Improving performance in an office environment via training the non-dominant hand on the computer mouse: A study of learning curve of the non-dominant hand and the bilateral transfer effect to the dominant hand

by

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The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this thesis. The Graduate College will ensure this thesis is globally accessible and will not permit alterations after a degree is conferred.

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DEDICATION

I dedicate this to my mom, dad, and brother for their endless love and support throughout my lifetime. Your effortless love, encouragement, and belief in me has been the backbone of my accomplishments. You have always believed in me and motivated me to follow my dreams. Thank you for being a wonderful family.

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ABSTRACT

Operating a computer mouse is a daily task in the workplace and is primarily completed with the right hand due to workstation setup, forming hand dominance. By consistently using the same hand on the mouse over many years, people can develop repetitive use injuries, such as carpal tunnel syndrome, and performance on the computer can come to a natural stagnation. This study examined training the non-dominant hand on the computer mouse, during a typical work week, to examine the effect on performance of the dominant hand due to bilateral transfer of learning. The performance and learning curve of the non-dominant hand on the computer mouse and the effect weekend breaks had on performance were also analyzed. Previous research on bilateral transfer of upper and lower extremities has demonstrated improvement to the dominant limb from training the non-dominant limb. Additionally, research has shown there is an ability to improve the performance of the non-dominant hand through training for a variety of tasks. However, current research on the effectiveness of bilateral transfer and training of the non-dominant hand does not have a practical application related to improving performance in industry, which our research addresses. Eleven right-handed computer mouse users trained their non-dominant hand for 15 minutes a day, five days per week, for six weeks. After training, significant improvements were observed in performance, based on click speed and accuracy, of both the dominant and non-dominant hand. Further, the non-dominant hand took, on average, 13.6 days to reach the dominant hand’s initial performance level with a 95% confidence interval ranging from 6.7 days to 20.4 days. Weekend breaks from training initially caused a performance decline, but the decline was significantly reduced by the end of the study. Thus, our results show that training the non-dominant hand on the computer mouse allows for improved performance for both the dominant and non-dominant hand while also providing safer, more sustainable, and more achievable work in a multitude of economies.

CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

Dominant hand preference is formed in early childhood and continually trained throughout one's lifetime. People reinforce dominant hand preference when performing tasks with the same hand by building muscle memory and becoming more accustomed and comfortable having always done tasks a certain way. Many tools and human interfaces are designed for people who are predominantly right-handed which further promotes the usage of a single hand for the majority of work functions. The formation of hand dominance, known as handedness, becomes apparent between the ages of seven and nine months when children begin reaching and grabbing objects with a single hand repeatedly (Hildreth, 1949b). Handedness truly occurs when the "motor apparatus matures and the nerve fibers that conduct the muscle are developed," which begins to become more prevalent between the ages of twelve and twenty-four months as children begin to learn how to use both hands together with one hand dominating while the other supports (Hildreth, 1949b). All tasks, such as using a computer mouse, eating, kicking, leaning, shoveling, throwing, and writing, have a preferred dominant side which is not always the same. A person may complete many tasks with their left hand while using a computer mouse in their right hand. Thus, handedness is often task specific, and tasks performed daily have a much stronger handedness formed than those done only a few times a year (Hildreth, 1949a). The dominant hand continues to be used through midlife to reduce processing time and make tasks instinctual while allowing for higher performance. If a dominant hand is not formed, the performance of otherwise simple work tasks can become confusing or feel awkward, and time is lost due to the think-time over which hand should be used (Hildreth, 1949a). As humans age into their 50s, there remains a large prevalence in hand dominance when it comes to finger and wrist speed and agility (Sebastjan, Skrzek, Ignasiak, & Sławińska, 2017). However, as age increases into the 60s and 70s, there begins to be a reduction in hand superiority as the body begins to rebalance performance with each hand (Sebastjan et al., 2017).

One motivation for our study is that injuries to the dominant hand can occur quite easily, leaving people susceptible to becoming temporarily impaired as they have not performed familiar tasks with the non-dominant hand. Outside of work, people can injure their dominant hand, for example, slipping on ice in a cold Wisconsin winter. Hand and wrist injuries occur outside of the workplace due to falls, contact with objects, or hobby accidents (De Putter et al., 2016). Basic tasks such as eating, writing, brushing teeth, or using a computer mouse initially become a struggle as people try to adapt to using the non-dominant hand. Over time, tasks begin to become more routine until the dominant hand can be used again. The non-dominant hand may not be used again unless another injury occurs. This is also true of dominant hand injuries in a work environment. Workers execute most daily work tasks with their dominant hand which can cause injury to their dominant hand due to overuse.

Further research on hand usage affirms there is an association between hand dominance and injury to the hand. A primarily right-hand dominant person is estimated to be five times more likely to get carpal tunnel syndrome in their right hand than in their left (Zambelis, Tsivgoulis, & Karandreas, 2010). People who use the computer mouse with the same hand throughout the day have significantly more symptoms of injury on the mouse side hand than the non-mouse side (Jensen et al., 1998). Another study found that in 83% of people who had a hand injury, the dominant hand was affected and an upper extremity disorder of the hand was more likely to occur to those who injured their dominant hand compared to those who injured their non-dominant hand (Kucera & Robins, 1989). Once the hand is injured, the dominant hand was shown to have significantly higher erosion, joint space narrowing, and damage progression than the non-dominant hand (Koh et al., 2015). After surgery, both hands have significantly less pain, but the rate of pain reported after surgery is higher for those with surgery in the dominant hand versus the non-dominant hand (Beaulé et al., 2000; Çivi et al., 2018).

In today's society, computers are used daily by the majority of the population and most people have a lifetime of experience performing in mouse and keyboard tasks. Workstations are setup with the mouse on the right leading to consistent use of the mouse in people's right hand, forming hand dominance. By having employees consistently use one hand on the mouse over many years, they can develop repetitive use injuries, such as carpal tunnel syndrome, tendonitis, arthritis, or other musculoskeletal injuries to the hand which can hinder their ability to work (Mani & Gerr, 2000). Carpal tunnel syndrome occurs from compression of the median nerve caused by repetitive wrist movements in extension or flexion (Armstrong & Chaffin, 1979). The prevalence of carpal tunnel injuries has been widely researched and proven to range between 3.8 and 7.8 percent of the workforce and occurs more frequently in the dominant hand (Atroshi et al., 1999; Dale et al., 2013; Silverstein et al., 2010). In a manufacturing environment, repetitive force injuries to the hand could develop from tasks such as driving screws or picking and placing parts. Blue collar, male workers, have higher incidence of carpal tunnel syndrome than all other occupations for men (Roquelaure et al., 2008). By contrast, repetitive force injuries to the hand in an office environment could develop from daily tasks such as clicking a mouse through files or using a keyboard or 10-key to type. Women performing white collar work, such as data entry or clerical positions, have the highest prevalence of carpal tunnel syndrome than all other occupations for women (Roquelaure et al., 2008). Work-related injuries lead to companies paying workers' compensation claims and finding temporary employees to fill positions while the injured recover from surgery. However, these can be costly to companies as there are

"500,000 carpal tunnel releases costing over $2 billion performed each year in the United States" (Milone, Karim, Klifto, & Capo, 2019). Companies pay a large portion of this in workers' compensation for hand and wrist injuries (Dunning et al., 2010), but there is also additional recruiting, onboarding, and training costs incurred by companies in order to fill temporary open positions. Injuries can occur in both hands in the workplace but are more prevalent in the dominant hand and can lead to large costs incurred by companies.

To reduce dominant hand injuries, an interest of this study is to examine performance related to hand dominance for computer use and assessing if the non-dominant hand can be trained to perform at a similar level to the dominant hand. If the non-dominant hand can attain the same level of efficiency as the dominant hand, this would allow for a more balanced use of both hands, thus decreasing the risk of injury related to overuse of the dominant hand. Also, if an injury does occur to either hand, in or outside of work, employees can still complete many tasks as they would be able to use their uninjured hand. In the context of an office environment and common tasks that require the use of a computer mouse, existing literature has not addressed if the level of proficiency by the dominant hand is achievable by the non-dominant hand through adequate training of the non-dominant hand. Additionally, literature does not address the learning curve of the non-dominant hand on a computer mouse and the time it takes to perform as well as the dominant hand. Learning curves are important tools for analyzing the relationship between performance and a period of training or learning a task (Jaber, 2016). Visually, learning curves traditionally have an immediate improvement as the learner becomes more familiar with the task (Jaber, 2016). However, there are natural limits people reach in their performance which is exhibited by a leveling off in the curve (Jaber, 2016). Learning curves are affected by many factors, making them very task specific (Anzanello & Fogliatto, 2011), and this study addressed the learning curve of the non-dominant hand on the computer mouse.

Research has shown there is an ability to improve the performance of the non-dominant hand for a variety of tasks. Training with chopsticks for 30 days in experienced users' non-dominant hand for 30 minutes a day resulted in significant improvement in the smoothness and speed of the non-dominant hand (Sawamura et al., 2019). Also, ten days of training the non-dominant hand in precision drawing tasks showed significant improvement in smoothness and speed of the non-dominant hand (Philip & Frey, 2016). Fifteen days of training the non-dominant hand in writing showed an improvement to the non-dominant hand that more represented the dominant hand (Sandve, Lorås, & Pedersen, 2019). Finger tapping operations showed the non-dominant hand can perform just as many taps as the dominant hand after training (Peters, 1976, 1981). When evaluating training the non-dominant arm in dexterity tasks for four weeks, three times a week, researchers found significant improvements to the dexterity of the non-dominant arm but also a significant increase in the number of times the non-dominant arm was used in reaching for objects (Dunn, 2017). Basic everyday tasks such as using chopsticks (in countries for which this is the primary utensil), drawing, writing, or hand selection when grabbing items, are hand movement skills that have been trained over a lifetime. Importantly, each of these have demonstrated improvements after training the non-dominant hand. A component of this study is to determine if non-dominant hand improvements from prior research can occur in a work application of using a computer mouse and identify the time it takes for the non-dominant hand to approach the capability of the dominant hand. If the performance parity is possible, then this allows for new research to advance systems to improve performance on the computer through further development of two-mouse systems where both hands operate simultaneously.

The primary objective for this study was to examine if training the non-dominant hand on a computer mouse can improve the performance of the dominant hand on the same task. Many companies are consistently looking at performance metrics to increase production by improving the efficiency of their employee’s workflow. Regarding tasks that are completed on a computer, this may entail reducing the number of entries needed or rearranging the position of icons to help reduce time spent on the computer. Eventually, the changes to the user interface and number of entries cannot be reduced and companies must accept the performance. However, current literature does not address if performance is limited due to failure to train our non-dominant hand and if performance of the dominant hand can increase via training the non-dominant hand. Bilateral transfer is the phenomenon where training one side of the body can lead to improvements to the other side of the body (Norcross, 1921). Bilateral transfer of learning has occurred in both training the dominant side and training the non-dominant side of the body. For example, training the dominant hand for rapid finger movement improved the performance to the untrained non-dominant hand (Lee, Hinder, Gandevia, & Carroll, 2010). Additionally, research has shown a short period of training the dominant hand resulted in modifications in how the brain was activated when completing the same task with the non-dominant hand (Uggetti et al., 2016). However, bilateral transfer from training the non-dominant side of the body was the interest of this study as this has more practical application.

Bilateral transfer of learning has been observed in a variety of applications with upper and lower extremities from training the non-dominant limbs. Soccer players who trained only their non-dominant leg for eight weeks performed significantly better than those who trained normally in a variety of soccer tasks with both their non-dominant and dominant leg (Haaland & Hoff, 2003). Long jump athletes who trained their non-dominant leg for twelve weeks, two days a week, for 1.5 hours a day, saw a significant increase in jumping performance than those who only trained their dominant leg (Focke, Spancken, Stockinger, Thürer, & Stein, 2016). Additionally, fencers who trained the non-dominant hand for six weeks, five days a week, for 30 minutes a day, showed improved performance with the dominant hand beyond participants who only trained their dominant hand (Witkowski et al., 2018). Experienced golfers who trained their non-dominant arm and core for eight weeks, three days a week, for an hour a day, saw an improvement of approximately 9.8% in their drive distance over those who did not have specialized training, and improved drive distance by approximately 4.8% than those who only trained their core (Sung, Park, Kim, Kwon, & Lim, 2016). Further, outside of sports applications, studies have shown bilateral transfer occurred in the hand when training different aiming, steadiness, and finger tapping exercises with the non-dominant hand, as there was a significant decrease in time for both the trained and untrained hand (Grothe et al., 2017). Current research on the effectiveness of bilateral transfer of learning does not have a practical application related to improving performance in industry, which our research addresses. We hypothesize people can train with a computer mouse in their non-dominant hand and see an improvement in performance with their dominant hand because of the bilateral transfer of learning. Training the non-dominant hand could help to remove the natural stagnation people develop in their computer performance.

CHAPTER 2: METHODOLOGY

Objective:

The purpose of this study is to examine if computer mouse clicking performance can be improved in the dominant hand by training, during a typical work week, the non-dominant hand, via bilateral transfer. The study also examines the learning curve of the non-dominant hand on the mouse, and if performance decline from idle weekends are reduced as the non-dominant hand becomes more comfortable with the computer mouse.

Hypotheses:

1. The dominant hand performance on a computer mouse for clicking tasks will improve by training the non-dominant hand for 15 minutes a day, five days per week, for six weeks.
2. The non-dominant hand will perform as well as the dominant hand originally did in clicking tasks after training the non-dominant hand for 15 minutes a day, five days per week, for six weeks.
3. After weekend breaks, the participants will initially have a decline in performance since they did not train for two days, and the task is unfamiliar to their non-dominant hand. The decline in performance will be reduced or eliminated after training the non-dominant hand for 15 minutes a day, five days per week, for six weeks.

Participants:

Eleven healthy right-handed computer mouse users (four males and seven females) completed the study. The age range was 20-58 years with an average age of 36.7 years. Although three participants ate, wrote, and threw with their left hand, all used the computer mouse with their right hand. The Iowa State Institutional Review Board (IRB) approved the study as exempt, IRB 19-492, and details are in Appendix A.

Experimental Procedure:

Prior to beginning the study, participants were read a description of the study and informed that participation was voluntary, and that they had the right to not participate or to leave the study at any time. Demographic characteristics were collected to gain information about the participants including which hand they regularly use to complete tasks and how often. Next, participants completed the Minnesota Dexterity Placing and Turning test three times with their dominant hand and three times with their non-dominant hand to record baseline dexterity prior to completing tasks for the study.

Following the dexterity tests, participants played a mouse clicking game which can be found at http://www.roomrecess.com/mobile/ClickSpeed/play.html. Playing the game five times equates to approximately 15 minutes which coincides with the training time in our hypotheses. The game is suitable for the study because it includes a variety of clicking motions people often employ when completing tasks on the computer in industry settings. Additionally, this game was selected because of its competitive scoring providing a more natural incentive for participants to consistently do well; the higher the score, the better the player performed. The scoring in the game is based on the accuracy of clicking the center of the target and speed at which the participants click. There is a total of 119 targets in the game. The point value for clicking the center of the targets varies between 10 and 30 points. If the centers are not clicked, participants received one, three, or, five points depending on how close to the center they were. Additionally, half the levels in the game have bonus points which begin at 100 points and drop by approximately nine points per second. The last level is the most unique and has 48 targets. The bonus points begin at 1,000 points and drop by approximately nine points per second. The bonus points encourage participants to click fast, and the added points for clicking the center of the target encourage accuracy. A more detailed description of the game levels is in Appendix B.

Participants played the game five times with their dominant hand, and the score they received was recorded after each game. These scores serve as a baseline performance measure for each participant's dominant hand. The primary mouse key was then changed from left to right. Changing the primary key adjusted the mouse to mirror how the dominant hand uses the mouse with the index finger clicking and the middle finger resting on the secondary key. This allowed for bilateral transfer effect to be analyzed as the hands performed the same task with the same motions. The game was played five times with the non-dominant hand, and the score they received was recorded after each game to identify a baseline performance for each participant's non-dominant hand.

The participants played the game five times each day for the next four days (for a total of five days in week 1) with their non-dominant hand. They took two days off to simulate a weekend, as seen in most working environments. For the next five weeks (a total of six weeks), participants played five times for five straight days and took two days off. Due to participants' changing schedules, a few days were missed by all participants. However, this did not negatively affect the statistical analysis and reliability of the results as every participant played at least three days in each week and analysis was performed based on number of days of training, not on the specific days trained. All participant training lasted six weeks, but the number of days each participant played the game five times varied. Six participants completed 29 out of 30 days, two completed 28 out of 30, and one completed 26, 25, and 23 out of 30 days. On the final day, participants played five times with their dominant hand to determine if their performance had improved, despite not playing the game with that hand since the first day. The participants then completed the Minnesota Dexterity Placing and Turning test three times with their dominant hand and three times with their non-dominant hand to assess post-dexterity after completing the study tasks.

We consider the following variables in the study.

Independent Variables:

- Which hand was being trained by participants
    - Non-dominant hand
- Duration the hand is trained, measured in days
    - Six-week training period
- Number of days away from training between week cycles
    - Two days off to simulate a weekend in most working environments

Dependent Variables:

- Performance
    - Score of dominant hand based on the participants speed and accuracy
        - Ranging between 0 and 3,500
    - Score of non-dominant hand based on the participants speed and accuracy
        - Ranging between 0 and 3,500

Statistical Analysis:

Statistical analyses were computed using R Version 3.6.1 (Team, 2019). Over the course of six weeks, each participant performed the experiment five times a day for five consecutive days, before taking a two-day break. This resulted in six blocks of five measurements each, for the ideal participant. Due to participants' changing schedules, a few days were missed by each participant as discussed in the experimental procedure. The five score measurements within each day were averaged for each individual, yielding overall five means collected for each week for each participant. An example participant week is shown in *Figure 1*.

Day	Week	Score 1	Score 2	Score 3	Score 4	Score 5	Average
1	Week 1	1,733	2,256	2,268	2,367	2,337	2,192
2		2,654	2,595	2,660	2,713	2,722	2,669
3		2,692	2,612	2,681	2,869	2,666	2,704
4		2,780	2,765	2,807	2,928	2,953	2,847
5		2,795	2,838	2,843	2,836	2,865	2,835

Figure 1: Typical week for each participant. Five days, with five scores each day, which were then averaged for analysis

To answer the hypotheses of interest in this study, we use the data in three distinct ways. For hypotheses one and two, we analyze the difference in the average score received from the beginning to the end of the study by calculating the difference between pre- and post-test score average for each of the eleven participants. These differences were averaged across all participants to test if the mean difference is greater than zero, implying all participants improved, on average, over the six-week period. A matched pairs t-test was used to analyze the mean difference, but because of the small sample size (n=11), and potential lack of normality of the data, a Wilcoxon Rank Sum Test was also performed as a follow-up. In all cases, the conclusion from the Wilcoxon Rank Sum Test was the same as from the t-test, namely, to reject the null hypothesis. Although not identical, p-values from each test were of similar magnitude. To calculate the number of days for the non-dominant hand to achieve performance of the dominant hand initial (hypothesis two), the number of days for all participants were averaged and a 95% confidence interval was constructed. To test the performance decline from the weekend (hypothesis three), the one-sample sign-test was used to assess how consistent the first weekend to the last weekend differences were. Specifically, we looked at the score decline magnitude after weekend one and weekend five to see if the weekend five decline was of smaller magnitude. The one-sample sign test was done in R Version 3.6.1 (Team, 2019) using the *DescTools* package (Signorell et al., 2016).

CHAPTER 3: RESULTS

Bilateral Transfer Effect:

The first hypothesis to be tested states that, on average, performance of the dominant hand on clicking tasks using a computer mouse will improve by training the non-dominant hand for 15 minutes a day, five days per week, for six weeks, because of bilateral transfer of learning.

The average pre- and post-test scores for the dominant hand and non-dominant hand are displayed in *Figure 2*. The performance improvement from pre- to post-test for the dominant hand, a goal that was not emphasized during the six-weeks of training, increased from (mean score ± standard deviation) 2,617 ± 344.3 to 2,962 ± 146.5, corresponding to a 13% performance improvement on average. The non-dominant hand increased from 2,182 ± 405 to 2,857 ± 148, corresponding to a 31% improvement on average. Observing the improvement by individual participants, we saw the largest improvement to the dominant hand was 833 points (41.8%) for one participant. This participant rarely uses a mouse as they use a trackpad when working on a computer. The smallest improvement to the dominant hand was 8.2 points (.3%) for a participant who plays video games with the computer mouse routinely and who had an average baseline score of 3,061. The highest possible score a participant could earn in the game is 3,500, so there was less opportunity to improve for this particular participant.

For both the dominant and non-dominant hand, a matched-pairs t-test on the mean difference of post – pre for all participants was performed. The t-test for the dominant hand illustrates that the post-test mean score is significantly higher ($t_{(df=10)} = 4.96$, $p = 0.0003$) than that of the pre-test with an observed increase of (mean score ± standard deviation) 345 ± 230.6. The t-test for non-dominant hand also showed a significant improvement from pre- to post-test ($t_{(df=10)} = 7.07$, $p<.0001$) with an observed increase of 675 ± 316.4.

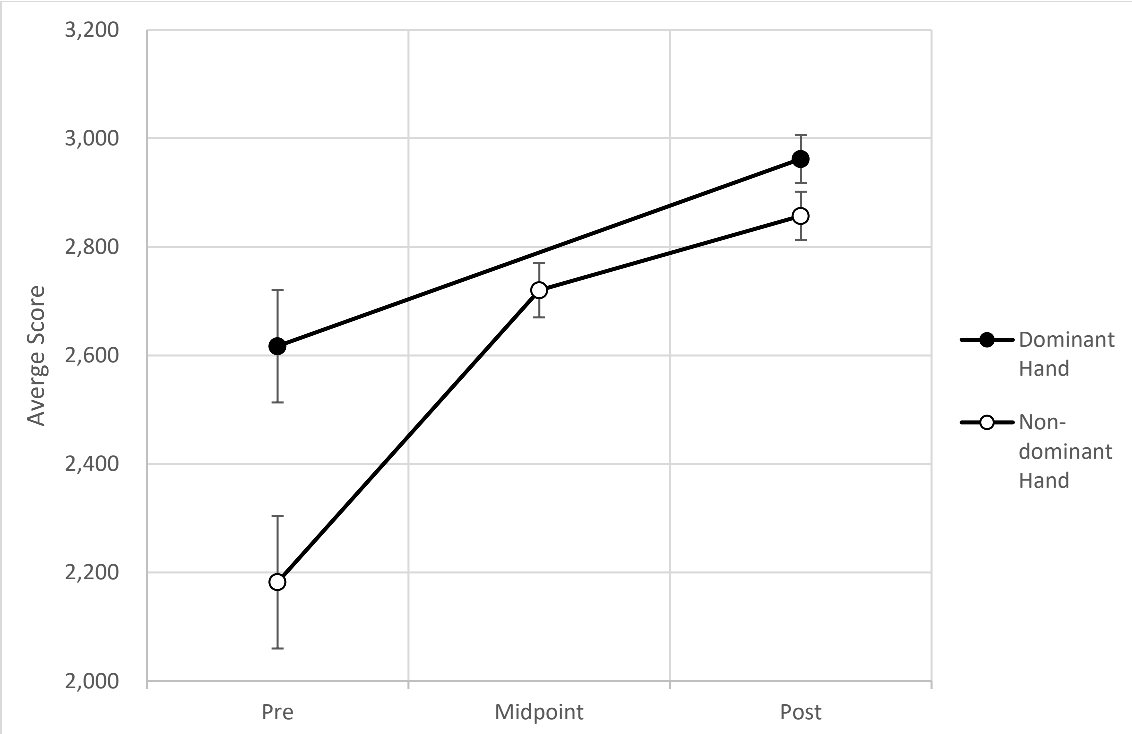

Figure 2: Mean values and standard error for scores received with the dominant and non-dominant hand

The average median improvement was also analyzed to provide insight on possible influence of extreme values as these are known to distort the value of the mean. In addition, medians provide a better understanding about how individual participants behave as opposed to the average of the entire group. In this analysis, the mean score of each participants' pre and post score was replaced by the median score. These median scores were then averaged over all participants to allow for the continued use of the matched pairs t-test. The dominant hand median scores, on average, increased from (mean score ± standard deviation) 2,645 ± 335.5 to 2,963 ± 144.1 and the non-dominant hand median scores, on average, increased from 2,203 ± 403 to 2,861 ± 142.5. Median and mean analysis were performed for the bilateral transfer effect. The observed similarity in the results suggests that the data are not severely skewed and that the mean is representative of the data as all observed median values were within 1.1% of the observed mean values.

Non-dominant Hand Learning Curve:

The second hypothesis to be tested states that, on average, performance of the non-dominant hand will perform as well as the dominant hand originally did in clicking tasks after training the non-dominant hand for 15 minutes a day, five days per week, for six-weeks.

The resulting learning curve of the non-dominant hand is illustrated in *Figure 3*. The fitted curve relatively follows a traditional learning curve and shows continued growth throughout, before flattening at the end of the six weeks. The R^2 value, as a goodness of fit measure of the fitted curve to the natural log curve, is 97.2%, corresponding to the amount of variability observed in the average score that can be explained by the fitted model. All participants' performance with their non-dominant hand improved, while 91% of the participants exceeded their initial dominant hand scores. The only participant for whom this was not the case was the participant who plays video games with the computer mouse regularly and started out with a high score as their baseline value. Additionally, a 95% confidence interval was constructed to estimate the average number of days it took for the non-dominant hand to reach the dominant hand's initial performance level. The confidence interval ranged from a lower bound of 6.7 days to an upper bound of 20.4 days (mean ± margin of error; 13.55 ± 6.82).

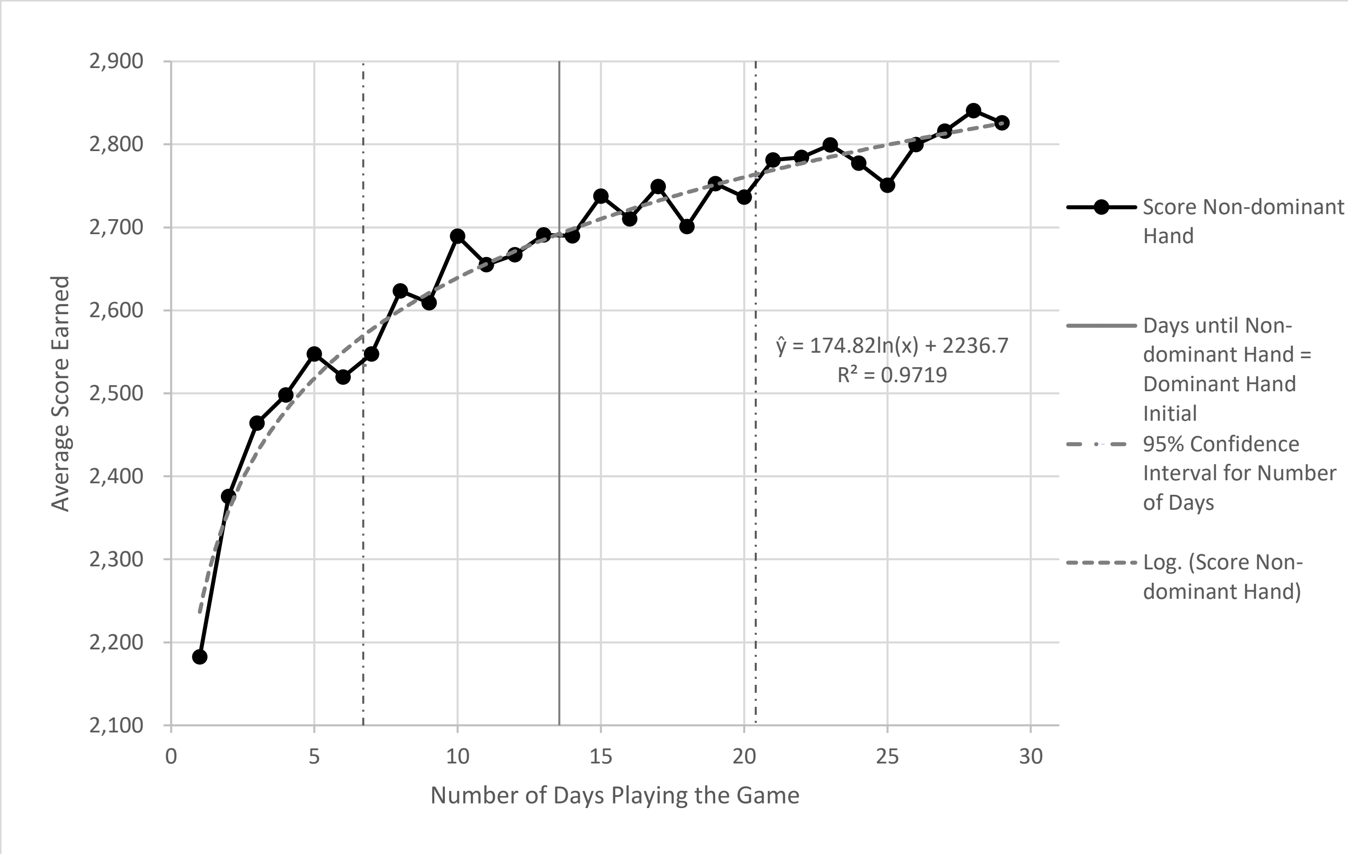

Figure 3: Learning curve of the non-dominant hand to complete computer clicking tasks

The demographics data were analyzed to determine how often the mouse was used by each participant. Six of the participants use the mouse daily, and five of the participants use the mouse weekly. Weekly users tend to use laptops with trackpads rather than a mouse. Those who use the mouse daily took an average of 19.8 days for their non-dominant hand to reach and stay above the performance of their dominant hand. In contrast, those who used the mouse less frequently, took an average 6.0 days for their non-dominant hand to reach and stay above the performance of their dominant hand. An approximate 95% confidence interval for those who use the mouse daily ranged from a lower bound of 10.3 days to an upper bound of 29.4 days (mean ± margin of error; 19.83 ± 9.58). An approximate 95% confidence interval for those who use the mouse less frequently ranged from a lower bound of .05 days to an upper bound of 12.0 days (mean ± margin of error; 6.00 ± 5.95).

Weekend Performance Decline:

The third and final hypothesis to be tested states that weekends not using the mouse with the non-dominant hand will initially cause a decline in performance because of the task being unfamiliar, but this decline will be reduced or eliminated by the end of the study after training the non-dominant hand for 15 minutes a day, five days per week, for six weeks.

The results from the pre- and post-weekend performance decline for the non-dominant hand is shown in *Figure 4*. The data highlight that 82% of the participants scored lower on the second Monday than they had on the first Friday of the study (mean point decline ± standard deviation; 60.62 ± 57.88). After the final weekend, 55% of the participants, who initially had a decline in performance, still had a decline in performance from the second last Friday to the final Monday. However, the decline was less than the initial weekend for 89% of the participants (mean point decline ± standard deviation; 12.47 ± 5.12). The hypothesis only considers if there was a reduction in decline consistently for all participants rather than accounting for the actual magnitude of the decline. To assess this consistency, a one sample sign test was used which found that the performance decline was significantly reduced by the end of the study ($p = .01953$).

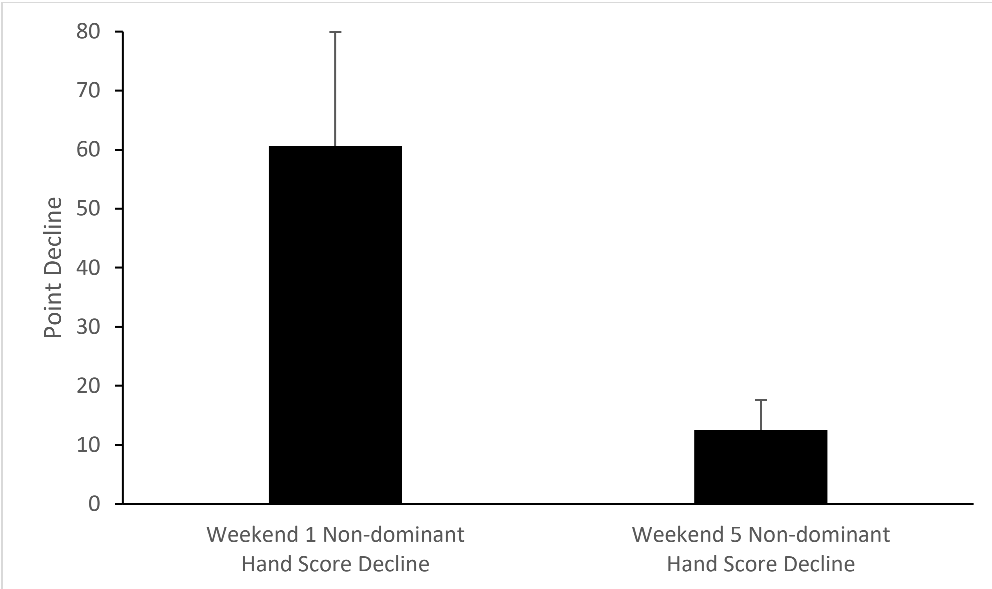

Figure 4: Mean values and standard error for non-dominant hand performance decline after first and last weekend.

CHAPTER 4: DISCUSSION

The results from six weeks of training the non-dominant hand suggest a significant improvement in the click speed and accuracy of both the dominant and non-dominant hand as represented by the improved scores from the pre- to the post-test. These results strongly suggest that tasks being completed in an office environment, such as clicking tasks completed with a computer mouse, can experience improved performance in the dominant hand through the training of the non-dominant hand. This indicates bilateral transfer of learning exists when training from the unused hand to the traditionally used hand for computer mouse clicking operations. Coombs and Frazer support that bilateral transfer of learning has the largest performance improvement when training the non-dominant hand for the dominant hand's benefit (Coombs et al., 2016). As discussed in the introduction, previous research has shown bilateral transfer has been seen in a variety of applications (Focke et al., 2016; Grothe et al., 2017; Haaland & Hoff, 2003; Sung et al., 2016; Witkowski et al., 2018). This study differs as it specifically addresses how bilateral transfer of training the non-dominant hand can be used to improve an industry application of the computer mouse in the dominant hand. With the dominant hand improving for participants by 13% on average, this equates to the participant getting the same amount of work done in 62 minutes less than they had prior to training the non-dominant hand for a typical eight-hour workday. Most people's days are broken up by meetings, breaks, and unanticipated distractions (Rogelberg, Shanock, & Scott, 2012). While saving an hour per person is not likely because of these consistent breaks in the day, the potential to improve performance and save time each day is achievable based on the results of this study. These results suggest that training the non-dominant hand may allow companies to accomplish more work via their current employees. Prepared with bilateral transfer training, employees may work more efficiently and avoid repetitive stress injuries, mitigating the need to hire more people.

Using a computer mouse to click objects involves many minute movements and motor control skills of the hand and wrist to control the pointers placement (Dennerlein & Yang, 2001), which has been extensively trained and refined by the dominant hand throughout peoples' lifetime. This study explored the impact on performance of training on a computer mouse with the non-dominant hand for 15 minutes a day, five days per week, for six weeks. Our results suggest that even a complex task that has been widely trained over many years with the dominant hand can be improved in the non-dominant hand – reaching or even exceeding the initial dominant hand performance – through training. Delisle, Imbeau, Santos, Plamondon, and Montpetit found similar results in the non-dominant hand's performance while studying the impact of the mouse on a person's upper extremity posture (Delisle, Imbeau, Santos, Plamondon, & Montpetit, 2004). Our findings were consistent with their post-study which identified the performance of the non-dominant hand improved to the initial performance of the dominant hand for the majority of their participants (Delisle et al., 2004). Our study developed a learning curve for operating a computer mouse with the non-dominant hand. The learning curve developed in our study for the non-dominant hand to perform and remain above the initial performance of the dominant had a 95% confidence interval that ranged from 6.7 to 20.4 days for all participants. Rounding the upper end of this range to the next day, 21 days, for 15 minutes a day, equates to 5.25 hours of total training. Considering the grand scheme of an average of 2,000 hours of work in a year, 5.25 hours is a short period of time training to increase the performance of the traditionally used hand.

By examining how the participants' mouse experience affected the learning of the non-dominant hand, we found that less experienced users (minimal use in a week) were able to learn, on average, fourteen days faster with their non-dominant hand than the experienced users (daily use). There was a substantial difference, as the experienced users took, on average, 19.8 days for their non-dominant hand to reach and stay above the performance of their dominant hand. In contrast, the less experienced users only took, on average, 6.0 days. However, when looking at the participants' initial scores with their dominant hand, this difference is no longer surprising. Participants who use the mouse less frequently did not score as well initially with their dominant hand. This accurately represents slower and less accurate clicking performance for less experienced participants. Referring to the learning curve from this study, in *Figure 3* of the results, the scores rapidly increased in the first ten days before beginning to gradually level off. For the less experienced users, the non-dominant hand quickly adapted and performed better than the dominant hand. Participants who used the mouse daily originally scored, on average, 16% higher with their dominant hand than the weekly mouse users. Therefore, for the daily mouse users, it took longer for the performance of the non-dominant hand to achieve those same scores. Baher and Westerman found that in specific Photoshop tasks, expert users took longer to complete tasks than novice users because rather than using the parts built into the interface to make their work faster, they used more familiar approaches which took longer (Baher & Westerman, 2009). The experienced users of the mouse may have more familiar mouse patterns which involve more refined, minute movements that their non-dominant hand takes additional time to learn. Also, learners may have, or develop, a negative outlook and resist attempting to learn difficult tasks where the benefit is not immediately clear (Furnham, 2004). In discussing our research with others, a common reaction is, they could not imagine learning to use the mouse with their non-dominant hand. This is an attitude that may be greater in those who use the mouse daily which may also make the learning more difficult.

The results from the pre- and post-weekend performance decline reinforce the non-dominant hand improvement. Research has identified that industry performance is effected by employee's weekend activities but currently does not address employees experience with the job or task as a factor for the impact (Fritz & Sonnentag, 2005; Van Veldhoven, 2008). Our results imply user familiarity with tasks are affected by weekend breaks. When participants initially took weekends off, their performance regressed because the task was still unfamiliar. This is important to note, as weekend breaks are important to enhance employees' well-being (Ryan, Bernstein, & Brown, 2010), but our research shows it does initially affect the training of the non-dominant hand. By the end of the study, however, the participants' performance declined significantly less, suggesting the task has become more familiar and routine.

The use of a computer mouse in one hand for extended periods of time can put people at risk of cumulative trauma disorders such as carpal tunnel syndrome. Since the use of a mouse requires the wrist to be in extension for long periods of time performing multidimensional movements, this causes carpal tunnel pressure to increase (Keir, Bach, & Rempel, 1999). However, research has shown when the mouse was in the non-dominant hand, the wrist extension was reduced in the non-dominant hand (Delisle et al., 2004). Successful training of the nondominant hand could lead to a reduction of carpal tunnel syndrome and other repetitive force injuries that are currently seen in the dominant hand from overuse. Another way carpal tunnel syndrome and other repetitive force injuries could be reduced is by breaking up the hand the mouse is used with throughout the day. Research has shown that rest is an easy way to prevent fatigue (Callegari, de Resende, & da Silva Filho, 2018; Halim, Omar, Saman, & Othman, 2012).

Using the non-dominant hand to complete computer mouse operations will allow for workers to switch hands during the day to reduce load and give the hands and wrists time for rest and repair. Rather than frequent breaks to prevent fatigue (Fritz, Ellis, Demsky, Lin, & Guros, 2013), in which there is no production from the employee, companies can alternatively rest the dominant hand while continuing to work with the non-dominant hand. Also, rotating the hand use is similar to a job rotation program in the sense that it changes the posture the workers are in for long periods of time. Worker rotation programs have been an effective industry practice for many years and have been proven to prevent ergonomic injuries as they reduce static postures being assumed by employees for long periods of time (Otto & Scholl, 2013). Implementing hand rotation based on this successful practice, which is often used in manufacturing or service settings, may reduce the risk of injury in office environments.

The results of this study suggest training programs should be incorporated in industry for employees' non-dominant hand to improve performance while reducing risk of injury to the dominant hand. Recent bilateral transfer studies show having people visualize themselves completing tasks fosters a bilateral transfer effect, but that physically performing the task is more effective in increasing performance (Land et al., 2016). When implementing a system to train the non-dominant hand to improve the dominant hand, employees should first be informed of the benefits of reducing injury and improving performance to give them incentive to adhere to the training. Based on our results, a training program should begin with a game to naturally motivate the employees in conjunction with the verbal benefits. The training could be performed each day until the employees are comfortable with the mouse in the non-dominant hand. At the conclusion of the training of the non-dominant hand, employers should have consistent enforcement, reminders, and metrics to ensure employees continue to use the non-dominant hand and rest the dominant hand during the day. This is a systematic approach that helps show why the change is important, initiates a process to the change, and creates rules to keep the system in place, drastically improving the probability the change will be successful (Lightbody & Weber, 2016; Strebel, 1996).

Some may argue the clicking game is not representative of work and cannot represent an industry task. However, many tasks in the work environment involve clicking with a computer mouse, as a study found the average computer user clicks 7,400 times each week while working on the computer for an average of 12.4 hours a week (Kevin Taylor, 2007). This averages to 9.95 clicks/minute equating to just over a click every six seconds while working on the computer in the workplace (Kevin Taylor, 2007). Whether it be opening software, changing cells in Excel, switching tabs, or closing browsers, clicking is one of the most common computer tasks. The game aspect was used for participants to have natural motivation to perform better and limit variability of the participant’s motivation to improve (Burguillo, 2010). The game is representative of the same sensory motor applications people would use in their job, making it an appropriate tool to judge performance of industry tasks.

Since the non-dominant hand demonstrates potential to improve with training and can improve the dominant hand, improvements to systems can be realized by incorporating the use of both hands. There are a variety of ways clicking tasks can be completed on the computer such as a mouse, trackpad, and trackball, and research shows that each type of input device has different learning for the dominant and non-dominant hand (Kabbash, MacKenzie, & Buxton, 1993). For tasks where two hands are used, people often assume the dominant hand should perform the main operation while the non-dominant hand supports. However, research has shown this is not the case for every job, and our non-dominant hand should be considered for completion of more tasks (Durand-Bailloud et al., 2017). Kabbash, MacKenzie, and Buxton identified that each hand has an advantage for mouse tasks, the dominant hand for width movements and the non-dominant hand for amplitude movements (Kabbash et al., 1993). If each hand could be utilized at the same time, performance could be increased. Buxton and Meyers also found that we can improve human performance through the use of two hands even if the one hand is not trained (Buxton & Myers, 1986). However, Balakrishnan and Patel found when an untrained, non-dominant hand had to make multiple movements in a two-handed system, there was an increase in time and errors (Balakrishnan & Patel, 1998). They identified the non-dominant hand is best utilized in a two-handed system if it only moves in one direction (Balakrishnan & Patel, 1998). If we train the non-dominant hand to the level of the dominant hand, as done in our study, we could give this hand more capability. This improved capability could lead to a reduction in time and errors made in a two-handed system, making it a viable way to improve human performance across a variety of industries.

CHAPTER 5: CONCLUSION

This study explored the effects on clicking performance (based on speed and accuracy) of the dominant and non-dominant hand from training the computer mouse in the non-dominant hand. Computer mouse use is a daily operation in the workplace and requires minute hand and wrist movements developed and refined through practice and training for many years. Our study showed the dominant hand can improve performance with the computer mouse by training the non-dominant hand because of the bilateral transfer effect of training. Additionally, our study showed that after training, the non-dominant hand is capable of learning the complex movements that our dominant hand has trained for many years. There is evidence that participants' mouse use frequency effects the training time needed to become familiar with the mouse in their non-dominant hand. Specifically, more familiar mouse users took longer for their non-dominant hand to achieve the same performance as their dominant hand than those who used the mouse less frequently. Also, when initially training the mouse in the non-dominant hand, there is a decline in performance after weekend breaks because participants did not train for two days and the task is less familiar in their non-dominant hand. However, this decline in performance is reduced or eliminated after training the non-dominant hand as the participants become more familiar with the task in that hand. Overall, training the non-dominant hand on the computer mouse will allow for improved performance while allowing for safer, sustainable, and more achievable work in a multitude of economies.

CHAPTER 6: LIMITATIONS

Due to the length of the study, voluntary participation was difficult to find, leaving our study with a smaller sample size than originally planned. However, because the results from the non-parametric statistical tests were of the same magnitude as the parametric tests, we were confident in using all the parametric analysis techniques. Also, because of participants' changing schedules, a few days were missed by the participants. However, these few days missed were deemed not statistically deteriorating as every participant played at least three days in each week and analysis was performed based on number of days of training, not on the specific days trained. Thirdly, we evaluated the scores collected, which were based on the clicking accuracy and speed of the user completing the task. However, we cannot evaluate individually if accuracy, speed, or both improved more significantly.

Some may argue that the increased scores by the dominant hand could be from the participants developing better strategies for performing the task. However, the game has very little strategy that can be employed because in order to get a high score, the participant must go as fast as they can while clicking the centers. If they take the strategy to click the centers, they don't get a good score, and same if they go for speed. The participants need to get both in order to improve. Additionally, four of the levels the targets show up in random spots on the screen so for those levels, a strategy cannot be formed. The levels where the targets are worth the most points, the targets must be clicked before they leave the screen, so those levels are also solely performance based. The only level where a strategy could be used in the game is on the last level where there is a 6x8 grid of targets. How a participant goes about clicking the targets in that grid does affect the speed, which affects the points. If the participants didn't go from top to bottom, left to right, or vice versa originally, then this would be a strategy that could be developed.

However, within the first five attempts on the first day, all participants were clicking using one of those patterns, meaning they had already formed their strategy within this first day. Due to the game having no strategy, we feel our results prove bilateral transfer, but for future studies on bilateral transfer, the game should be played with the dominant hand until the scores level off on the first day to affirm the results. This would prove the dominant hand already has a strategy and the improvements were solely from bilateral transfer.

Lastly, all tasks performed in the game were clicking, but there are other types of computer tasks, such as dragging and placing, that add more complexity and minute movements with the hand which could take longer to train. Therefore, we can only comment on the application of clicking tasks with the computer mouse. In future studies, these limitations should be considered.

CHAPTER 7: FURTHER RESEARCH

Existing research has shown handedness is easier to control when training people when they are young (Hildreth, 1949b). Future research is needed to examine if the learning curve changes when training the mouse in both hands happens at a young age. More research is also needed to examine if training both hands from a young age helps prevent injury while improving human performance. Research is needed to identify if dragging, placing, and other mouse movements with the non-dominant hand influence the learning curve. A non-dominant hand training program should be implemented across a variety of industries to understand if the impacts on performance and injury reduction are stronger in some industries than others. Additionally, findings from our post-weekend performance suggest there is a decline in performance after weekends in unfamiliar tasks. Research should be conducted in industry training and education to investigate performance after weekend breaks. Analysis should be conducted on how to mitigate performance decline while still allowing time away from work or school. Lastly, utilizing two-handed systems with both hands trained could allow for improved performance in industry. Sufficient breaks would have to be given to ensure there is reduced load on the hands and wrists, so injuries are not caused from using both hands. Further research should be conducted to balance using both hands to improve performance while preventing repetitive use injuries to the hands.

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APPENDIX A: IRB APPROVAL

Study 19-492-00 (IRB) | **Help Drew's Set**

Study

Study:	**19-492**	**Sponsor(s):**	
Committee:	IRB #1	**Sponsor Id:**	
Category:		**Grants:**	
Department:	Industrial and Manufacturing Systems Engineering		
Agent Types:	SBER	**CRO:**	
Title:	Learning Curve of Bilateral Transfer - Month Long Study	**Year:**	2019
2018 Common Rule Date:	10/21/2019	**HIPAA:**	No
Exempt Categories:	2018 - 2 (i): Research that only includes interactions involving educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording) when the information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects., 2018 - 3 (i.A): Research involving benign behavioral interventions in conjunction with the collection of information from an adult subject through verbal or written responses or audiovisual recording when the subject prospectively agrees to the intervention and information collection and the information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects. - 3 (ii) If research involves deception, it is prospectively authorized by the subject.	**FDA Study:**	No
Comments:	The purpose of the study is to understand the learning curve of bilateral transfer in an office environment, or in simple terms, how long it takes f (hover for more...)		

Study-Site

Site(s):	**00 - Unspecified**	**PI:**	**Stone, Richard T**
Status:	Active	**Additional:**	N
Approval:	October 21, 2019	**Expiration:**	**Exempt**
Initial Approval:	October 21, 2019	**Other Expirations:**	Exempt Determination Expiration - 10/19/2022
Tags:	Exempt		
Comments:			

Study-Site Contacts (1)

Name	Role
Schweiger, Drew	Research Staff

APPENDIX B: DETAILED EXPLANATION OF THE CLICKING GAME

Part 1:

To start the game, the participant sees a single target appear in the middle of the screen (see *Figure B1*). The participant receives 10 points if they click the center of the target, 3 points if they click the inner white or inner red ring, and 1 point if they click the two outer rings. The center value depends on the part of the game as some are worth 10, 20, or 30 points. The center point values will be described in each part of the Appendix. The 3-point portion and 1-point portion of the target is the same for all targets throughout the entire game so they will not be explained further in the later parts.

Figure B1: Part 1 of the Clicking Game

Part 2:

3 targets appear and clicking the center is worth 10 points for each target. The targets are evenly spaced across the middle of the screen (see *Figure B2*). Additionally, there are bonus points on this level. There are bonus points that begin at 100 and drop by approximately nine points per second. This encourages speed to earn a higher score value. For every level there are bonus points, the bonus score is added to the value they received for clicking the target. The score for each level is then added to the total score.

Figure B2: Part 2 of the Clicking Game

Part 3:

10 targets appear and clicking the center is worth 10 points for each target. The targets are evenly spaced across two rows on the middle of the screen (see *Figure B3*). There are bonus points that begin at 100 and drop by approximately nine points per second.

Figure B3: Part 3 of the Clicking Game

Part 4:

1 target appears and clicking the center is worth 20 points. The target begins in the center and moves from left to right (see *Figure B4*).

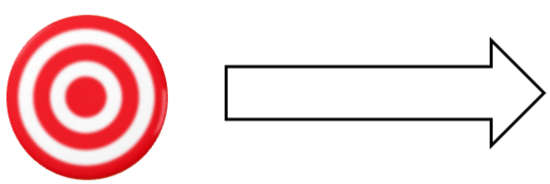

Figure B4: Part 4 of the Clicking Game

Part 5:

3 targets appear and clicking the center is worth 20 points for each target. The targets begin in the center and the first and third target move from left to right and the second target moves from right to left (see *Figure B5)*.

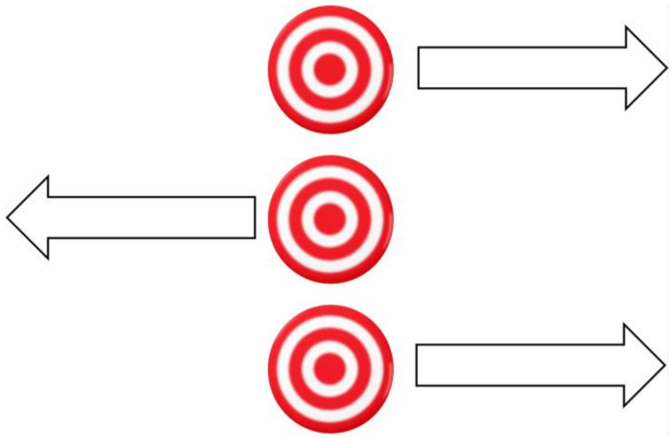

Figure B5: Part 5 of the Clicking Game

Part 6:

This part is the same as part 5 of the game but has the bonus points added. 3 targets appear and the center is worth 20 points for each target. The targets begin in the center and the first and third target move from left to right and the second target moves from right to left (see *Figure B6*). The bonus points begin at 100 and drop by approximately nine points per second.

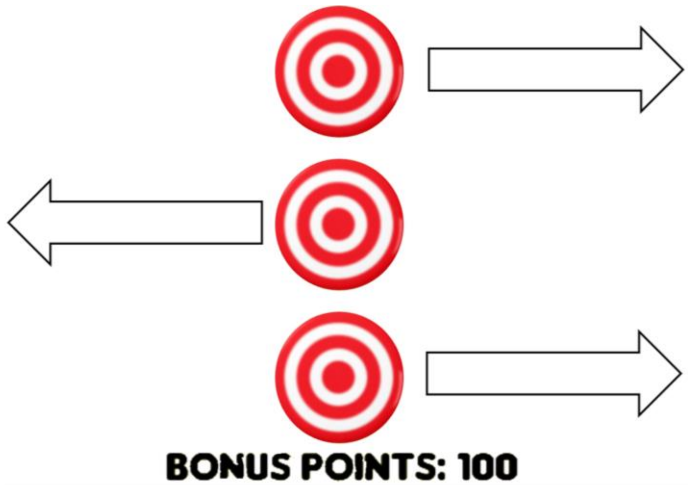

Figure B6: Part 6 of the Clicking Game

Part 7:

4 targets appear and clicking the center is worth 20 points for each target. The targets appear in each of the four corners of the screen (see *Figure B7*). There are bonus points that begin at 100 and drop by approximately nine points per second.

Figure B7: Part 7 of the Clicking Game

Part 8:

3 targets appear and clicking the center is worth 20 points for each target. The targets begin in the center of the screen and drop towards the bottom of the screen (see *Figure B8*). The targets must be clicked before they reach the bottom of the screen or the game restarts and the scores are not submitted.

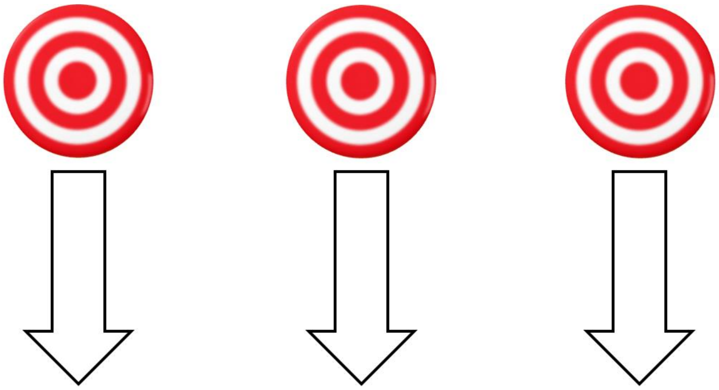

Figure B8: Part 8 of the Clicking Game

Part 9:

7 targets appear and clicking the center is worth 30 points for each target. The targets begin in the center of the screen and drop towards the bottom of the screen (see *Figure B9*). The targets must be clicked before they reach the bottom of the screen or the game restarts and the scores are not submitted.

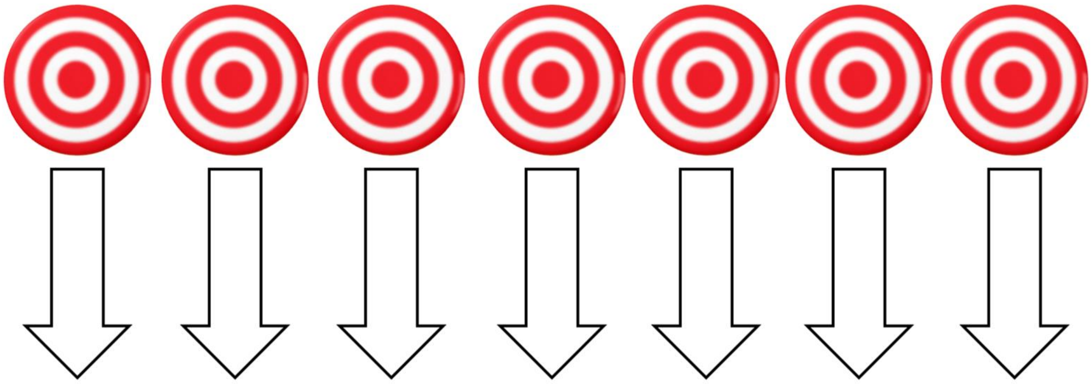

Figure B9: Part 9 of the Clicking Game

Part 10:

1 target appears and clicking the center is worth 30 points. The target begins in the center of the screen and gradually starts to disappear. If the target is not clicked it reappears in a different location (see *Figure B10*).

Figure B10: Part 10 of the Clicking Game

Part 11:

10 targets appear and clicking the center is worth 30 points for each target. The targets appear in a variety of transparencies and the participant is required to click them all before they disappear. If they do not click the targets before they disappear, the targets come back in a different location (see *Figure B11*).

Figure B11: Part 11 of the Clicking Game

Part 12:

The targets appear 1 at a time in a random location on the screen. Once a target is clicked the target disappears and the next target appears in a random location (see *Figure B12*). Clicking the center of the target is worth 30 points for each target. There are bonus points that begin at 100 and drop by approximately nine points per second.

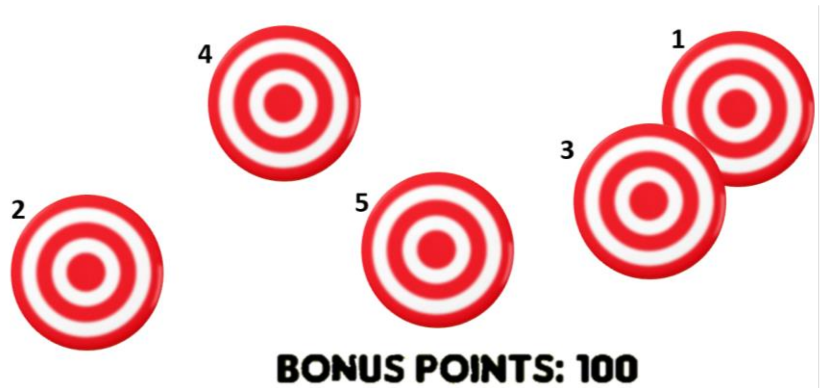

Figure B12: Part 12 of the Clicking Game

Part 13:

The targets appear 1 at a time in a random location on the screen (see *Figure B13*). Once a target is clicked the target disappears and the next target appears. Clicking the center of the target is worth 30 points for each target. There are bonus points that begin at 100 and drop by approximately nine points per second.

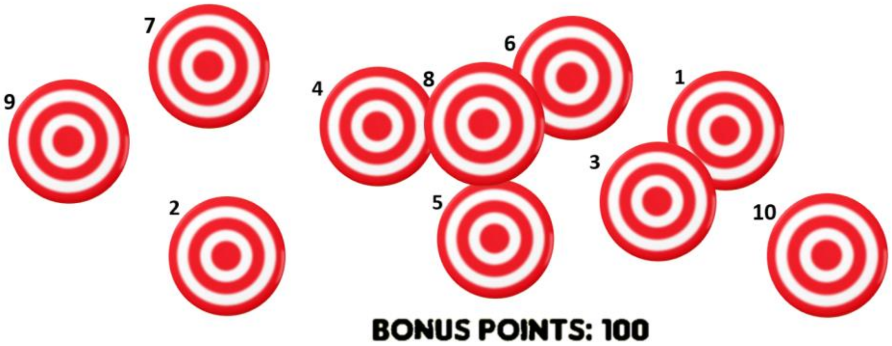

Figure B13: Part 13 of the Clicking Game

Part 14:

The targets appear 1 at a time in a random location on the screen (see *Figure B14*). The participant must double click the target's center as fast as they can. If the participant gets the second click immediately, they receive 20 points. If there is a half second in between clicks, the participant only gets 13 points and if a full second or more time goes by, they only get 8 points or less. These point values are approximations based on time.

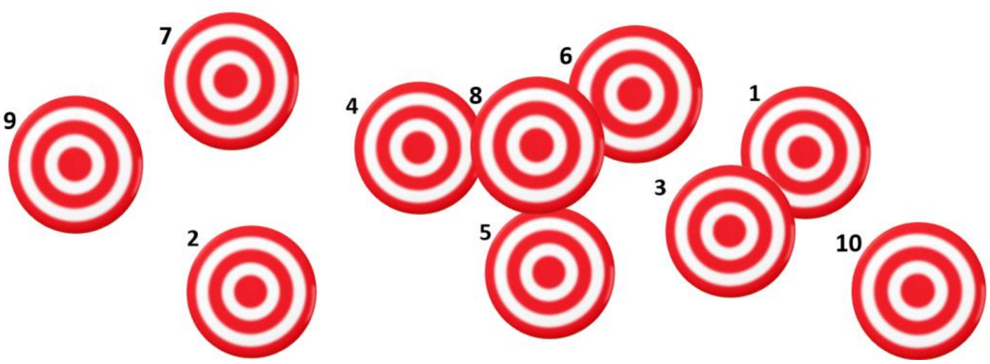

Figure B14: Part 14 of the Clicking Game

Part 15:

48 targets appear and clicking the center is worth 10 points for each target. The targets are in a six by eight grid (see *Figure B15*). There are bonus points that begin at 1,000 and drop by approximately nine points per second.

Figure B15: Part 15 of the Clicking Game

Part 16:

Once the participant completed the game, they received a score on the top of the screen (see *Figure B16*).

Figure B16: Score Given in the Clicking Game