The Effects of Handedness and Dominance on Motor Task Performance

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Two studies were carried out to examine the effects of user handedness and hand dominance on a motor task using Fitts' law. Study one was designed to validate our previous findings showing differences between left- and right-handed participants who completed a mouse-pointing task using Fitts' law. Results showed that right-handed participants were significantly faster than their left-handed peers, thereby validating our previous findings. Study two examined the effect of handedness and hand dominance on motor task performance by requiring two groups of left- and right-handed participants perform the motor task using both their dominant and non-dominant hands. Results showed a significant interaction between handedness and hand dominance on task performance. Right-handed participants were again significantly faster than their left-handed peers when both groups were using their dominant hand. However, left-handed participants were significantly faster than their right-handed peers when both groups were using their non-dominant hand. These findings might be attributed to prior training with computer mice designs that do not account for user handedness. Both theoretical and practical implications, as well as directions for future studies are also discussed.

INTRODUCTION

Advances in computer technologies have offered the end-user numerous life opportunities such as rapid means of communication using the World Wide Web, financial transactions, social media, gaming, training, and computational programs (see Allan, 2001; Campbell-Kelly, 2009). However, these advances have resulted in some serious behavioral, engineering, and design challenges with regards to their effective and efficient utilization. The aim of HCI research is to implement solutions that improve individualized human interaction with computer interfaces. However, computer industry standards seldom integrate individual differences such as handedness into the design principles. Assessing users' differences is vital for device usability, performance efficiency, and safety.

One model of HCI referred to as "Fitts' Law" was developed by Fitts (1954) in order to examine human movement time in relation to distance. This model is relevant to our current studies because it involves movement tasks such as pointing and dragging an object in space using an input device such as a computer mouse (Fitts, 1954; MacKenzie, 1992; Mouloua et. al, 2017). The importance of people's hand movements through space and time is vital for the vast majority of the human population (see Hancock & Newell, 1985). Such movements occur frequently in our daily activities. Regarding the usage of input devices, it is critically important for human device controllers to maintain consistency and high-performance output across a variety of applications (Hancock, 1996). To this end, there are certainly a variety of studies that have been conducted on input devices. Previous Fitts' method research has investigated the relationship between various divergent measures of handedness and mouse, trackball, stylus, and steering wheel input devices (Whisenand & Emurian, 1999; Kabbash, MacKenzie, & Buxton, 1993; Todor & Kyprie, 1980; Davis, Cui, & Spence, 2008). Furthermore, prior studies have also investigated the relationship between various measures of handedness and bimanual coordination and attention, upper versus lower limb tapping, and real versus imagined task performance (Amazeen & Ringenbach, 2005; Rohr, 2006; Maruff et al., 1999). A previous study by Hoffmann (1996) reported that both right-handed and left-handed users showed equivalent motor task performance levels when using their preferred hands. However, left-handed users performed significantly better than their right-handed counterparts when using their non-preferred hand. In a subsequent study, Hoffmann, Chang, and Yim (1997) further examined the same effect of computer user handedness on a movement task presented at varying levels of amplitudes and target sizes, and determined by Fitts' Index of Difficulty (see Fitts, 1954 and Mouloua et al., 2017 for further details). Their results were consistent with their previous findings, thereby suggesting that left handers were not at a disadvantage when they were experienced in using the mouse with both their preferred and non-preferred hand. The state of current research regarding the roles of user handedness and motor behavior in the design and evaluation of computer input devices is still scarce and not well understood. Understanding the impact of handedness and hand dominance on motor behavior is thus highly relevant for users' effective performance, usability, and safety.

The present studies were designed to further examine the effects of handedness and hand dominance on a motor task. Study one was a validation study aimed at replicating our previous findings showing differences between left- and right-handed participants using Fitts' method (Mouloua et al., 2017). Study two examined the same handedness effects on motor performance by having the left- and right-handed participants perform the task using both their dominant and non-dominant hands. We used Fitts' paradigm as a task-related measure for participants' movements in time and space, as well as an objective measure of handedness. It was hypothesized that handedness and hand dominance would affect users' performance on such a ubiquitous mouse-pointing task.

STUDY ONE METHOD

Participants

Forty-one college students (10 males and 31 females) consisting of 17 left-handers and 24 right-handers participated in this study. Participants ranged between 18 and 34 years (M = 21.24, SD = 3.56). They were given course credits for their participation and were treated in accordance with the tenets of the American Psychological Association ethical guidelines.

Task and Materials

Participants were first required to complete a handedness (Oldfield, 1971) inventory to index their handedness as described in our previous paper (Mouloua et al., 2017). Subsequently, they completed a mouse-pointing task consisting of clicking with the left mouse button on two vertical green bars appearing on a computer screen (left and right side of screen), presented via E-Prime 2.0 (see Mouloua et al., 2017 for further details). To perform this task, participants were required to use a symmetric, two-button Dell mouse.

The mouse-pointing task was adapted from Fitts' Law (Fitts, 1954), used to predict human movement. We first calculated the average rate of information generated by a series of movements in order to obtain the index of performance (IP) for each participant. Then, participants' averaged IP scores were averaged as a function of their handedness (for more details on this procedure, see Mouloua et al., 2017; Fitts, 1954).

Design and Procedure

The present study used a simple between-participant design consisting of two experimental (left-handed versus right-handed) conditions. The dependent variables were participants' IP scores and the Edinburgh Handedness Inventory.

STUDY ONE RESULTS AND DISCUSSION

A series of independent *t*-tests were performed to examine the mean difference between left-handers and right-handers on each of the dependent variables. Results showed a significant effect of handedness [$t_{(39)} = 3.143$, $p < 0.005$, $\eta^2 = .20$] on participants' IP scores. This indicated that right-handed participants were significantly faster (M = 9.4 bits/sec, SD = 1.13) than their left-handed peers (M = 7.8 bits/sec, SD = 2.18). This effect is depicted in Figure 1.

Results also showed a highly significant effect of handedness on the Edinburgh Handedness Inventory (EHI) augmented index [$t_{(39)} = 9.65$, $p < .0005$]. This indicated that, on average, the right-handed participants were strongly right-handed (M = 80.14, SD = 26.62) and their left-handed peers were moderately left-handed (M = -37.84, SD = 51.06). This effect is depicted in Figure 2. In its essence this is a manipulation check, since handedness is neither so simple nor as pristine a dichotomy as is generally conceived (Hancock, 2011).

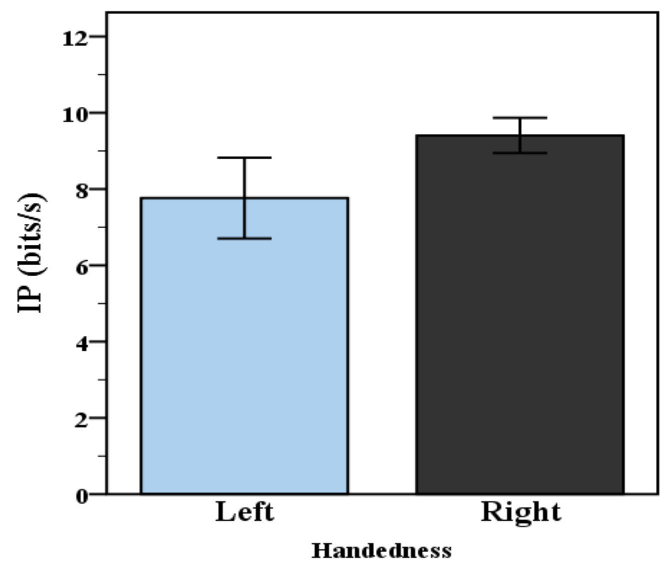

Figure 1. Effects of Handedness on IP.
Error Bars represent ±2 SE.

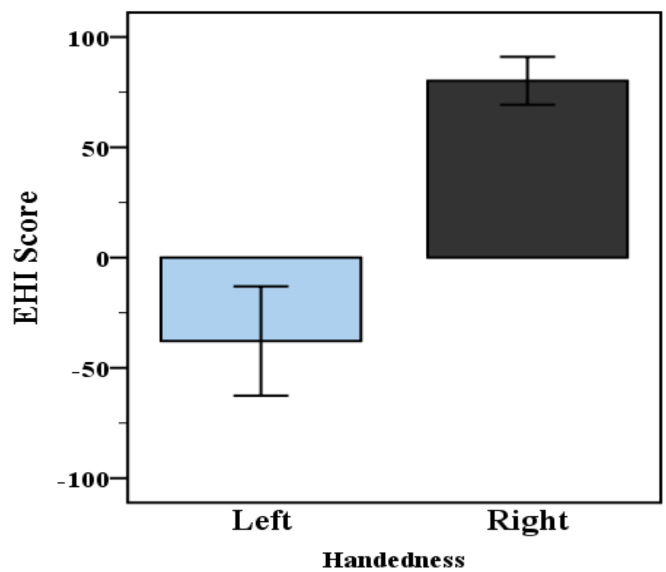

Figure 2. Edinburgh Handedness Inventory Scores.
Error Bars represent ±2 SE.

In light of these results which confirmed our previous findings (Mouloua et al., 2017), we proceeded to a more detailed evaluation of the factors contributing to such effects in our second study.

STUDY TWO METHOD

Participants

Seventy-two college students (33 male and 39 female) consisting of 9 left-handers and 63 right-handers participated in this study. This proportion closely resembles the ratio as drawn from the general population. Participants ranged between 18 and 28 years (M = 18.81, SD = 1.76). They were given course credits for their participation and were treated in accordance with the tenets of the American Psychological Association ethical guidelines.

Task and Materials

Participants were first required to complete the handedness (Oldfield, 1971) inventory described in study one. Subsequently, they completed a mouse-pointing task using exactly the same procedure described in study one. To perform this task, participants were first required to use a symmetric, two-button Dell mouse with their dominant hand, and subsequently with their non-dominant hand.

Design and Procedure

Study two used a 2×2 mixed-factorial design consisting of handedness (left-handed versus right-handed) as a between-participant variable, and hand dominance (dominant versus non-dominant hand) as a within-participant variable. The dependent variable was participants' IP scores.

STUDY TWO RESULTS AND DISCUSSION

Results confirmed a significant effect of hand dominance [$F_{(1,70)} = 6.26$, $p < 0.05$] on performance in the motor task. This indicated that participants using their dominant hand were significantly faster (M = 9.19 bits/sec, SD = 1.70) than participants were when using their non-dominant hand (M = 6.98 bits/sec, SD = 1.76). Furthermore, there was a significant interaction between hand dominance and handedness on performance in the motor task [$F_{(1,70)} = 67.19$, $p < .001$, $\eta^2 = .49$]. Figure 3 depicts this interaction. Although not significant, male participants were faster (M = 9.52 bits/sec, SD = 1.73) than their female peers were when using their dominant hand (M = 8.86 bits/sec, SD = 1.63), and faster (M = 7.21 bits/sec, SD = 1.81) than their female peers were when using their non-dominant hand (M = 6.78 bits/sec, SD = 1.77). Figure 4 depicts these mean differences. Tests of simple effects indicated that there was a significant difference between dominant hand and non-dominant hand performance in the motor task for the right-handed participants (M_{diff} = 2.74 bits/sec, $p < .001$), and for the left-handed participants (M_{diff} = 1.46 bits/sec, $p < .005$). In addition, there was a significant difference between right-handed and left-handed participants for the dominant hand (M_{diff} = 1.34 bits/sec, $p < .05$), and for the non-dominant hand (M_{diff} = 2.85 bits/sec, $p < .001$).

When observing the interaction between hand dominance and handedness on motor task performance, we see the apparent paradox that the left-handed participants were significantly faster using their non-dominant hand than their dominant hand. This echoes our early observation concerning the complexities of handedness and is motivating further experimental evaluation.

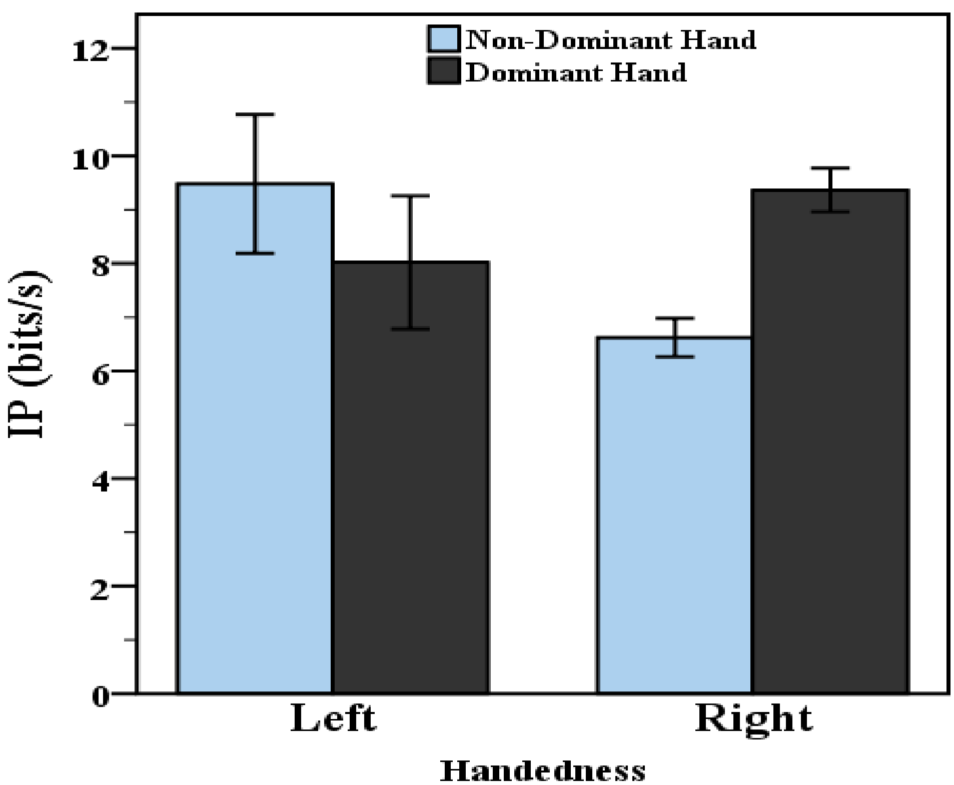

Figure 3. Effects of Handedness and Dominance Interaction on IP. Error Bars represent ±2 SE.

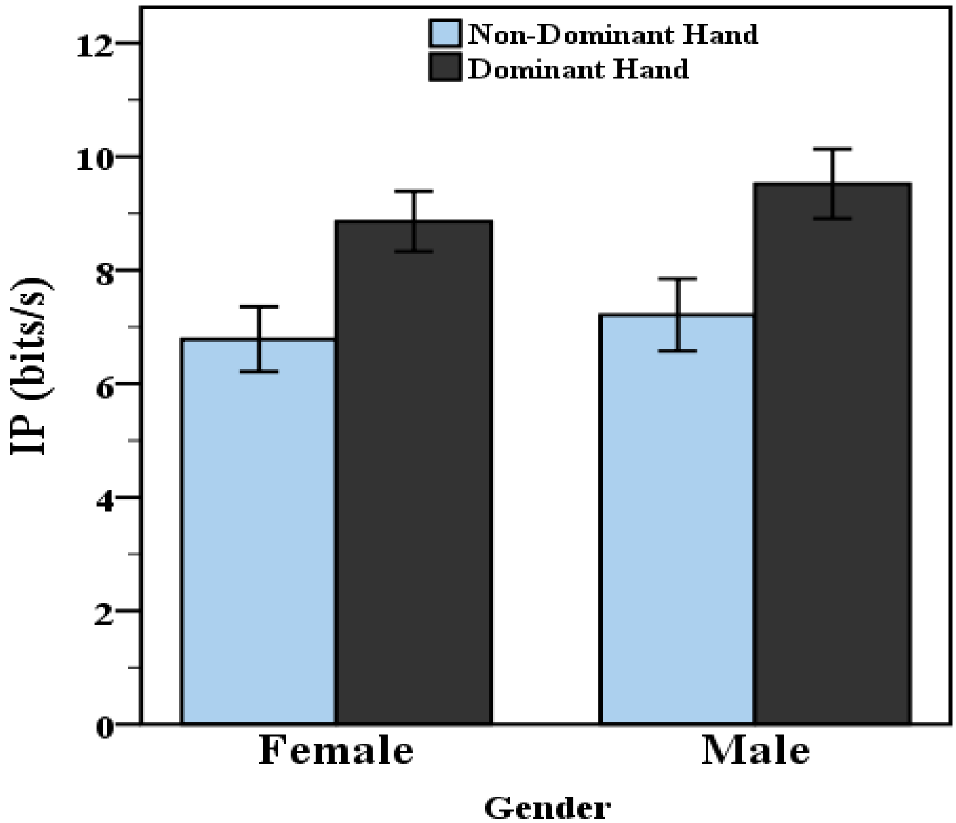

Figure 4. Gender and Dominance Mean Differences for IP. Error Bars represent ±2 SE.

CONCLUSIONS

The present studies were designed to empirically examine the effects of handedness, hand dominance, and gender on a ubiquitous mouse-pointing task. In study one, our findings clearly showed that right-handed individuals were by far faster than their left-handed peers on the mouse-pointing task. These results validated our findings from a previous study and added more evidence to the effects of handedness on motor behavior. However, study two's results showed that no difference between left-handed and right-handed participants was present when both groups used their right hand. Results also indicated that male participants were not significantly different from their female peers, although slightly faster across both hands. As such, the present findings suggest that the role of gender in Fitts' Law may be limited in regards to participants' averaged IP scores.

Left-handed participants were faster than their right-handed peers when both groups were using their left hand. However, left-handed participants' variability was much greater than their right-handed peers across both hands. This finding supports the large body of literature detailing the high variability in the left-handed populace. The consistency of the right-handed participants confers some advantage in regards to the predictability of their hand movement, when compared to their left-handed peers. Therefore, the present findings may reflect participants' prior degree of training with a mouse using a given hand. In our studies, participants' use of the mouse with the left hand required use of the middle finger to click the left button. This was done to simulate a real-world environment in which comfortable and stable use of the mouse with the left hand demands orienting the index finger over the right mouse button, and middle finger over the left mouse button. Switching the mouse buttons through reprogramming is thus a future experimental design option. However, it is unlikely that such a change would reflect participants' prior experience using a mouse with their left hand. In the present studies, no left-handed or right-handed participants reported ever reprogramming their mice. Reprogramming the mouse buttons may decrease mean differences between left-handed and right-handed participants in the aforementioned mouse-pointing task.

Study two's findings showed that left-handed participants performed significantly faster using their right hand, perhaps because of their developed motor skills or experience using the mouse with their right hand. Our results are consistent with and expand upon previous findings by Hoffmann (1996) and Hoffmann et al., (1997). Contrary to their studies, our left-handed participants were inexperienced in using computer mice with their left hand. As such, it is possible that participants' hand-specific mouse experience plays a larger role in Fitts' Law than previously thought. In effect, "left-handed" mice are extremely rare in normal computer operations. We also know that many contextual designs disproportionately disadvantage left-handers. The right-handed participants were more consistent in their handedness than their left-handed peers here. However, perhaps the present between-group differences actually decrease as the latter group receives focused training with their dominant hand. When conducting studies involving both the left and right hand, it is pertinent to account for intermanual transfer (Parlow & Kinsbourne, 1989; Laszlo et al., 1970; Halsband, 1992; Gordon et al., 1994; Dickins, Sale, & Kamke, 2015). In our second study, participants first performed the task with their dominant hand, in order to create a baseline score. It is therefore important to mention that, due to intermanual transfer, participants' scores with their non-dominant hand may be somewhat dependent on their initial scores with their dominant hand. The within-participant differences shown in this study may become greater in a procedure where participants do not first engage in the task using their dominant hand. We propose that the between-group differences illustrated in this study are more a function of user training than device design. This proposition is open to further experimental evaluation. Furthermore, results are likely more related to prior hand-specific mouse experience across participants' lifespans, rather than their handedness alone.

These findings have practical implications for various computer input devices such as mice, game controllers, joysticks, etc. Such devices are widely used in a variety of applications such as training in military, aviation systems, education, medical, and simulation technologies (Vincenzi et al., 2009). Our findings may also aid in the development of adaptive tools used for the retraining of reaching movements among disadvantaged users (Zimmerli et al., 2012). Furthermore, the present research has implications in clinical sEMG assessment with relation to upper extremity disorders, muscle activity, hand posture, and mouse design (see Agarabi, Bonato, & De Luca, 2004; see also Pizzamiglio et al., 2017; Chowdhury et al., 2013). Future studies should aim to not only incorporate and validate such highly relevant methods of physiological analysis, but also aim to implement multi-modal integration between functional neuroimaging methods (fMRI, fNIRS, and EEG/ERP) and sEMG (see Hong & Khan, 2017). These methods may be paired with robust measures of human movement and behavior such as Fitts' Law.

REFERENCES

Allan, R. A. (2001). *History of the Personal Computer: The People and the Technology.* Allan Publishing (ACM). London, Ontario.

Agarabi, M., Bonato, P., & De Luca, C. J. (2004). A sEMG-based method for assessing the design of computer mice. *The 26th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2450-2453.*

Amazeen, E. L., Ringenbach, S. D., Amazeen, P. G. (2005). The effects of attention and handedness on coordination dynamics in a bimanual Fitts' law task. *Experimental Brain Research, Vol 164(4), 484-499.*

Campbell-Kelly, M. (2009). The Origin of Computing, *Scientific American, 301, 62-69.*

Chowdhury, R. H., Reaz, M. B. I., Ali, M. A. B. M., Bakar, A. A. A., Chellappan, K., & Chang, T. G. (2013). Surface Electromyography Signal Processing and Classification Techniques. *Sensors, 13(9), 12431–12466.*

Davis, N. J., Cui S., Spence, C. (2008). The dynamics of reciprocal aiming with a steering wheel. *Experimental Brain Research, 188(1), 141-146.*

Dickins, D. S. E., Sale, M. V., Kamke, M. R. (2015). Intermanual transfer and bilateral cortical plasticity is maintained in older adults after skilled motor training with simple and complex tasks. *Frontiers in Aging Neuroscience, Vol 7, 73.*

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology, Vol 47(6), 381-391.*

Gordon, A. M., Forssberg, H., Iwasaki, N. (1994). Formation and lateralization of internal representations underlying motor commands during precision grip. *Neuropsychologia, 32(5), 555-568.*

Halsband, U. (1992). Left hemisphere preponderance in trajectorial learning. *Neuroreport, Vol 3(5), 397-400.*

Hancock, P. A., & Newell, K. M. (1985). The movement speed-accuracy relationship in space-time. In H. Heuer, U. Kleinbeck, & K.-H. Schmidt (Eds.), *Motor behavior: Programming, control, and acquisition* (pp. 153- 185). Berlin: Springer-Verlag.

Hancock, P. A. (1996). Effect of control order, augmented feedback, input device and practice on tracking performance and perceived workload. *Ergonomics,* 39, 1146-1162.

Hancock, P.A. (2011). On the left hand of time. American Journal of Psychology, 124 (2), 177-188.

Hoffmann, E.R. (1997). Movement of times of left and right handers using their preferred and non-preferred hands. *Int. J Industrial Ergonomics, 19 (1),* pp. 49-57.

Hoffmann, E.R., Chang, W.Y., and Yim, K.Y. (1997). Computer mouse operation: Is the left-handed user disadvantaged? *Applied Ergonomics, 29, (4*). pp. 245-248.

Hong, K.-S., & Khan, M. J. (2017). Hybrid Brain–Computer Interface Techniques for Improved Classification Accuracy and Increased Number of Commands: A Review. *Frontiers in Neurorobotics, 11, 35.*

Kabbash, P., MacKenzie, I. S., Buxton, W. (1993). Human Performance Using Computer Input Devices in the Preferred and Non-Preferred Hands. *Proceedings of the CHI '93 Conference on Human Factors in Computing Systems, New York: ACM, 474-481.*

Laszlo, J. I., Baguley, R. A., Bairstow, P. J. (1970). Bilateral transfer in tapping skill in the absence of peripheral information. *Journal of Motor Behavior, Vol 2(4), 261:271.*

MacKenzie, I. S. (1992). Fitts' Law as a Research Interaction. http://www.yorku.ca/mack/hci1992.html.

Maruff, P., Wilson, P. H., de Fazio, J., Cerritelli, B., Hedt, A., Currie, J. (1999). Asymmetries between dominant and non-dominant hands in real and imagined motor task performance. *Neuropsychologia, Vol 37(3), 379-384.*

Mouloua, A. S., Mouloua, M., Hancock, P. A., McConnell, D. S. (2017). The effects of computer user handedness on a mouse-clicking task. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 61(1), 1220-1223.*

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia, Vol 9, 97-113.*

Parlow, S. E., Kinsbourne, M. (1989). Asymmetrical transfer of training between hands: implications for interhemispheric communication in normal brain. *Brain and Cognition, Vol 11(1), 98-113.*

Pizzamiglio, S., De Lillo, M., Naeem, U., Abdalla, H., & Turner, D. L. (2017). High-Frequency Intermuscular Coherence between Arm Muscles during Robot-Mediated Motor Adaptation. *Frontiers in Physiology, 7, 668.*

Rohr, L. E. (2006). Gender-specific movement strategies using a computer-pointing task. *Journal of Motor Behavior, Vol 38(6), 431-437*

Todor, J. I., & Kyprie, P. M. (1980). Hand differences in the rate and variability of rapid tapping. *Journal of Motor Behavior, Vol 12(1), 57-62.*

Vincenzi, D., Wise, J., Mouloua, M., & Hancock, P. A. (2009)(Eds.). *Human Factors in Simulation and Training.* CRS Press (Taylor & Francis Group). Boca Raton: FL.

Whisenand, T. G., & Emurian, H. H. (1999). Analysis of cursor movements with a mouse. *Computers in Human Behavior, Vol 15(1), 85-103.*

Zimmerli, L., Krewer, C., Gassert, R., Muller, F., Riener, R., and Lunenburger, L. (2012). Validation of a mechanism to balance exercise difficulty in robot-assisted upper-extremity rehabilitation after stroke. *Journal of NeuroEngineering and Rehabilitation, 9-6*, pp. 1-13.