20 with scroll wheel

Reasonable Price $5-$10, $15, $30 for Dell optical; vertical $25, $15 because completely different design, only the design is different but the function is the same
Default features- optical, scroll wheel, adjustable sensitivity
Additional buttons
Programmable buttons
Perfect Mouse- $30-$60—with scroll wheel, very comfortable, multiple buttons, things a gamer would want; comfort, scroll wheel, button; comfort, programmable buttons

Mice-
Normal mouse- used to it so rated it high

Trackball Mouse- like ball, but didn't fit (too big); have used it but still not completely comfortable

Vertical Mouse- like how hand felt; felt weird with hand position; think wrist would get tired

Joystick- like it best, used one before so felt easy on hand; wasn't used to it but might if exposed; didn't like it at all because is not stable; liked and didn't like button placement

Zero Tension Mouse- spectacular; third slot should have a button; didn't like look, confusing (too industrial)

What they know
What is it?- don't know
What causes it?- from being on computer all day; hand tenses up; injury makes it more sensitive; position
Who is affected?- people who are on the computer all day; nased on job; avid gamers

Personal Experience?- gaming

How does it affect people?- probably sucks; not able to do job so bad for economic well being

Keyboards- the funny, tilted keyboard with split it middle- was uncomfortable; no not really; used one before but wasn't used to it so it was uncomfortable

Focus Group #4 – (date not listed)

Prompts – broken mouse (or no mouse), new computer
Decide – Wireless, not Apple (need right click), scroll wheel (said it was "needed"), price (extremely important, listed multiple times)
Influences – price, friends
Manufacturers – not important, but name recognition is good
Likes – optical, scroll wheel, comfort (proper sizing), quality laser (sensitive)
Programmable buttons are unimportant

Pricing exercise : wut's a reasonable price for a generic mouse in the computer lab:
wut's a reasonable price for a 2 button mouse with a scroll wheel?

$15, 5, 4, 0 : 3 used, 8 new
scroll wheel : 20, 8, 4,
vertical : 35, 20, 10,
dream mouse : 30 (including keyboard), 10, 40, 40
- sensitive laser, scroll wheel that's smooth (transitionwise), close to a standard mouse, 2 buttons, has to work well on other surfaces
- already has it : mx3 200, scroll wheel, laser, wireless, fits niceless, forward and backward buttons

Normal mouse - pretty good

Trackball –
NO...it's like a touchpad, too used to moving, would have to get used to it - awkward for larger hands to get the left and right buttons, button is in an awkward position

Vertical mouse –
Interesting, felt okay, comfortable (moreso than tthey thought), wish it were bigger....don't know wut to do with ur pinky, surprised that there were 3 buttons

Zero tension Mouse
Awful, don't like the scroll with the thumb and the scroll wheel was poorly posiitioned, most intuitive way to hold the mouse would be eto wrap ur hand around it completely

joystick –
Doesn't rest easily, doesn't support ur hand, no scroll wheel, touch to get used to the 2 buttons, see it leaning so u want to move it...could break it, might give an advantage for counterstrike, could put a scroll wheel on the the front
- only the downward click feels natural
- didn't know there were 2 clicks
- bad for big thumbs

Carpal Tunnel is:
inflammation from repeated activity
repeated activity, causes pain

what causes it : repeated use of something over and over
who gets it : old people, office workers, old office workers, desk jobs all day for 40 years of their life,
how does it affect people : can't grip things, would need to medicate, can't use hands and u use them

have u seen ergonomic comp mice - yes
- one has 4 clicks, don't know where to put ur thumb...2 clicks, scroll wheel, 2 clicks
- soft jelly pad for ur wrist, trackball where ur thumb is

have u seen erg keyboards - yes
- don't like it
- do notice how the keyboard is sorta scrunched
- wouldn't work if u didn't type properly

Focus Group #5 – (date not listed)

Prompts – broken mouse
Influences – Large retailers
Manufacturers – unimportant, name recognition a plus
Likes – two buttons, scroll wheel, possibly programmable/zoom buttons, not expensive
Comfort – very important
Scroll wheel- also very important
Additional buttons – programmable button to zoom/open
Programmable buttons – not terribly important, but useful – cost is important

Pricing
Importance of differing product lines
Reasonable Price - most important, about $10 without scroll, 13-15 with scroll
Vertical mouse - $40

Scroll wheel – increase of about $5

Perfect Mouse - $70 for a gelatin mouse/smart touchpad

Designs

Favorable/Unfavorable designs – worst were trackball and joystick

Individual breakdown/pricing

Normal mouse – fine, gets the job done

Trackball Mouse – enh – didn't really like it, not used to it, looks like a spaceship, trackball is annoying, interesting but not useable, old person mouse

Vertical Mouse – pretty bad, kind of weird, like holding a cup the whole time, not tall enough, traps pinky underneath

Joystick – uncomfortable, why moving the joystick around (joystick that moves is also poor), not a resting position

Zero Tension Mouse – weird, no finger trapping but still weird, the scroll wheel is inconveniently placed, have to do something with size – might be easier if it was larger

Features preferred
Not particularly

Ergonomics Knowledge/Work Related Musculoskeletal Disorders

What causes it? Having your wrist at unnatural angles for long periods of time (reason for using gel pads while typing)

Who is affected? Old people, office workers, programmers, gamers (possibly), physical labor, clerks

Personal Experience?
None

How does it affect people?
Trouble gripping, loss of movement in wrist and possibly fingers, possibly very painful

Ergonomic Computer Input devices

Mice – seem them before, but not all of them (especially the joystick)
Adjustment period to new mouse – depends on how much it was needed, content with generic scroll mouse

Keyboards – waves, three different parts, angled keyboards

Focus Group #6 – (date not listed)

Prompts – inadequate mouse, broken/lost mouse, need gaming mouse
Decides – sales, reviews, online articles, friends, physical interaction with mouse (at store, with friends)
Manufacturers – Not important, but name brand is good
Likes – Wireless, optical mouse, slightly more expense paid for quality mouse

Features

Ease of use - important
Comfort – Vertical mouse will rub the skin off my hand
Scroll wheel – very important, love scroll wheel, hate tilt scroll wheel
Additional buttons – not terribly important
Programmable buttons – forward/backward buttons

Higher end/Cheaper mice – the low end of the higher end mice
Importance of differing product lines
Reasonable Price – default mice is $15

Perfect Mouse – $40-50 dollars, two buttons and a scroll, comfortable, forward/back button, fast scroll wheel, frictionless wheel bearing, a way to adjust/detect the difference between mouse and touchpad

Normal mouse – scroll wheel is $10-$20, $5-$10, raises up too high, mouseball bad

Trackball Mouse – would it be comfortable for long term use? How accurate would it be? Kind of awkward, have to move hands a lot, looks like an ugly manta ray, lose trackball

Vertical Mouse – $20, fingers drag on the table, need ledge, stabilizing is hard, spaces for fingers are not always useful, mistakes are possible (no theoretical headshots or possible miracle cream) – too much force while clicking?

Joystick – comfortable, needs a scroll, not so much on the thumb clicking

Zero Tension Mouse – better than the vertical, has a ledge, shape is uncomfortable, bigger buttons, change orientation of scroll wheel

Features preferred

Scroll wheel

Ergonomics Knowledge/Work Related Musculoskeletal Disorders

What is it? Injured nerves
What causes it? Worn down cartilage, movement of wrist, repeated motion, awkward posture

Who is affected? Secretaries, everyone, college students, DOTA players, older people - older people are more susceptible

Personal Experience - none

How does it affect people? Painful, “no more headshots,” everyday tasks are harder

Ergonomic Computer Input devices

- Mice
- Keyboards
  - Split keyboards to fit the rotation of your hand – not always comfortable

Focus Group #7 – (date not listed)

Prompts – Broken mouse, want new mouse
Decide – Price, size, comfort, portability, scroll wheel, cord vs. wireless
Influences – family/friend with experience
Manufacturers – name brand is positive and helps ensure quality, if off brand is recommended then might be worthwhile

Comfort is listed as important again

Functionality is important – need two buttons and a scroll wheel
Wireless and laser mouse

Features
Ease of use – really important
Comfort – important, as is size, wrist support is important
Scroll wheel - extremely
Additional buttons – scroll wheel that clicks/goes side to side, not much else
Programmable buttons – unaware of

Pricing
Higher end/Cheaper mice
Importance of differing product lines – important for people who need special mice, not terribly important for the interviewers
Reasonable Price – start in the low area and work up

Perfect Mouse – around $100, Bluetooth, optical, comfort gel built into it
$25-50 - same as above
$12 – wireless, two buttons and a scroll wheel
$10-15, wireless isn't important, just two buttons and a scroll wheel (preferably optical)

Designs
Favorable/Unfavorable designs
Individual breakdown/pricing

Normal mouse – $10-15, $7, $8
Normal mouse with scroll – $12-15, scroll wheel adds value

Trackball Mouse – what is this, really awkward, "I would feel wrong using it," mouse has weird button placement

Vertical Mouse – maybe around $50, $30, $15, i

Joystick – how do you use this? Nothing to scroll, immobile joystick is a joke, possible unwanted clicking

Zero Tension Mouse – improved vertical mouse, but fingers don't fit, awkwardly placed scroll wheel

Features preferred

Not a fan of wired mice

Optical is nice

Vertical mouse was comfortable to some, Zero Tension mouse was nice but probably too expensive/too large to carry around – these are the same mouse with just a ridge to make it cost more

Still like the dell mouse

Ergonomics Knowledge/Work Related Musculoskeletal Disorders

What is it? Carpal tunnel

What causes it? Repeated typing, computer use, things like tennis, thought it was only from typing

Who is affected? Musicians, tennis players, people who type for 8 hours a day

Personal Experience? Mom, mother's friend, friend

How does it affect people? Pain, have to stop using your wrist, like arthritis, have to go to physical therapy, have to get surgery

Ergonomic Computer Input devices

Mice

Seen the trackball before, thought it was pointless

Indentations for fingers and wrists

Keyboards

Stand up keyboard

Bent in a V

Focus Group #8 – (date not listed)

Prompts – Broken, don't have one, possible interest in mouse
Decide – Scroll wheel, two buttons, simple design, comfortable, responsive
Influences – cost, store employees, Amazon (reviews), what is familiar
Manufacturers – Name recognition is positive, but not necessary (Apple mice are disliked)

Features

- Ease of use – utmost importance, needs to be natural to focus on the screen
- Comfort – number one
- Scroll wheel – crucial
- Additional buttons
- Programmable buttons – not really important

Pricing
Importance of differing product lines – really important

Reasonable Price

- Normal mouse - $10, 3, 5
- Scroll wheel – $15, 3, 10
- Vertical mouse - $35, 30, 40
- Perfect mouse – $50, 60, 20, 40

Individual breakdown/pricing

Normal mouse – feels really nice, thumb is tucked in so perfect – maybe just familiarity?

Trackball Mouse – hated it a lot, pretty uncomfortable – not in control, hand movement is better, like a bug

Vertical Mouse – comfortable but the side was awkward, ergonomic, could learn to like it (buttons are little weird) but nothing to rest on, can't relax

Joystick – while playing a video game maybe, but didn't really like it, like it the most because it can be gripped

Zero Tension Mouse – more comfortable than it looked but not fun, awkward positions, buttons don't stick out

Features preferred – scroll bar, easy clicking, hated the track thing, big buttons, hand should be horizontal, hand rest is necessary

Ergonomics Knowledge/Work Related Musculoskeletal Disorders

What is it?

What causes it? Not moving it, moving it too much, constant awkward positions of the hand (video games), carpal tunnel syndrome

Who is affected? Video gamers, secretaries, people who work with computers, people with computers

Personal Experience? Roommate got carpal tunnel playing too much Counter Strike

How does it affect people? Can't play Wii, your clan will kick you out, computers and mice go hand in hand

Ergonomic Computer Input devices

Mice – a ball with indents and a flat bottom, angled mouse

Keyboards – sloped keyboard, slanted, with some triangular buttons

Appendix I: Experimental Testing Script

When we first meet the participant, we will introduce ourselves:

“Hello, we are member of Gemstone Team MICE. Thank you for coming today and participating in this research study.”

Next, we will pass out consent forms. We will review the main points of the form before the participants sign it.

“We are passing out consent forms for our study. Before we begin the set-up and computer mouse tests, you must sign this form. The number at the top of the consent form will be your identification number to ensure confidentiality. This number will be linked to your name in a master list. Only members of Team MICE will have access to this list.”

“As the consent form explains, this is an ergonomic mouse study. While you perform our simple mouse test, we will collect data through EMG and motion capture equipment. In order to attach the EMG electrodes, we will shave sections of your arm and exfoliate with a pumice stone. Next we will attach the electrodes. The motion capture markers will be attached next. Once this set-up is complete, you will be given 10 minutes to become accustomed to your randomly assigned ergonomic mouse. Next, you will perform the mouse test, which we will explain in more detail, while we gather data. Last, the ergonomic mouse will be switched with the control mouse. Are there any questions?”

After the forms are signed, we will explain how to complete the mouse test.

“After you’ve positioned yourself at our ergonomic workstation, wait for the program to load and the screen to appear. To begin, left-click the center circle. Another circle will appear on the screen. Move as quickly and as accurately as possible to the center of the new circle and left-click. Then, move back to the center circle and left click. Repeat until the test ends. Next, the test sequence will be repeated with a dragging-and-dropping test. Once again, move from the center circle to the new circle that appears on the screen. Then, move back to the center circle and click. Be careful not to accidentally drop the circle because it will count as a trial. This entire test will be repeated with the control mouse. Are there any questions?”

Appendix J: Fitts' Test Data

Table 1: Control Mouse Effective Target Width and Throughput for 16 Experimental Conditions

d	W	W_{xe}	W_{ye}	Id_e	Throughput
75	25	22.22529983	17.41007183	3.032057123	2.894578066
75	50	40.63372196	28.27039451	2.656703212	2.795780341
75	75	49.47005684	32.4997223	2.67461011	2.820010367
75	100	186.3628297	51.59699104	2.285755828	2.445724315
100	25	20.76888895	16.17056427	3.361222916	3.111949961
100	50	34.3597929	29.24387637	2.804086361	2.909529879
100	75	70.1305649	36.93299872	2.681496833	2.803596036
100	100	79.45963677	42.73749042	2.64724507	2.788761821
125	25	20.76150109	17.17914574	3.483721588	3.09492201
125	50	78.85361397	31.04149501	2.895882036	2.807661667
125	75	119.3397976	42.30672556	2.659537203	2.73079061
125	100	69.10345744	43.60910218	2.7511955	2.880637479
150	25	26.20033281	17.97280064	3.60026098	3.178882451
150	50	39.33958783	30.27136879	3.076005918	2.981682597
150	75	70.03760801	41.95567407	2.798811511	2.722285054
150	100	89.04000025	47.50571756	2.763151673	2.794917986

Table 2: Vertical Mouse Effective Target Width and Throughput for 16 Experimental Conditions

d	W	W_{xe}	W_{ye}	Id_e	Throughput
75	25	25.52287118	20.46421366	2.829489136	2.468145743
75	50	40.13173723	27.23448069	2.702153042	3.527614938
75	75	47.23634775	41.51338171	2.382807829	2.41419233
75	100	84.51515015	38.4140217	2.633764169	2.53520796
100	25	27.95459158	21.13866212	3.017209742	2.553080908
100	50	36.86710115	37.93106306	2.522753695	2.299538747
100	75	40.32698501	53.49494657	2.575181196	2.66069291
100	100	33.52151967	74.03145194	2.947124918	2.841172848
125	25	21.89298456	19.83112228	3.296385922	2.597340567
125	50	164.498128	28.93111055	2.984219922	2.702927735
125	75	75.09566681	41.97127616	2.669210294	2.602943686
125	100	52.49495561	44.48893852	2.726694863	2.549934799
150	25	25.65938188	31.86528522	3.136588438	2.44934348
150	50	85.25860941	35.9892293	2.858353157	2.461003615
150	75	123.5895136	38.74159743	2.897823617	2.76751957
150	100	54.28093699	40.67092709	2.956351614	2.64208972

Table 3: Trackball Mouse Effective Target Width and Throughput for 16 Experimental Conditions

d	W	W_{xe}	W_{ye}	Id_e	Throughput
75	25	30.44782468	22.20476413	2.728883212	2.175901917
75	50	36.25729503	45.78845843	2.36095373	2.083756264
75	75	63.58956304	44.45474917	2.303514034	2.074796533
75	100	85.78531895	56.60360078	2.180575679	2.031381959
100	25	24.22641884	42.25591939	2.846310338	2.234128185
100	50	47.02198184	43.42309172	2.330591032	1.861370541
100	75	71.6947218	50.45393762	2.311506521	2.031126442
100	100	84.74891289	64.98964852	2.157719552	1.976637586
125	25	23.24929778	25.80145155	3.092056709	2.192213828
125	50	114.7381213	43.33660992	2.489295184	2.001890464
125	75	64.44292737	58.96560318	2.267770659	1.949349786
125	100	81.37534663	63.66189206	2.300708321	1.868321612
150	25	132.6112859	23.6905748	3.239119362	2.324309773
150	50	115.5357965	41.04166782	2.696490956	2.157168796
150	75	67.22369334	54.38074914	2.484709186	2.067408519
150	100	86.37268977	68.72801681	2.322297213	1.926551439

Table 4: Joystick Mouse Effective Target Width and Throughput for 16 Experimental Conditions

d	W	W_{xe}	W_{ye}	Id_e	Throughput
75	25	111.9396657	39.99056265	2.044652021	1.614305168
75	50	45.33303145	36.80085137	2.343689983	1.94703557
75	75	45.39683742	40.09918733	2.42335717	1.715448681
75	100	60.84396842	48.71232128	2.352119342	2.08554601
100	25	85.15707918	25.66014195	2.775185818	2.190479822
100	50	97.25342051	46.58861014	2.249834531	1.945662609
100	75	53.11753258	40.64772135	2.565676378	1.996397956
100	100	74.96181582	62.77616462	2.19665831	1.807949227
125	25	30.34930858	46.21987015	2.758344535	2.025402137
125	50	97.20679839	29.52278484	2.958736657	2.387843156
125	75	58.02234463	33.2473396	2.957442679	2.336514066
125	100	68.84013795	55.01322859	2.471021336	1.972543225
150	25	45.06955268	22.41170182	3.310908587	2.254981963
150	50	175.2305194	55.17729562	2.344193397	1.821223896
150	75	199.6795126	45.70179939	2.693820149	2.216173252
150	100	59.97558063	48.85391916	2.728796995	1.998650943

Appendix K: Exertion Force Data

Below is the summary data for individual trials, arranged by the mouse used in the trial. The summary data for each mouse follows the trials of that mouse. Because this chart is much wider than a page, it is continued on the subsequent lines.

Data in lbs	control 1	control 2	control 3	control 4
Algorithm Threshold	0.45984456	0.351450777	0.280181347	0.359818653
# Peaks Found	296	259	397	276
Maximum Force	0.735751295	0.739896373	0.747150259	0.757512953
Average Force (includes non peaks)	0.259605907	0.145123627	0.11784114	0.090717098
Average Peak Force	0.601340849	0.498669654	0.426974328	0.507749493
STDDEV	0.058009174	0.072872039	0.107283598	0.076399515

control 5	control 6	control 7	control 8	control 9	control 10
0.366709845	0.310932642	0.263316062	0.211398964	0.298160622	0.132607979
199	245	259	248	232	245
0.772020725	0.731606218	0.957512953	0.497409326	0.701554404	0.723316062
0.124694093	0.133445285	0.095903523	0.124850155	0.108727668	0.057599585
0.582013695	0.486446019	0.442935163	0.296210095	0.450920136	0.300145924
0.088098406	0.0778453	0.111628606	0.056084459	0.075360837	0.104278855

control 11	control 12	control 13	control 14	control 15	control 16
0.231986218	0.270293575	0.316632124	0.298324663	0.208462902	0.130569948
261	362	315	281	287	235
0.605181347	0.648704663	0.703626943	0.778238342	0.735751295	0.522279793
0.122647876	0.161295544	0.170451503	0.152398964	0.104027047	0.061789223
0.383399837	0.441685512	0.470795296	0.513322147	0.44229929	0.312239003
0.069713433	0.092191178	0.064916938	0.108473462	0.130118331	0.075917457

control 17	control 18	Means of Control	STD DEV	STD NORM	joystick 1
0.323385181	0.480552642	0.294146039	0.093733106	0.022093105	0.468911917
325	212	274.1111111	50.63814987	11.93552639	387
0.625906736	0.779274611	0.709038572	0.103869606	0.024482301	0.750259067
0.17009658	0.175573886	0.132043817	0.047122604	0.011106904	0.239057409
0.41554723	0.598875745	0.453976079	0.092387578	0.021775961	0.547466228
0.046598245	0.049576979	0.081409267	0.023479621	0.0055342	0.043794197

joystick 2	joystick 3	joystick 4	joystick 5	joystick 6	joystick 7
0.410751295	0.691632124	0.210708083	0.367633886	0.275647668	0.337150259
230	527	402	276	269	263
0.78238342	0.838341969	0.505699482	0.760621762	0.787564767	0.749222798
0.130975544	0.520273679	0.08826487	0.198394611	0.202887565	0.146570984
0.619071863	0.731825203	0.323408862	0.518160997	0.534309529	0.468142686
0.06903987	0.022978857	0.060904098	0.103889687	0.186528854	0.072890094

Means of Joystick	STD DEV	STD NORM	trackball 1	trackball 2	trackball 3
0.394633605	0.155993984	0.058960184	0.447487047	0.13365285	0.369136477
336.2857143	106.5296739	40.26443207	264	265	323
0.739156181	0.107422234	0.040601788	0.778238342	0.76373057	0.76373057
0.218060666	0.142555303	0.05388084	0.167621762	0.044002073	0.151233886
0.534626481	0.126152954	0.047681335	0.620238656	0.325568482	0.533255266
0.080003665	0.053255224	0.020128583	0.064139232	0.126337648	0.065150284

trackball 4	trackball 5	Means of Trackball	STD DEV	STD NORM	vertical 1
0.215284974	0.294749534	0.292062176	0.123584802	0.055268804	0.318782383
297	274	284.6	25.24480145	11.28981842	325
0.861139896	0.768911917	0.787150259	0.041783638	0.018686211	0.554404145
0.08608943	0.124954197	0.114780269	0.050143084	0.022424669	0.161814093
0.448404599	0.487500473	0.482993495	0.108813854	0.048663035	0.423856517
0.138056739	0.114415934	0.101619967	0.034774927	0.01555182	0.045533257

vertical 2	vertical 3	vertical 4	vertical 5	vertical 6	vertical 7
0.266010363	0.363056995	0.453903316	0.373989637	0.45492228	0.51454228
251	365	248	309	268	341
0.625906736	0.660103627	0.664248705	0.831088083	0.666321244	0.630051813
0.116532642	0.224353161	0.260206321	0.232078342	0.335653264	0.483531503
0.377565386	0.474066293	0.538860104	0.53295102	0.547877194	0.558275721
0.06519145	0.049830263	0.035255611	0.087907944	0.043480793	0.019038169

vertical 8	Means of Vertical	STD DEV	STD NORM
0.477979275	0.402898316	0.085895595	0.030368679
245	294	47.02279083	16.62506713
0.699481865	0.666450777	0.079070311	0.027955577
0.372185078	0.273294301	0.11900483	0.042074561
0.551028868	0.500560138	0.067977118	0.024033541
0.039874073	0.048263945	0.020649207	0.007300597

Appendix L: EMG Data

The following two charts show the average value of each measurement for each testing run. Test runs are displayed horizontally, while corresponding measurements are listed vertically. The average value for each measurement type across all tests is displayed at the bottom.

Fitts' Test Analysis Results | Average Values

Subject	ECR-Avg	ECU-Avg	FCR-Avg	FCU-Avg	ECR-Peak	ECU-Peak	FCR-Peak	FCU-Peak	ECR-Area	ECU-Area
D2	0.058839889	0.117949654	0.058300599	0.064268103	0.249080101	0.662604486	0.269796886	0.305049623	0.029361435	0.05882054
D2S	0.042413708	0.110528862	0.09115256	0.080971425	0.176178491	0.521216065	0.42124638	0.357089701	0.021164851	0.05515173
E1	N.A.	0.867209024	0.905243602	0.964553265	5.018242185	2.912155998	2.908940753	3.041420763	2.480549205	0.43269103
E1S	N.A.	0.869375418	0.893133797	0.969461255	5.014846903	2.892433976	2.906490322	3.036641256	2.482181429	0.43381186
F1	0.007123451	0.19050719	0.111953144	0.041089608	0.038920478	0.935392715	0.552558456	0.200966417	0.003554578	0.09504903
F1S	0.087308831	0.18005089	0.21820179	0.205052475	0.43824101	0.93944605	0.930785824	0.788252165	0.043565321	0.08983490
F2	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
F2S	0.038994421	0.073823427	0.052555665	0.055951164	0.170827527	0.320104042	0.222613769	0.242171075	0.019457713	0.03683540
G1	0.054255298	0.188813057	0.068828721	0.064680818	0.358574078	1.267227269	0.413267997	0.360353466	0.027075253	0.09421733
G1S	0.036103662	0.143882487	0.050507806	0.044905047	0.246985547	0.991782643	0.304557531	0.257543843	0.018016252	0.07179788
G2	0.036465189	0.087329937	0.044878755	0.098799681	0.156735666	0.359420186	0.193474201	0.470093324	0.018196306	0.04357139
G2S	0.040876159	0.101319946	0.042362446	0.069688788	0.176799104	0.450147244	0.178230868	0.327337788	0.020395619	0.05055592
H1	0.083084718	0.137181208	0.072938894	0.077238298	0.465079575	0.736412634	0.377025022	0.404488473	0.041462182	0.06845425
H1S	0.035249284	0.08865545	0.041308248	0.046260339	0.189594896	0.421943932	0.208959692	0.213918299	0.017581365	0.044226
H2	0.029642513	0.097415585	0.043673726	0.027533173	0.157447929	0.416936073	0.219671408	0.124572752	0.014792406	0.04860463
H2S	0.03392236	0.098530615	0.040474247	0.026923772	0.173693996	0.460882753	0.190501574	0.120111729	0.016929217	0.04916469
H3	0.085321084	0.134054587	0.095489222	0.100247832	0.407979771	0.685633073	0.439433981	0.476117511	0.042577761	0.06689532
H3S	0.083108058	0.135727027	0.096489168	0.096975961	0.394350015	0.636104071	0.446314383	0.458004238	0.04147215	0.06772668
I1	0.057391809	0.130627734	0.090912349	0.087549601	0.257807771	0.696814689	0.423640823	0.372171034	0.028641627	0.06517587
I1S	0.040109845	0.096687651	0.058211521	0.073699853	0.180448158	0.466642452	0.251904795	0.317993588	0.020014741	0.04825062
J1	0.024074922	0.125688303	0.065053526	0.034934637	0.129088327	0.576651809	0.356423457	0.170163614	0.012013384	0.06271872
J1S	0.023331059	0.09846713	0.063844129	0.041409961	0.109421072	0.530554713	0.320329538	0.192910939	0.011641796	0.04913059
J2	0.041708965	0.085401664	0.111007635	0.07935909	0.313484901	0.576098499	0.581562602	0.553543571	0.020821299	0.04262730
J2S	0.023711801	0.047384493	0.033484386	0.039124854	0.155851829	0.322150016	0.216837448	0.295616811	0.011831949	0.02364489
J3	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
J3S	0.039379598	0.113946247	0.149462236	0.061858679	0.277329605	1.035081355	1.434214915	0.411393749	0.019650183	0.05686757
K1	0.067106481	0.147373446	0.0648621	0.091335508	0.289455345	0.667853374	0.280719433	0.395228774	0.033484471	0.07353702
K1S	0.068238405	0.156626043	0.064277874	0.098132309	0.289419442	0.676325116	0.269560269	0.407698011	0.034049883	0.0781605
K2	0.060033626	0.110199687	0.154181054	0.072172877	0.296965592	0.597085764	0.686472642	0.340687816	0.029952535	0.05498444
K2S	0.052143106	0.101052446	0.116103133	0.087995057	0.207168554	0.485187309	0.500369659	0.398738321	0.026018499	0.05043036
L1	0.04191132	0.160268742	0.054533095	0.076634358	0.203966562	0.704195014	0.360817985	0.349122164	0.020912276	0.0799714
L1S	0.036261725	0.116959368	0.04314637	0.068677969	0.232764821	0.501054601	0.330494027	0.338961676	0.018093784	0.05836533
L2	0.066289418	0.130825718	0.106620247	0.133541096	0.343206934	0.782504635	0.510234161	0.585420255	0.033080866	0.06526864
L2S	0.060827493	0.134214138	0.078955482	0.078441049	0.510184602	1.060859239	0.633326796	0.571304126	0.030347143	0.06696693
L3	0.024774873	0.072475312	0.036241385	0.040703338	0.167722059	0.390408321	0.238062694	0.246654487	0.012362052	0.03616861
L3S	0.022275157	0.064134685	0.029339304	0.041578157	0.147281098	0.364993614	0.206835083	0.254967969	0.011117129	0.0320055
M1	0.043570142	0.094679825	0.038080286	0.053328267	0.257524654	0.465975212	0.212107699	0.281055026	0.021740093	0.04724576
M1S	0.015019647	0.052944197	0.0825705	0.02532642	0.084928046	0.266151255	0.422903923	0.119977406	0.007494587	0.02641961
M2	0.004775532	0.030381281	0.025432852	0.015353271	0.025378394	0.160934696	0.183045735	0.097781698	0.00238299	0.01515945
M2S	0.006342382	0.039325093	0.028721386	0.022726277	0.036993268	0.21609592	0.170154778	0.15869756	0.00316469	0.01962386
N1	0.10131061	0.229606824	0.1632401	0.124589618	0.456072152	1.114208182	0.699894237	0.527043754	0.050556903	0.11458389
N1S	0.097333216	0.167355215	0.102143843	0.107519916	0.447652961	0.808428535	0.479233145	0.466012775	0.048566415	0.08350817
N2	0.066665744	0.113069084	0.115087616	0.071584143	0.500362062	0.7410346	0.710250926	0.494202407	0.033265624	0.05642523
N2S	0.038753362	0.081631882	0.070027251	0.061607681	0.224183757	0.436528269	0.371789389	0.277060328	0.019339728	0.04073946
P1	0.148340255	0.140168094	0.150160808	0.214457749	1.128601168	1.114080477	1.133700228	1.253767563	0.073990464	0.06991617
P1S	0.071417063	0.089728041	0.080892931	0.16219882	0.415273634	0.559537509	0.454259635	0.807935845	0.03563526	0.04476676
P2	0.039854229	0.065725696	0.105670688	0.060210202	0.190139513	0.38034757	0.815295576	0.276773863	0.019888214	0.03280281
P2S	0.044595345	0.065192834	0.103773256	0.064183043	0.211463193	0.417424311	0.811769047	0.32370445	0.022253567	0.03253413
Q1	0.028562964	0.053452076	0.049398497	0.033218323	0.155244633	0.278446527	0.335998366	0.163218567	0.014253523	0.02667451
Q1S	0.028232115	0.049921577	0.033009355	0.02972557	0.172848133	0.258221613	0.201278223	0.171393637	0.014087067	0.02491077
Q2	0.017130838	0.07150533	0.019187567	0.019181392	0.093798155	0.394134773	0.099804476	0.101026985	0.008546489	0.03566796
Q2S	0.021176425	0.081469514	0.02280297	0.022430099	0.117173737	0.456176853	0.120887147	0.122459959	0.010567884	0.04065366
R1	0.033791335	0.123691053	0.081176774	0.048849607	0.212820788	0.802990113	0.591337268	0.296170967	0.016858973	0.061720
R1S	0.075253862	0.1016233	0.098639648	0.083343815	0.620456903	0.602654867	0.813076359	0.695198849	0.03754572	0.05070998
Average	0.047688066	0.137810732	0.108033549	0.105030454	0.448001136	0.683032212	0.527162722	0.461926749	0.118317401	0.06876436

MVC Analysis Results	Average Values									
Subject	ECR-Avg	ECU-Avg	FCR-Avg	FCU-Avg	ECR-Peak	ECU-Peak	FCR-Peak	FCU-Peak	ECR-Area	ECU-Area
D2	0.00153813	0.140356797	0.216820868	0.09130889	0.006220116	0.674030488	0.931632949	0.556155617	0.003843783	0.350794
D2S	0.001697039	0.114722449	0.116991463	0.091897749	0.00688339	0.576168755	0.574238726	0.431718492	0.004241684	0.2866446
E1	N.A.	0.955466341	0.85685653	0.818366907	N.A.	3.398293596	3.378524511	3.196380803	N.A.	2.3877075
E1S	N.A.	0.864800076	0.722372705	0.937435875	N.A.	3.002654857	2.985740607	3.14132539	N.A.	2.1613954
F1	0.003863663	0.216949535	0.498028922	0.311581543	0.009611261	1.208852041	2.382049524	1.617348074	0.009658116	0.5422462
F1S	0.001585131	0.229477483	0.376491738	0.213672659	0.007242839	1.083273348	1.684513577	0.923751789	0.003960726	0.5735102
F2	0.001837877	0.051019157	0.06995974	0.08594585	0.007850959	0.245873424	0.407271919	0.412586519	0.004593883	0.127501
F2S	0.001585908	0.070902272	0.089837389	0.08087486	0.007239199	0.365617004	0.571206785	0.429632566	0.003962674	0.1770953
G1	0.001426949	0.270093114	0.093367623	0.225854422	0.00639052	1.57955198	1.09129113	1.350472232	0.003565925	0.6747736
G1S	0.001842255	0.076179889	0.108217413	0.108535409	0.007279821	0.468802501	0.768124888	0.54888255	0.004602492	0.1903740
G2	0.001416649	0.100671071	0.092105956	0.181600296	0.006038619	0.456590632	0.885160283	0.7880745	0.003540312	0.2514705
G2S	0.002094382	0.116299843	0.075496059	0.080169274	0.007082201	0.842648197	0.470426376	0.621975561	0.005233433	0.2907328
H1	0.001359028	0.696374457	0.54685418	0.436189828	0.006239521	4.558035555	2.657621336	2.575375548	0.003394505	1.7405468
H1S	0.002621152	0.759188125	0.725939713	0.479764191	0.00816517	5.027901051	4.239664747	3.036077475	0.006549247	1.8975688
H2	0.001959074	0.314131507	0.213739022	0.179676263	0.007810845	1.317234716	1.089999871	0.982708959	0.004895865	0.7850548
H2S	0.002669638	0.452252485	0.557554318	0.179906694	0.008707125	2.740045752	2.859802548	1.053355464	0.00667106	1.1304460
H3	0.002547782	0.191235536	0.125772238	0.15102002	0.008558718	0.938455098	0.59523519	0.70586932	0.006365963	0.4777876
H3S	0.001439115	0.112581437	0.15845898	0.108979481	0.006740623	1.163299385	0.818887401	0.709994345	0.003596976	0.2812023
I1	0.002939527	0.412543343	0.280335888	0.16988605	0.008648409	1.731433972	2.666443136	1.026632696	0.007346149	1.0310132
I1S	0.002703001	0.663320739	0.471021417	0.255986601	0.008041722	2.835722498	2.885826168	1.821327767	0.006754412	1.6577638
J1	0.001400241	0.662458898	1.081370555	0.347068036	0.006915211	3.491025927	4.298697302	2.378659458	0.003499267	1.6552052
J1S	0.002942526	0.719810068	0.667812963	0.367157747	0.009210348	3.806954569	3.349532509	1.994386829	0.007354646	1.7990470
J2	0.001409076	0.023226775	0.019160013	0.084866469	0.006273368	0.109041404	0.177623849	0.587937774	0.003521242	0.0580606
J2S	0.002935509	0.030808232	0.03047601	0.119665149	0.008748883	0.318012716	0.161245624	0.944858519	0.007337439	0.0770001
J3	0.001990012	1.064393285	0.496461608	0.289165623	0.007506183	6.08036133	2.626689861	2.865515567	0.004972338	2.6596726
J3S	0.001902888	0.714557134	0.414623064	0.281779859	0.00728716	4.960324047	2.461811272	3.440742532	0.004754767	1.7856492
K1	0.003477055	0.333295952	0.127732051	0.241840394	0.009870694	2.189708907	0.58953874	1.254284734	0.008690595	0.8330946
K1S	0.001363595	0.40540434	0.161715183	0.260358992	0.006874088	1.926866509	0.794528238	1.017348048	0.003408627	1.0134056
K2	0.003942928	0.74519755	0.646961997	0.17949527	0.009615975	3.367221017	2.920497799	0.80124998	0.00985412	1.8624540
K2S	0.001386317	1.313043332	1.058314268	0.22019226	0.009231439	5.734780986	4.626918433	0.949727073	0.003465315	3.2817723
L1	0.00246877	0.180400033	0.154266072	0.149788501	0.008514704	0.989431801	0.881355778	0.706298763	0.006168759	0.4508997
L1S	0.002702916	0.206037789	0.295719792	0.26879355	0.009061408	1.226578276	2.967850561	1.340095788	0.006755403	0.5145806
L2	0.003283233	0.422593185	0.236138042	0.233395208	0.008100019	2.817716145	1.597438956	1.109068041	0.008203357	1.05589
L2S	0.003010263	0.237909041	0.210253019	0.214397259	0.008609232	1.156595139	1.069957165	1.050487214	0.007522988	0.5944673
L3	0.003176539	0.151052749	0.131568615	0.11058558	0.009036173	0.953403535	0.70408304	0.504497838	0.007938443	0.3775831
L3S	0.003190487	0.186679339	0.151711471	0.115743159	0.008480584	1.340422582	0.877758157	0.903656008	0.007975514	0.4666266
M1	0.00227156	0.477553311	0.426142773	0.41861749	0.00870904	2.716603772	2.406675795	1.594764037	0.005676574	1.1931958
M1S	0.002497887	0.867938144	0.725785389	0.39658752	0.008608388	4.926274727	4.184807634	1.817069781	0.006241398	2.1695703
M2	0.003094149	0.11477558	0.134988137	0.09204429	0.009305035	0.688314773	0.855717391	0.670557597	0.007733223	0.2867992
M2S	0.003293848	0.093862994	0.124758262	0.10644156	0.008465727	0.78619496	0.724153228	0.644882674	0.008231448	0.23446
N1	0.001388444	0.566845559	0.371588333	0.299815636	0.006361901	3.721592319	2.180555366	1.755966942	0.003469574	1.415897
N1S	0.003882292	0.531605156	0.666954775	0.250085782	0.009444628	3.014132892	3.34650128	1.330332101	0.009702851	1.328778
N2	0.005077389	0.180662216	0.648738866	0.275024346	0.012345497	1.262647465	4.083379321	1.279200874	0.012687853	0.4515867
N2S	0.004980716	0.278591658	0.562166697	0.287361675	0.010601055	1.666504954	3.682380978	1.247930439	0.012446468	0.6962408
P1	0.002885779	0.17446531	0.226362186	0.143284563	0.00925056	1.893711385	3.073112357	0.819950356	0.007213778	0.4355622
P1S	0.002429458	0.15974617	0.162225657	0.148519474	0.007654057	1.306789503	0.726234722	0.859973256	0.006073399	0.3991903
P2	0.003502167	0.574193365	0.44962164	0.234096111	0.010343743	2.748039632	4.032180475	1.421682075	0.008751186	1.4348815
P2S	0.003429562	0.753354219	0.620998246	0.244050859	0.008864033	3.477650445	3.590166158	1.523338734	0.008571894	1.8828983
Q1	0.001436686	1.218407436	0.324995044	0.245583772	0.006851195	6.268701736	2.12959749	1.518618867	0.003590335	3.0437295
Q1S	0.003840062	0.729033935	0.235602023	0.182789584	0.009256969	4.258435871	1.473158481	0.923531138	0.009596008	1.8220535
Q2	0.005447347	0.500475514	0.25800543	0.111747711	0.011419673	3.2917179	1.440639599	0.524868231	0.013614258	1.250992
Q2S	0.005430589	0.152111966	0.115298742	0.121046468	0.014306058	0.995347823	0.856977912	0.766479073	0.013570591	0.3801719
R1	0.003700747	0.823927462	1.118111841	0.397592589	0.014190523	6.238392943	5.232484633	2.03046963	0.009245348	2.0590106
R1S	0.001843177	0.486810362	0.757142514	0.500827745	0.006804013	3.009533453	4.416608272	2.426916535	0.004606364	1.2167629

Appendix M: Motion Capture Data

Average Joint Angles in Degrees				
	Control Mouse	Vertical Mouse	Trackball Mouse	Joystick Mouse
Finger Joint	140.358	139.3382	146.4887	107.5847
Wrist Joint	151.1984	151.2901	147.0388	144.0995
Elbow Joint	107.6477	101.8723	115.5431	104.5423

Table 1

Standard Error of Joint Angles in Degrees				
	Control Mouse	Vertical Mouse	Trackball Mouse	Joystick Mouse
Finger Joint	0.194805815	0.55004	0.813601	2.263185
Wrist Joint	0.252101643	1.312074	0.853708	1.140187
Elbow Joint	0.481284954	2.091298	1.959517	1.701686

Table 2

Average Range of Motion in Degrees				
	Control Mouse	Vertical Mouse	Trackball Mouse	Joystick Mouse
Finger Joint	39.70028	33.31752	30.15479	48.44362
Wrist Joint	27.55929	19.80144	20.39159	41.28737
Elbow Joint	21.17654	27.78275	21.5375	24.7919

Table 3

Standard Error of Range of Motion in Degrees				
	Control Mouse	Vertical Mouse	Trackball Mouse	Joystick Mouse
Finger Joint	1.191753221	2.733011	1.340722	6.663505
Wrist Joint	0.813600756	1.157376	0.933922	5.127977
Elbow Joint	0.423989127	3.099704	1.999624	1.518339

Table 4

Average Difference in Average Angle Between Ergonomic and Control Mouse in Degrees			
	Vertical Mouse	Trackball Mouse	Joystick Mouse
Finger Joint	4.090922	-2.57258	-0.49274
Wrist Joint	4.509182	-3.78725	1.50688
Elbow Joint	-33.6212	-6.35984	-2.53821

Table 5

Average Difference in Average Angle Between Ergonomic and Control Mouse in Degrees			
	Vertical Mouse	Trackball Mouse	Joystick Mouse
Finger Joint	0.360964	1.380829	1.163105
Wrist Joint	0.532851	0.446907	1.65012
Elbow Joint	2.326211	0.360964	1.266238

Table 6

Standard Error of Difference in Range of Motion Between Ergonomic and Control Mouse in Degrees			
	Vertical Mouse	Trackball Mouse	Joystick Mouse
Finger Joint	-6.05044	4.159677	4.245621
Wrist Joint	-12.7139	-13.0921	-5.48894
Elbow Joint	11.22425	14.33542	8.51989

Table 7

Standard Error of Difference in Range of Motion Between Ergonomic and Control Mouse in Degrees			
	Vertical Mouse	Trackball Mouse	Joystick Mouse
Finger Joint	5.534777	0.899544	2.956465
Wrist Joint	5.013385	4.062274	1.850655
Elbow Joint	8.078712	7.425539	1.117269

Table 8

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