THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF KINESIOLOGY

MIXED-HANDEDNESS IN YOUNG ADULT ADHD POPULATIONS

NICOLETTE MORREALE
SPRING 2015

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Kinesiology
with honors in Kinesiology

Reviewed and approved* by the following:

Kristina A. Neely
Assistant Professor of Kinesiology
Thesis Supervisor

Jinger Gottschall
Associate Professor of Kinesiology
Honors Adviser

* Signatures are on file in the Schreyer Honors College.

ABSTRACT

Handedness is a lateralized process in which one hemisphere of cerebral cortex exhibits more control than the other, resulting in right-handedness, left-handedness, or mixed-handed. Various neurodevelopmental disorders such as attention deficit hyperactivity disorder (ADHD) exhibit abnormal cortical lateralization that is manifested as a tendency towards mixed-handedness. In the current study, handedness is used as an indicator of cortical lateralization. Handedness is assessed through both performance asymmetries and hand preference measures. The main goals of this study are to 1.) provide evidence for the importance of both hand performance and hand preference measures in the determination of dominance, and to 2.) assess both of these types of measures in a young adult ADHD population to evaluate abnormal cortical lateralization in this group. It is expected that the ADHD population will exhibit a trend towards mixed-handedness, indicating an abnormal process of cortical lateralization when compared to control data from a previous study (Przybyla, Coelho, Akpinar, Kirazci, & Sainburg, 2013). In this study, 8 diagnosed ADHD adults (19-23 years) completed a Kinereach ® reaching task to assess hand performance and the Edinburgh Handedness Inventory along with a Kinereach® hand selection reaching task to assess hand preference. I found that the ADHD patients exhibited a trend towards mixed-handedness in hand performance and hand preference measures. These findings suggest an abnormal cortical lateralization in ADHD, as well as the importance of both performance and preference measures in determining hand dominance.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

Many thanks to all of the individuals who made the completion of this work possible. I owe my success to those who supported me along the way both intellectually and personally.

To my thesis supervisor, Dr. Kristina Neely, thank you for your constant assistance and encouragement over the past two years. It has truly been an honor to work with you and I cannot begin to describe how much I have learned through my years working in the lab. You have made my research experience at Penn State truly enriching and invaluable. I am honored to have been your first Schreyer Honors student as well as one of the first undergraduates to work in the Motor Control, Cognition, and Neuroimaging Lab. Many thanks for all of your continued support.

To my honors advisor, Dr. Jinger Gottschall, thank you for your continued support as an advisor and a teacher alike. You are an inspirational professor as well as a dependable advisor. You were always supportive through all of my decisions and accomplishments, and I cannot thank you enough. You have guided my path as a Kinesiology Honors Scholar since the very beginning, and I would not be where I am today without your guidance and assistance.

To the Schreyer Honors College staff, I would like to express my gratitude for all of my valuable experiences and opportunities as an Honors Scholar. With the help of the Schreyer Honors College, I had the opportunity to study abroad in London, UK as well as present a poster at SCAPPS Neuroscience Conference in London, Ontario. These experiences would not have been possible without the monetary and moral support of the Schreyer Honors College.

Many thanks to all of the undergraduates and research assistants in the Motor Control, Cognition, and Neuroimaging Lab who assisted with my thesis project. My project would not have been possible without your help with data collection, scheduling, and many other lab responsibilities. I am truly grateful and honored to have had the opportunity to not only work with all of you, but to have formed personal relationships with you as well.

Finally, I would like to thank my family and friends for their continued support throughout my years at Penn State. I owe my many accomplishments to their unwavering love and support. Thank you especially to my parents, Steve and Gina Morreale, who continuously bolster me in all that I do. Words cannot describe my gratitude for your unwavering support throughout my entire life, especially though my years at Penn State. Thank you, from the bottom of my heart, for always being supportive through this entire process.

Chapter 1

Introduction

Certain functions of the human brain are carried out by only one hemisphere of the cortex rather than both hemispheres. For example, language is lateralized to the left hemisphere in most healthy adults. This phenomenon, known as cortical lateralization, is the confinement of a specific function to one of the two hemispheres of the cerebral cortex. In order to maximize efficiency, the right and left hemispheres are differentially specialized for certain tasks. Such a division of labor provides a high level of organization that ensures clustering of neurons dedicated to a specific function in a particular hemisphere of the brain. Cortical lateralization has been extensively studied, beginning with the work of Paul Broca in 1861. Broca studied a number of lesion patients in the nineteenth century, particularly those experiencing language deficits. His case studies provided the first evidence of functional localization within a single hemisphere (Broca, 1861). Broca's work led to the discovery of a region of cortex in the temporal lobe of the left hemisphere that is dedicated to speech production, named Broca's area.

Cortical lateralization exists in primates and other animals. The division and specialization of cortical tasks has been studied in animal models including chimpanzees (Hopkins & Cantalupo, 2004) and chicks (MacNeilage, Rogers, & Vallortigara, 2009). Hopkins and colleagues have extensively studied sensory, motor, and cognitive asymmetries in the chimpanzee. They report that cortical asymmetries predictive of hand preference exist in non-human primates as well as humans (Hopkins et al., 2011). Their results suggest that comparable evolutionary processes underlie cortical lateralization of function in both humans and primates

(Hopkins, 2013; Hopkins et al., 2011). Similarly, Rogers and colleagues report evidence of cortical lateralization in chickens. Typically developing, lateralized chicks possess the ability to perform tasks simultaneously, for example searching for food and monitoring for predators (Rogers, Zucca, & Vallortigara, 2004). The ability to simultaneously engage in these tasks requires the left and right hemispheres be differentially engaged to achieve their respective functions. Rogers et al. (Rogers et al., 2004) demonstrated that non-lateralized chicks are able to perform the same tasks that can be performed by typically developing chicks; however, non-lateralized chicks are not able to perform these multiple tasks simultaneously. Therefore, the presence of cortical lateralization arises not only as a means of labor division, but as a means of synchronization of parallel processes across cortical hemispheres (Vallortigara & Rogers, 2005).

An example of cortical lateralization in humans is handedness. Handedness is typically assessed through measures of *hand performance* and *hand preference*. Hand performance assesses the ability with which a hand performs a given task (Williams, 1991). An example of a hand performance assessment is the Purdue Pegboard task, which measures how well an individual can perform fine motor tasks using the hands (Buddenberg & Davis, 2000). In the Purdue Pegboard task, participants must place metal pegs into holes as quickly as possible (Espe-Pfeifer & Wachsler-Felder, 2000). There are three task variations involving right, left, and both hands. The fourth task requires the assembly of a pin, washer, and metal collar at each hole on the pegboard. Each task is scored based on the number of pins placed in 30 seconds. Scores provide a measure of hand performance. Hand dominance is determined by the higher scoring hand. In contrast to this task-based assessment of hand performance, hand preference can be determined by the hand selected for use in everyday activities such as using a pair of scissors, striking a match, or writing. A popular hand preference evaluation is the Edinburgh Handedness

Inventory (Oldfield, 1971), which asks participants to report which hand is used in 10 common unimanual tasks (Oldfield, 1971; Williams, 1991). The participant is asked to indicate preference in hand usage by placing a check mark for “left hand”, “right hand”, or checks next to both right and left to indicate indifference. Then, the total number of check marks is tallied for each hand. The cumulative total is calculated by adding the tallies for both right hand and left hand. The difference is calculated by subtracting the left hand tally from the right hand tally. Finally, the result (R) is calculated by dividing the difference by the cumulative total and multiplying by 100. This result is used to determine handedness ($R < -40$ = left-handed, $R > +40$ = right-handed, $-40 \leq R \leq +40$ = mixed-handed). In contrast to these independent hand performance (e.g., Purdue Pegboard) and hand preference (e.g., Edinburgh Handedness Inventory) measures, a combined assessment of hand performance and hand preference may provide a more complete evaluation of handedness (Elliott & Roy, 1996). In this thesis, I will combine measures of hand performance and hand preference in order to present a more well-rounded assessment of handedness. To determine hand performance, I will compare endpoint accuracy and reaching trajectory curvature between the two arms. I will use the Edinburgh Handedness Inventory (Oldfield, 1971) combined with a hand selection task to determine hand preference.

Handedness is a behavioral manifestation that reflects neurological specialization (Elliott & Roy, 1996). Handedness is theorized to infer the dominance of one cerebral hemisphere over the other (Sainburg, 2014). This dominance, also known as cerebral asymmetry, indicates the superior capacity of one hemisphere to develop specific skills over the alternate hemisphere (Geschwind & Galaburda, 1985). A series of investigations from Sainburg and colleagues contributed to the development of the *Dynamic Dominance Model* (Coelho, Przybyla, Yadav, & Sainburg, 2013; Przybyla et al., 2013; Sainburg, 2002; Sainburg, 2005, 2014). This model states that in right-handed individuals, the left hemisphere is responsible for predictive or dynamic control such that the right hand will take the most efficient path to a target. In this case, the left hemisphere is the "dominant" hemisphere. Sainburg et al. (2002) utilized a reaching task to examine the performance asymmetries associated with each of the limbs. In particular, particpants … describe the task here – 32 targets across the work space, choice/forced, and so on. Dynamic control is measured by end point accuracy, or *final position error (FPE)*. Final position error (FPE) is a measure of the distance in meters between the final position of a reach and the center of the target. The Dynamic Dominance Model predicts that the right hand will have greater endpoint accuracy as measured by FPE compared to the left hand, as a result of dynamic control of the left hemisphere. Conversely, the non-dominant right hemisphere handles control of stability during a reaching motion, also referred to as impedance control. Therefore, the left hand will take more of a curved route during goal-directed reaching movements in order to sustain stability (Coelho et al., 2013; Sainburg, 2014). Curvature of hand trajectory can be measured by *hand path linear deviation (HPLD)*. HPLD is based on the most efficient trajectory from a starting position to a target, most commonly a straight line between the centers of both points. HPLD evaluates the deviation from this path by a ratio between the major axis, which extends from the starting and ending center points, and the minor axis, which is a straight line between the major axis and the point during the reach that creates the furthest distance from the most efficient trajectory. The dynamic dominance model predicts the left hand will have a greater HPLD compared to the right hand in order to provide stability, rather than accuracy, during movement. In summary, each hemisphere is optimized for separate, but complimentary control tasks. The right hand/left hemisphere system exhibits dynamic control, but the left hand/right hemisphere system exhibits stability control. Thus, examination of hand performance and preference may provide insight into cerebral organization in healthy adults as well as adults with neurological, neurodevelopmental, or neuropsychiatric disorders.

Motor skill acquisition in typically developing children provides a framework for understanding how handedness emerges. Infants develop fine and gross motor skills between the ages 9 and 21 months (Darrah, Hodge, Magill-Evans, & Kembhavi, 2003). Following a brief stage of mixed-handedness before the age of 9 months, single-hand preference emerges by the age of 10-11 months (Gesell & Ames, 1947). Complete lateralization occurs between the ages of 5 and 7 years (Coren, 1990; Gesell & Ames, 1947) and 75-95% of children are right-hand dominant by the age of 7 (Colby & Parkison, 1977; Coren, 1990; Elliott & Roy, 1996; Gesell & Ames, 1947). Annett's *Right-Shift Theory of Handedness* posits that the development of motor cortex favors the left hemisphere because language development occurs in this hemisphere as well. Consequently, the concurrent development of left motor cortex along with language areas may predispose children to become right-handed (Annett, 1998).

In contrast to typically developing children, left hand dominance and mixed handedness are more prevalent for children with developmental disorders such as dyslexia (Eglinton & Annett, 1994) or autism (Colby & Parkison, 1977). There is an increase in left-handedness and mixed-handedness in adults with dyslexia (Eglinton & Annett, 1994) and 65% of autistic children are left-handed or mixed-handed compared to only 12% non-right-hand dominance in typically developing children (Colby & Parkison, 1977). Smalley, Loo, Yang, and Cantor (2005) suggest this may happen as a result of abnormal cortical lateralization, which is a complex phenotype associated with attention-deficit/hyperactivity disorder (ADHD), dyslexia, and autism. Further, Geschwind and Galaburda (1985) report that 40% of left handers exhibit abnormal cortical lateralization, but only 3% of right handers show abnormal cortical lateralization (Geschwind & Galaburda, 1985). The link between handedness and neurodevelopmental disorders may originate from a lack of strong dominance by the right or left hemisphere (Orton, 1937). Mixed-handed children have a greater likelihood of language, scholastic, and mental health problems that persist into adulthood (Rodriguez et al., 2010). Interestingly, language, scholastic, and mental health problems are all symptoms of ADHD (American Psychiatric Association. & American Psychiatric Association. DSM-5 Task Force., 2013). According to Rodriguez and colleagues (2010), mixed-handed children are at a higher risk for developing ADHD relative to their right-handed peers. This suggests that the evaluation of handedness may compliment the diagnostic information for patients with ADHD (Rodriguez et al., 2010).

ADHD is a common, childhood-onset, heterogeneous neuropsychiatric disorder characterized by inattention and/or hyperactivity-impulsivity (American Psychiatric Association. & American Psychiatric Association. DSM-5 Task Force., 2013). ADHD persists into adulthood in up to 65% of cases (Faraone, Biederman, & Mick, 2006). In addition to the core behavioral features, motor impairments are reported in up to 50% of patients (Barkley, 1998) and up to 50% of pediatric patients have comorbid developmental coordination disorder (Gillberg et al., 2004; Kadesjo & Gillberg, 1999; Pitcher, Piek, & Hay, 2003). Motor control deficits can be associated with poor adaptive functioning in home life, socialization, and self-direction (Wang, Huang, & Lo, 2011). However, there is a paucity of literature examining motor deficits associated with this disorder, especially in adults. Studies of handedness in ADHD populations have largely been longitudinal in nature. For example, Rodriguez and colleagues completed a longitudinal assessment of a single birth cohort.   Children were assessed at 8 years old and again at 16 years old (N = 7871). Teacher and parent reports were used to assess language difficulties, scholastic performance, and overall mental health, whereas only a parent report determined handedness. The limitation of these types of studies is that they only assess handedness via hand preference inventories or self-report statistics and do not evaluate hand performance in motor tasks.

The goal of this study is to examine handedness in adults with ADHD. To that end, this study evaluates handedness through hand performance and hand preference measures. Hand performance is assessed through kinematic analyses of arm reaches, specifically looking at end point accuracy and reaching trajectory curvature. In the current work that studies young adults with ADHD, hand preference is evaluated through the Edinburgh Handedness Inventory (Oldfield, 1971) and a hand selection task involving reaching movements in peripersonal space.. Importantly, results of the hand performance task and the hand selection task have been described by Przybyla and colleagues (2013) for healthy young adults and thus the results of Przybyla et al. (2013) can be used in comparison to the ADHD group examined in this thesis. Przybyla et al. (2013) report that right-hand dominant adults exhibit greater endpoint accuracy and less reaching trajectory curvature for reaches completed with their right hand compared to their left hand. Further, when given a choice to use the right or left arm, participants used their right hand almost three fourths (68%) of the time to reach to targets distributed across left, middle, and right regions of peripersonal space. The results of the Przybyla et al. (2013) study are in line with the Dynamic Dominance Model, such that the right arm is optimized for endpoint accuracy through predictive feedback control. In the current study, I will use the same experimental design to assess hand performance and preference in young adults with ADHD. I hypothesize that endpoint accuracy and trajectory curvature will not be different as a function of hand. Since mixed-handedness is more prevalent in ADHD patients than among a healthy population, I hypothesize that the Edinburgh Handedness Inventory will demonstrate that young adults with ADHD who self-report as right-handed will score as mixed-handed in this assessment. Last, when given a choice of which arm to reach with, I hypothesize that young adults with ADHD will not select their right hand as often as healthy young adults.

Chapter 2

Method

Participants

8 young adults (6 female; ranging from 19-23 years old) who self-reported a previous diagnosis of ADHD persisting into adulthood participated in this experiment. All participants self-reported right-handedness. Table 1 provides demographic information on the participants in this study. Adults with ADHD were tested after 24-hour withdrawal from any stimulant medication prescribed to treat ADHD. This study was conducted in accordance with the ethical standards outlined in the 1964 Declaration of Helsinki. The Pennsylvania State University Institutional Review Board approved procedures, and all testing was carried out with the written consent of participants.

Table 1

Demographics

Variables	**ADHD**
Sample size	8
Females	6
Self- report right-handed	8
Age, years	20.6 ± 1.8
Education, years	14.6 ± 1.3
Weight, kilograms	60.4 ± 9.3
Caucasian	8

Experimental Procedure

Participants were seated at a custom-designed virtual aiming apparatus, the Kinereach® virtual reality workstation, which provides real-time 3-dimensional data acquisition for movements of the upper limbs. As shown in Figure 1, the top shelf of the Kinereach® holds a 60” Vizio E Series Razor LED Television (refresh rate = 120 Hz), which projects to a one-way mirror that comprises the middle shelf. The distance between the television and the mirror was 24 cm. This geometry created the illusion that targets shown on the mirror are on the reaching surface, which comprised the bottom shelf of the Kinereach®. The one-way mirror occluded vision of the arms. Participants were secured in a Corbeau Racing® chair (Corbeau USA, Sandy, UT) with shoulder harness belts to prevent confounding torso motion. The height of the chair was adjusted such that the participant’s chin was just above the surface of the mirror. The distance of the chair from the reaching space was adjusted on an individual basis for comfort throughout the session. Both arms were secured in wrist splints to prevent wrist and finger movement. The splints were mounted to air sleds which eliminated the effects of friction and gravity, which could otherwise cause fatigue throughout the session.

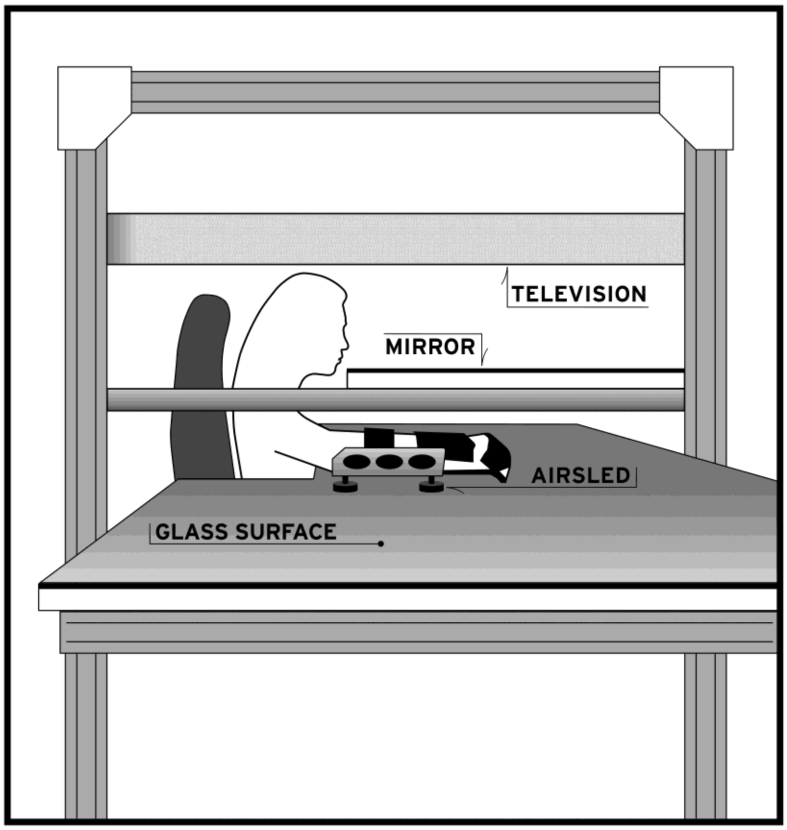

Figure 1: Kinereach Setup. The top shelf of the Kinereach® held a 60" Vizio E Series Razor LED Television which projected to a one-way mirror on the middle shelf. The geometry created the illusion that targets shown on the mirror were on the reaching surface, which comprised the bottom shelf of the Kinereach®. The one-way mirror hid the participant's vision of the arms. Targets in the reaching space were calibrated for each participant. Both arms were secured in wrist splints to prevent wrist and finger movement. The splints were mounted to air sleds which eliminated the effects of friction and gravity during the reaching trial**.**

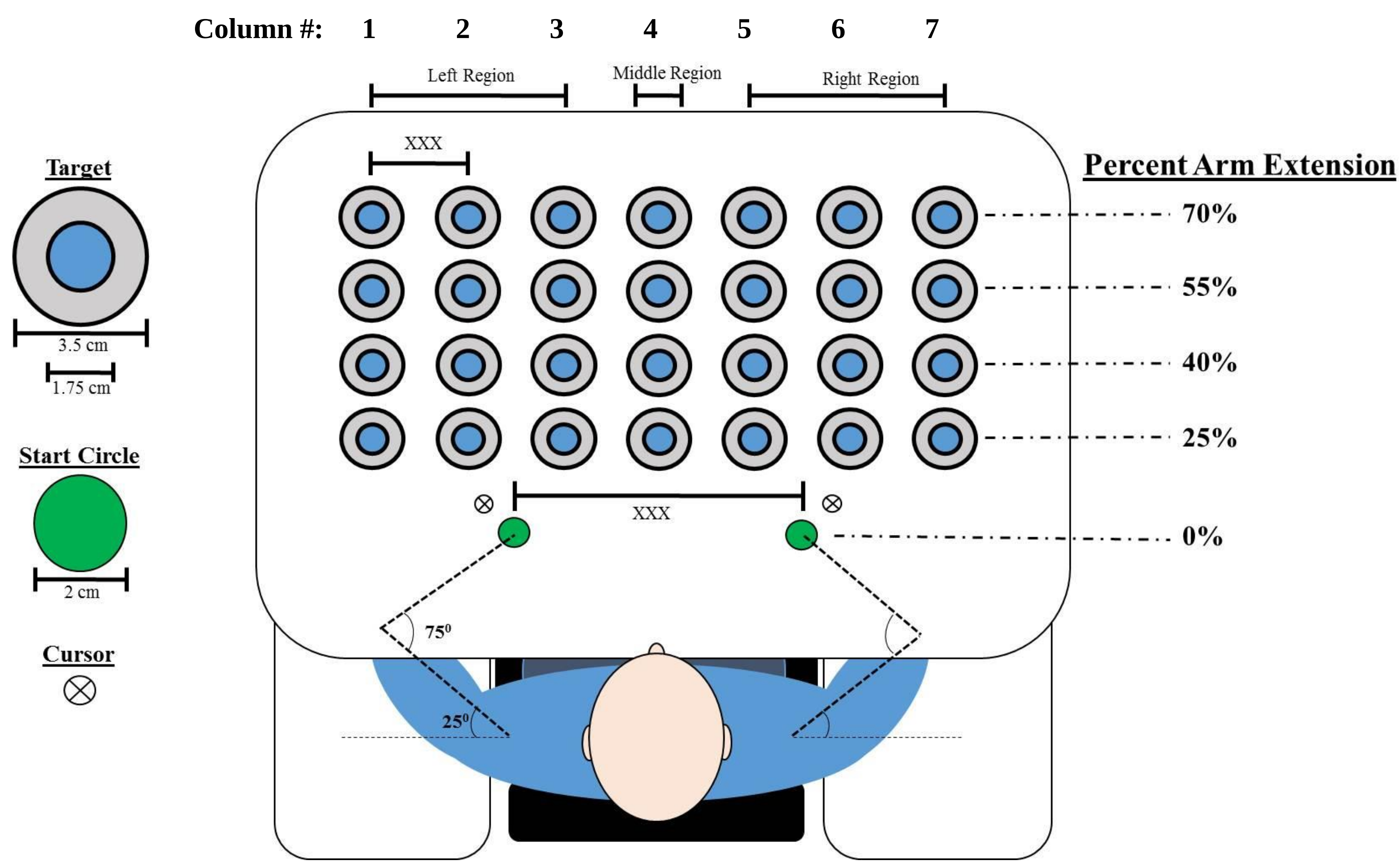

Figure 2: Target Layout. This figure provides the layout of all 28 targets possible in the paradigm. The workspace is divided into 3 different regions for analysis. Left space was defined as columns 1-3, middle space as column 4, and right space as columns 5-7. Two start locations were set for each individual with respect to the elbow joint internal angle, $\theta e = 75°$, and shoulder joint external angle, $\theta s = 25°$. The target array contained four rows of targets which corresponded to 25%, 40%, 55%, and 70% of arm length for each participant. The target array contained seven columns, which were set to 25% of the distance between the left or right start positions from the body midline. Only one of the possible 28 targets would appear during a trial, and the participant would perform a uni-manual reach from the start circle to the center of the target.

The Kinereach® uses the TrakSTAR Magnetic Tracking System (Ascension Technology, Shelburne, VT) to collect six degrees of freedom across three movement planes at 116 Hz. Magnetic sensors were placed on the dorsal surfaces of both hands and the lateral surfaces of both upper arms, halfway between the elbow and the shoulder. Sensors were attached using Mueller MWRAP® (Mueller Sports Medicine, Prairie du Sac, WI) throughout the experimental session. Before the experiment began, the position of each sensor was calibrated in an x, y, z coordinate system. Individual joint locations and limb lengths were recorded and a visual display containing 28 targets and two start locations were then scaled to the participant. As shown in Figure 2, the workspace was divided into left, middle, and right regions. Left space was defined as columns 1-3, middle space as column 4, and right space as columns 5-7. The start locations, one for each arm, were set for each individual with respect to the elbow joint internal angle, $\theta_e = 75°$, and shoulder joint external angle, $\theta_s = 25°$. The target array contained four rows of targets which corresponded to 25%, 40%, 55%, and 70% of arm length for each participant. The target array contained seven columns, which were set to 25% of the distance between the left or right start positions from the body midline. The start locations were 2 cm in diameter and all targets were 3.5 cm in diameter. Start locations were solid green circles. As shown in Figure 2, targets were similar to a bulls-eye: the center (1.75cm in diameter) was blue and the outer ring was gray. On each trial, points were awarded for endpoint accuracy. The point system was used for participant motivation and was not translated into monetary reward. Final cursor regions that were within 1.75cm, 3.5cm, and 5.25cm of the center of the target were awarded 10 points, 3 points, and 1 point, respectively. The session score was reported at the top of the screen outside of the target array. At the end of each trial, the total point score would increase appropriately and the cursor path was displayed for 1 s. Feedback indicating the cursor path during a reach was given by a trajectory of small circles (1 cm in diameter) immediately after each reach was completed.

Experimental Design

The experiment required reaching to one of 28 possible targets. The task was self-paced and began when the participant moved both hands into the green start circles. After 1 second in the start circles, an auditory tone provided the “go” signal. Participants were instructed to make a unimanual reach as quickly and accurately as possible to the target in response to the auditory go signal. Participants were instructed to stop in the middle of each target. After each reach, the participants were given visual feedback of their movement path for 1 s, as well as auditory feedback based on endpoint accuracy. A higher-pitched tone signaled 10 points, a lower-pitched tone indicated 3 points, and lack of a tone signaled missed targets. Each participant completed three session blocks and each block consisted of 140 trials: 5 reaches to each of the 28 targets. The first block for every participant was the CHOICE condition. In this condition, both hands must align with the start circle at the start of each trial. Participants were told they could use either hand to complete their reach. This block was designed to determine the pattern of reaching frequency (RF) across the workspace. In the second and third blocks, participants were forced to use only the right or left hand for the entire block. The Forced-Right (F-Right) and Forced-Left (F-Left) blocks were counterbalanced across participants. The targets within a session block were presented in a pseudo-randomized order. Randomization was constrained so that no two targets were presented consecutively in the same workspace region, seen in Figure 2 (left, middle, or right).

Data Analysis

The TrakSTAR Magnetic Tracking System (Ascension Technology, Shelburne, VT) records displacement of joints and limb segments with a maximum static and dynamic measurement error of approximately 2 mm^3. Kinematic data were processed with custom software programmed in IgorPro (WaveMetrics, Inc., USA). The data were smoothed using an 8 Hz dual-pass Butterworth filter and differentiated to yield velocities and accelerations of limb joints and segments. Tangential hand velocities were used to identify movement onsets and terminations. Movement onset was defined by the last minimum before tangential velocity (tanv) that was less than 0.01 m/s. Likewise, movement termination was defined by the first minimum after peak tangential velocity (tanv) less than 0.01 m/s (Sainburg & Wang, 2002).

Movement time (MT) was determined by the duration of a reach in seconds (s), from the time of movement onset (tanv<0.01 m/s) until movement offset (tanv < 0.01m/s). Final position error (FPE) was measured as the distance between the center of the target and the final cursor position: $FPE= ((x_e-x_t)^2 + (y_e-y_t)^2)^{0.5}$, where (x_e, y_e) is the coordinate location of final cursor position and (x_t, y_t) is the coordinate location of the target. Movement quality was measured as hand path linear deviation (HPLD), operationalized as a ratio between the major axis and the minor axis of the trajectory. A major axis was defined as the distance between the first and last points of the movement. The minor axis was defined as the furthest perpendicular distance from the hand path to the major axis. Finally, reaching frequency (RF) was measured during the choice condition to determine the hand selection percentage for each region of space. Reaches throughout the CHOICE trial were coded by hand and space. RF was measured as the percent of total reaches made to each space by each hand. For example, right hand RF to right space was calculated as the number of reaches made to right space with the right hand divided by the total number of reaches made to right space.

Movement time criteria were used to eliminate outliers from the data set. Upper and lower bounds of ± 3 standard deviations from the mean were used to identify outliers. 1.04% of the data was removed using this method. Additional outliers were removed based on false reaches during the trial sessions, for example, using the left hand in the forced right hand condition. An additional 13/3360 trials were removed through this method (0.387%). A total of 1.43% of the data points were removed.

HPLD, FPE, and MT were analyzed from only the F-Right and F-Left conditions. These variables determine interlimb differences in hand performance. HPLD, FPE, and MT were submitted to repeated measures 2 (Hand: right, left) by 3 (Space: Left, Middle, Right) analysis of variance (ANOVA). Since I am interested in the difference between the hands, interactions between hand and space were decomposed with three planned paired t-tests that compared the right and left hand in each region of the work space (left, middle, right). All statistical tests were evaluated at $\alpha = .05$.

RF from the CHOICE condition was analyzed to determine hand preference. During the CHOICE condition, the participant was instructed to reach with whichever hand he or she felt could reach more quickly and accurately to the target. Therefore, each of the 140 trials in the choice session was marked as either a “right hand reach” or a “left hand reach.” During analysis, the number of right hand reaches and left hand reaches were tallied for each region of space. RF was measured as the percent of total reaches made to each space by each hand.

Hand preference results from the Edinburgh Handedness Inventory were analyzed and displayed in Table 2. The cumulative total was calculated by adding the tallies for both right hand and left hand. The difference was calculated by subtracting the left hand tally from the right hand tally. Finally, the result (R) was calculated by dividing the difference by the cumulative total and multiplying by 100. This result was used to determine handedness ($R < -40$ = left-handed, $R > +40$ = right-handed, $-40 \leq R \leq +40$ = mixed-handed).

Chapter 3

Results

The results for MT displayed an interaction for hand by space, $F(2, 14) = 34.38$, $p < .001$, such that the right hand was slower in left space compared to the left hand ($t(7) = -3.68$, $p = .008$) and the right hand was faster in right space compared to the left hand ($t(7) = 8.23$, $p < .001$). The main effect of hand approached conventional levels of significance, $F(1,7) = 5.01$, $p = 0.06$. There was no main effect of space ($p = .425$). The results for MT are displayed in Figure 3.

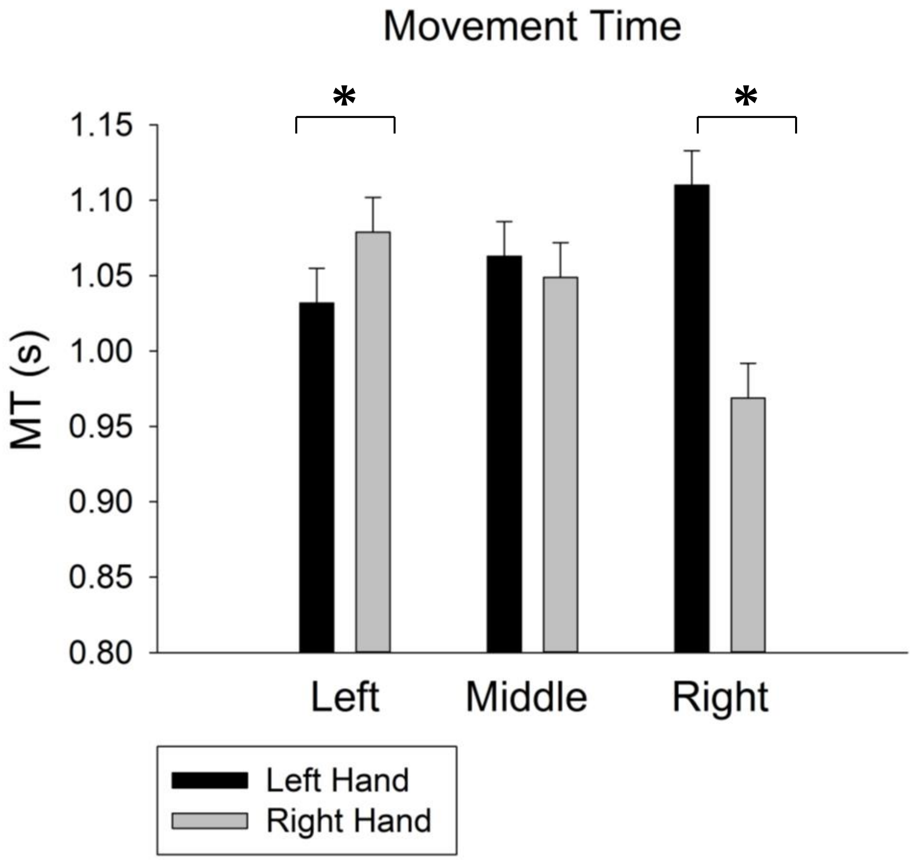

Figure 3: Mean MT in seconds as a function of reaching space and hand. MT for all reaches across all subjects were averaged into 3 workspace regions: Right, Middle and Left. Error bars represent standard error of the mean. This figure shows that reaches to contralateral space required the longest MT, whereas reaches to ipsilateral space required the shortest MT.

The results for HPLD displayed an interaction for hand by space, $F(2, 14) = 18.02$, $p < .001$, such that the left hand elicited greater HPLD in left space compared to the right hand ($t(7) = 2.75$, $p = .028$). There were no main effects of hand ($p = .437$) or space ($p = .607$). The results for HPLD are displayed in Figure 4.

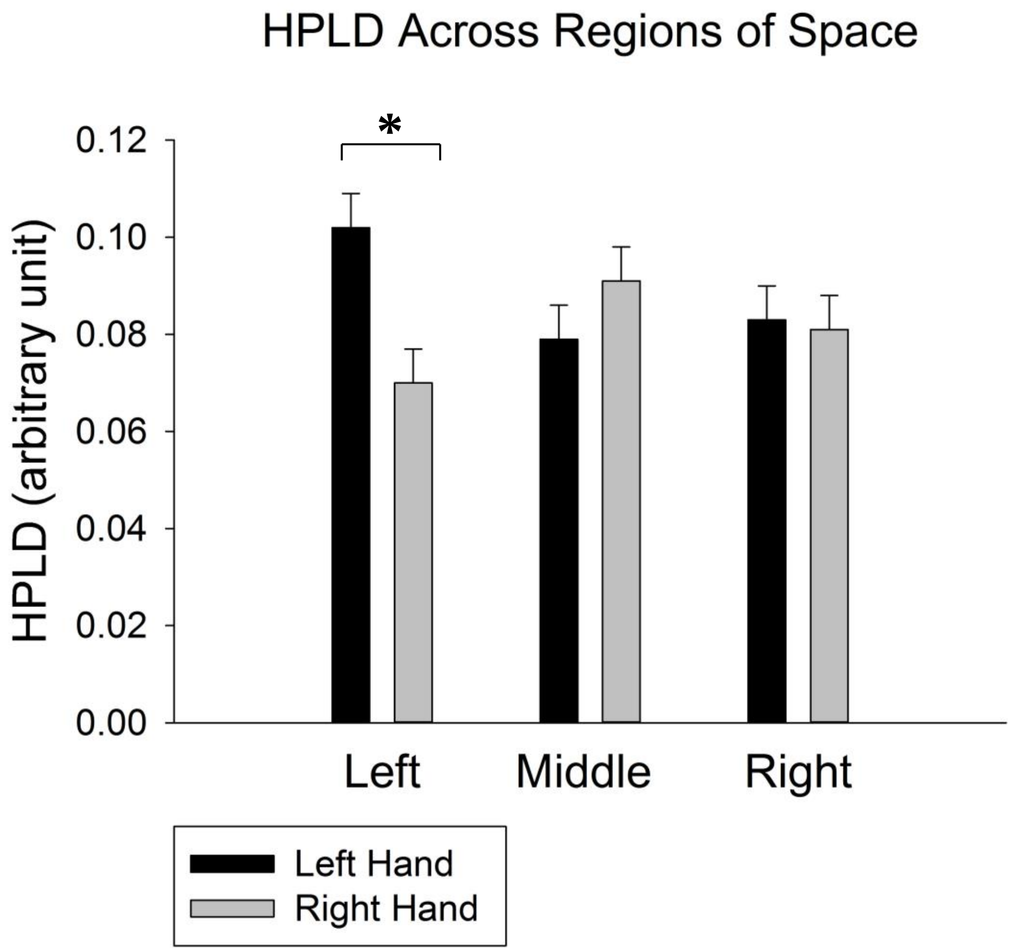

Figure 4: Mean HPLD in arbitrary units as a function of reaching space and hand. HPLD for all reaches across all subjects were averaged into 3 workspace regions: Right, Middle and Left. Error bars represent standard error of the mean. This figure shows that in left space, the HPLD for the left hand is significantly greater than the HPLD for the right hand. There is no significant difference for the HPLD of the right hand and left hand in either middle or right space.

The results for FPE did not elicit a main effect for hand ($p = .449$) or space ($p = .951$), or an interaction for hand by space ($p = .862$). The results for FPE are displayed in Figure 5.

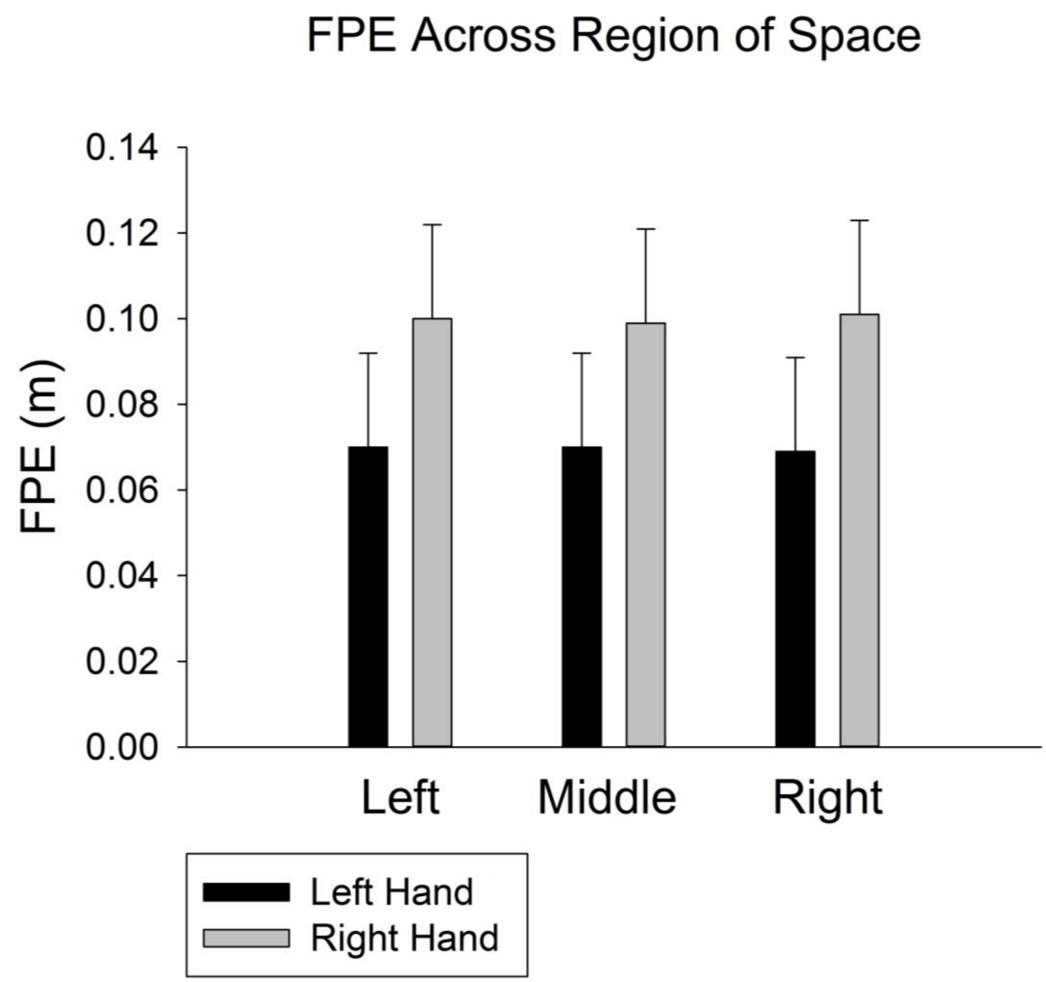

Figure 5: Mean FPE in meters as a function of reaching space and hand. FPE for all reaches across all subjects were averaged into 3 workspace regions: Right, Middle and Left. Error bars represent standard error of the mean. This figure shows that no significant difference existed between hands or regions of space.

The results for RF demonstrated an effect of space, $F(2, 14) = 1691.80$, $p < .001$, and an interaction for hand by space, $F(2, 14) = 290.32$, $p < .001$. The interaction was decomposed by three paired t-tests to examine RF for each hand as a function of reaching space. The left hand completed more reaches in left space compared to the right hand ($t(7) = 8.71$, $p<.001$). In contrast, the right hand completed more reaches in center (t(7) = -3.06, p=.018) and right (t(7) = -51.12,p<0.01) space. The percentage of reaches made by hand and space are displayed in Table 2. In order to determine how often participants used their left or right hand when given a choice, the RF was tallied for each hand. Participants selected their left arm to complete reaches 43.8 ± 8.0% of the time and their right arm 54.5 ± 8.8% of the time. Figure 6 shows RF as percentages of left and right hand reaches from the total number of reaches made to each space (left, middle, and right).

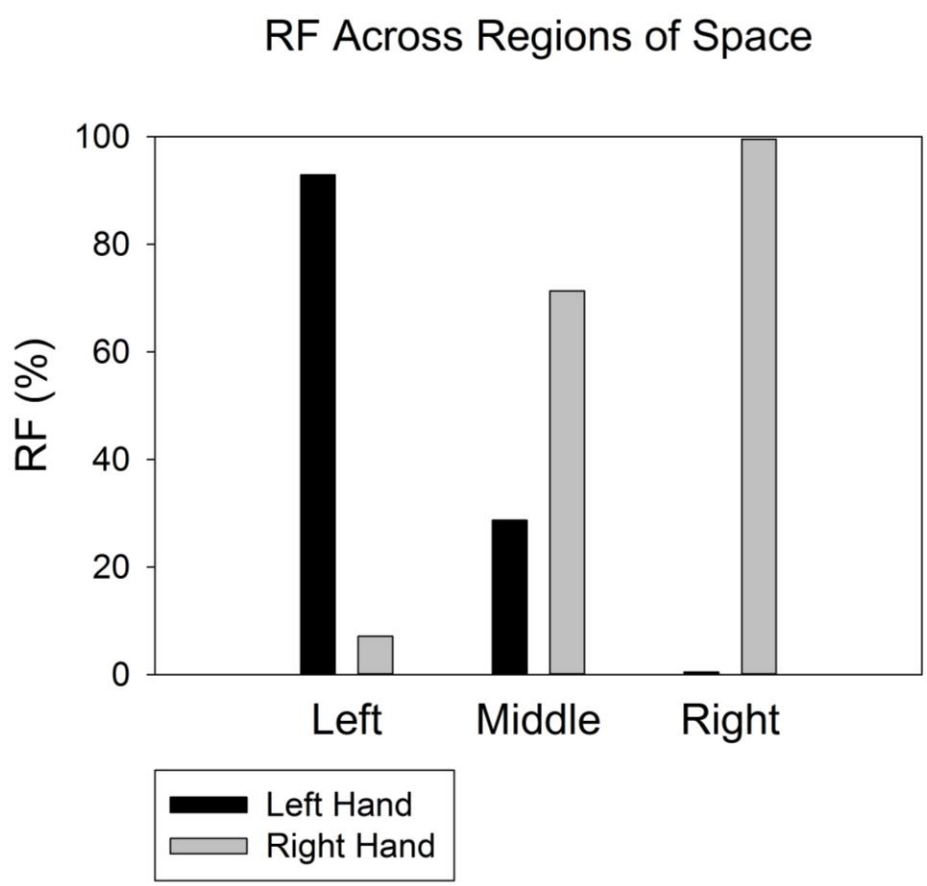

Figure 6: RF averaged across subjects. Reaches made during the CHOICE trial were coded by hand (Right or Left) and by the 3 categories of workspace regions: Right, Middle and Left. RF values for the left and right hands are displayed as percentages of the total number of reaches made to each space. This figure shows that the right hand was used more frequently in right space, while the left hand was used more frequently in left space. The right hand was used more frequently than the left hand in middle space.

Table 2

Hand Preference Measure Summary

	Hand Preference Task		**Hand Selection Task**					
	Edinburgh Handedness Inventory		**Left Hand**			**Right Hand**		
	Score	**Handedness**	**Left Space**	**Middle space**	**Right Space**	**Left Space**	**Middle space**	**Right Space**
S1	17.6	Ambidextrous	42%	8%	1%	1%	6%	36%
S2	87.5	Right Handed	37%	1%	0%	5%	13%	41%
S3	100	Right Handed	26%	1%	0%	17%	14%	42%
S4	100	Right Handed	43%	4%	0%	0%	10%	43%
S5	20	Ambidextrous	41%	4%	1%	1%	9%	42%
S6	71.4	Right Handed	43%	6%	0%	0%	8%	42%
S7	70	Right Handed	43%	6%	0%	0%	8%	42%
S8	80	Right Handed	42%	1%	0%	0%	13%	42%

As shown in Table 2, the results for the hand preference task, the Edinburgh Handedness Inventory, demonstrated that 6 of the participants were scored as right-handed and 2 of the participants were scored as mixed-handed. The mean score for the right-handed individuals was 84.82 ± 13.3, and the mean score for the mixed-handed individuals was 18.8 ± 1.7. The overall mean score on the inventory was 68.3 ± 32.6. The scores ranged from 17.6 (mixed-handed) to 100 (right-handed).

Chapter 4

Discussion

This study examined hand performance and hand preference in young adults with ADHD. I hypothesized that young adults with ADHD would demonstrate a pattern of non-right handedness compared to established patterns of healthy young adults who are right hand dominant. There were six main findings in this study. First, the reaches to contralateral space had the longest MT, whereas reaches to ipsilateral space had the shortest MT. Second, the left hand elicited greater trajectory curvature compared to the right hand, but only in the left space. Third, there was no difference in endpoint accuracy between the hands. Fourth, the left hand was selected more frequently when reaches were directed to targets in left space; however, the right hand was selected more frequently when reaches were directed to targets in middle or right space. Next, the Edinburgh Handedness Inventory revealed a trend towards mixed-handedness among the participants. Last, irrespective of target location in peripersonal space, participants selected to use their left arm 43.8% of the time, whereas they selected to use their right arm 54.5% of the time.

Hand Performance

Hand performance was evaluated by three kinematic variables: MT, HPLD, and FPE. For MT, the results demonstrated that the right hand was significantly slower in left space compared to the left hand ($p = .008$) and the right hand was significantly faster in right space compared to the left hand ($p < .001$). This finding is consistent with a plethora of work documenting that the hands elicit faster reaches in ipsilateral space (Coelho et al., 2013; Elliott & Roy, 1996; Przybyla et al., 2013; Sainburg, 2002). Elliot and Roy (1996) studied manual asymmetries in goal-directed reaching movements. Their work has created a model of MT behavior that ensures the validity of any reaching task by describing reaching behavior in ipsilateral and contralateral reaching space. My results were consistent with their model of hemispheric specializations in movement time. The main effect of hand for MT approached conventional levels of significance ($p = .06$), which suggests that hand influenced MT values. The Dynamic Dominance Model (2002) posits that the right and left hands are specialized for different aspects of reaching. This may explain the difference in movement time, inferring that one hand displays a movement time advantage over the other hand. However, a post-hoc analysis sample t-test would be necessary to determine this relationship if significance were reached. An increase in sample size could assist in the strength of this relationship. A final, notable difference seen in the ADHD population compared to healthy right handers was the overall amount of time taken for reaches in all of the spaces. Eliasson, Rösblad, and Forssberg (2004) report slower movement times among ADHD patients when compared to healthy adults in a reaching task, especially when visual feedback is not present. Eliasson et al. (2004) attribute this movement time disparity between ADHD patients and healthy adults to a detriment in motor programming capacity of reaching movements. Future research to compare the movement times between ADHD patients and healthy adults is needed to determine the validity of this observation.

The curvature of hand path trajectory during the reaching movement was measured by HPLD and was different for the left and right hand in left space, such that the left hand elicited greater HPLD than the right hand in left space. HPLD between the hands was not different in middle space or right space. Przybyla et al. (2013) found that the left hand had a significantly greater HPLD across all space (right, middle, left), indicating a more curved route taken by the left hand in all regions of space. In support of this finding, the Dynamic Dominance Model (Sainburg, 2002) states that in right-handed individuals, the left hemisphere is responsible for predictive or dynamic control such that the right hand will take the most efficient path to a target. The non-dominant right hemisphere handles stabilization control and will therefore take a curved route to the target rather than an efficient shorter path like the right hand (Coelho et al., 2013; Sainburg, 2014). Thus, the Dynamic Dominance Model is consistent with the HPLD findings in left space. However, no difference was found for HPLD in the ADHD group for reaches to middle or right space, suggesting a different pattern of cortical lateralization in this population as compared to the healthy young adult population described by the Dynamic Dominance Model. It is not conclusive if the left hand is becoming less deviant or if the right hand is becoming more deviant from the most efficient path in middle and right space. Further analysis of this data in comparison to healthy adult controls is needed to determine this relationship.

Endpoint accuracy was assessed by FPE. In the current work, FPE did not elicit an effect for hand or space, or an interaction between the two. FPE between the left hand and right hand reaches were not different in relation to space (right, middle, left). The Dynamic Dominance Model predicts that the right hand will have less FPE as compared to the left hand due to dynamic control of the left hemisphere. Przybyla et al. (2013) report that healthy young adults demonstrated a FPE that was smaller in the right hand in all space. However, my study concluded no difference between the hands in FPE among the ADHD patients. This comparison could mean that ADHD patients do not demonstrate the same cortical lateralization exhibited in the Dynamic Dominance Model. To that end, FPE differences between ADHD patients and healthy young adults can be attributed to either a decrease in right hand accuracy or an increase in left hand accuracy when compared to healthy controls. Further analysis is necessary to assess this relationship.

Hand Preference

Hand preference was determined by the Edinburgh Handedness Inventory and RF during the Kinreach® CHOICE trial. The Edinburgh Handedness Inventory classified six of the participants as right-handed and two participants as mixed-handed. These results are consistent with the longitudinal findings of Rodriguez et al. (2010), supporting the increased prevalence of mixed-handedness among the ADHD population. To that end, those who scored as right handed on the Edinburgh Handedness Inventory also showed a trend towards weak right handedness, as evidenced by the scores displayed in Table 2. 4 of the 6 right-handers scored ≤ 88 on the inventory, indicating a weaker right-handedness when compared to the other 2 right-handers who scored a 100 on the inventory, the highest possible score for right handedness.

RF results indicated that the left hand was selected more frequently when reaches were directed to targets in left space; however, the right hand was selected more frequently when reaches were directed to targets in middle or right space. The pattern of right hand dominance in right space and left hand dominance in left space is consistent with the tendency to use each limb for the closest region of peripersonal space (Elliot and Roy, 1996). An interesting finding was that adults with ADHD used their left hand more frequently (28.7% of the time) when reaching to targets in middle space, compared to 6.5% of the time for healthy young adults examined by Sainburg and colleagues (2014). This comparison between the ADHD participants in my study and the healthy controls in the previous study (Przybyla et al., 2013) indicates an abnormal cortical lateralization and lack of strong dominance by the right or left hemisphere, a trait attributed to ADHD and other neurodevelopmental disorders (Geschwind & Galaburda, 1985; Orton, 1937; Smalley et al., 2005).

I hypothesized that young adults with ADHD would not select their right hand as often as healthy young adults. When completing reaches to targets distributed across peripersonal space, adults with ADHD selected to use their right arm 54.5% of the time. This represents a substantial decrease from healthy controls, who selected the right arm 68% of the time Przybyla et al. (2013). Healthy controls chose to reach with the right hand a higher percentage of the time compared to the ADHD patients, indicating a weaker dominance of the left hemisphere. Thus, my findings are in support of the conclusion that ADHD patients exhibit an abnormal cortical lateralization as well as a prevalence of mixed-handedness (Brandler & Paracchini, 2014; Geschwind & Galaburda, 1985; Rodriguez et al., 2010; Smalley et al., 2005).

Importance of Combined Handedness Measures

Comparison of both hand performance and hand preference measures reveals the importance of using multiple measures to assess handedness. The use of multiple hand preference measures (the Edinburgh Handedness Inventory and Hand Selection Kinereach® Task) will be compared. For each participant, the percentage of reaches made by hand and space are displayed in Table 2. These values can be evaluated in conjunction with the scores in the Edinburgh Handedness Inventory, also presented in Table 2. Important conclusions can be drawn from the within-subject comparison of multiple hand preference measures in Table 2. First, the only participants who made left hand reaches to right space were the 2 participants scored as mixed-handed in the Edinburgh Handedness Inventory. This observation gives support to the reliability of these measures. Second, although participants 3 and 4 were both scored as strongly right-handed (100) on the Edinburgh Handedness Inventory, their CHOICE trial results showed a different pattern. Participant 3 shows a strong right-handedness throughout the choice trial, with only 27% reaches with the left hand and 17% reaches with right hand into left space. However, participant 4 shows more of a mixed-handed pattern, with no reaches to right space with left hand or reaches to left space with right hand. This observation shows that each of the measures contributes to the assessment of handedness, and that one measure alone may not be sufficient in determining handedness.

The combination of hand performance measures and hand preference measures may provide additional validity when determining handedness. In the study conducted by Przybyla et al. (2013), data obtained from performance measures confirmed the right handedness of all participants. Przybyla et al. (2013) concluded that right-handed participants showed the greatest end point accuracy with the right hand and the greatest hand path curvature with the left hand. However, in my assessment of hand performance of ADHD patients, there was no difference in end point accuracy between the hands and no difference in hand path curvature between the hands except in left space. The lack of difference in FPE and HPLD between the hands suggests a decrease or lack of cerebral dominance in ADHD participants. In comparison to these hand performance measures, my study of hand preference via the Edinburgh Handedness Inventory and the hand selection Kinereach® task revealed that varying levels of right hand dominance existed among my participant pool. Two of the participants scored as mixed-handed on the Edinburgh Handedness Inventory, and an additional two participants showed a pattern of mixed-handedness in the hand selection Kinreach ® task (Table 2). Although all participants self-identified themselves as right-handed, the measures (both performance and preference) indicate a trend towards mixed-handedness in six out of the eight participants, a conclusion that could not have been determined without both performance and preference measures.

Conclusions

In this study, I expected that adults with ADHD would show abnormal patterns of hand dominance, exhibited in both performance and preference measures. To that end, I also predicted the necessity of multiple handedness measures to accurately determine dominance. This research has produced 3 main conclusions that are consistent with previous literature.

The first conclusion is that ADHD participants exhibit a different pattern of cortical lateralization than the health young adult population, evidenced by hand performance. When observing hand performance measures, healthy young adults demonstrate dominance in accordance with the Dynamic Dominance Model (Sainburg, 2002), while ADHD show deviation from this model. In ADHD, there is no difference in end point accuracy between the hands and no difference in hand path curvature between the hands except in left space. In healthy adults, the right hand had greater endpoint accuracy while the left hand had more hand path curvature, indicating the right hand as dominant. The lack of difference in FPE and HPLD between the hands confirms the lack of dominance among the ADHD participants. Sainburg (2014) terms this deviation from the Dynamic Dominance Model as a hybridization of hemispheric control, a phenomenon originally observed in stroke patients. This conclusion has significance in the area of ADHD diagnosis. With further research using functional MRI, this lack of strong dominance in handedness could be supported by a lack of dominance at the cortical level as well. Further, these findings could eventually contribute to the diagnostic criteria of ADHD.

The second conclusion of this study is that ADHD patients exhibit a trend towards mixed-handedness, signifying abnormal cortical lateralization (Reid & Norvilitis, 2000). Hand preference measures demonstrate this trend towards mixed-handedness among ADHD patients. Both the Edinburgh Handedness Inventory and the hand selection Kinreach® task indicated either mixed-hand dominance or weak right handed dominance among 75% of the participants in this study. In conclusion, these preference results are in alignment with hypothesis of anomalous lateralization (Brandler & Paracchini, 2014; Geschwind & Galaburda, 1985; Reid & Norvilitis, 2000), which posits that abnormal cortical lateralization occurs more prevalently in ADHD populations. This mixed-handedness prevalence among ADHD populations is also supported by longitudinal analysis (Rodriguez et al., 2010).

The final conclusion of this study is the value of multiple measures of handedness in the assessment battery of hand dominance. In this study, hand performance was assessed through FPE and HPLD. In addition to hand performance, this study presented 2 different measures of hand preference - the Edinburgh Handedness Inventory and the hand selection Kinereach ® task determining RF. Although all of these measures ultimately determined hand dominance, information was gleaned from each of them to provide a more accurate assessment of dominance. While the Edinburgh Handedness Inventory only indicated 2 participants as mixed-handed, the RF, FPE, and HPLD indicated that 6 of the 8 participants presented a mixed-handed profile of reaches. This concludes the importance of multiple measures to assess hand dominance and concurrent hemispheric dominance.

Future Directions

This study evaluated hand performance and preference in adults with ADHD. This thesis examined a group of 8 ADHD participants, and compared to control data from an alternate publication. In order to perform more in-depth analysis of these comparisons, a between group analysis is necessary between the ADHD participants and a control group. Movement time data was not reported in the previous study by Przybyla et al. (2013), so these comparisons could be made with a full data set of both ADHD participants and matched controls.

The results of this study conclude an abnormal pattern of cortical lateralization in the ADHD population. However, these results are solely based on the behavioral data collected from the Kinereach ® and the Edinburgh Handedness Inventory. Magnetic resonance imaging (MRI) may be a useful tool to further assess cerebral organization. Anatomical and functional MRI could demonstrate structural and performance-related asymmetries between the hemispheres

This study examined handedness as an indicator of cerebral dominance. I elected to evaluate handedness because it is an example of a lateralized function in most individuals. I assessed handedness through multiple measures, and used these measures to infer lack of strong cerebral dominance in the ADHD population. Future research could examine different lateralized processes, such as language, in order to substantiate the idea of abnormal cortical lateralization in the ADHD population.

References

Akpinar, S., Sainburg, R. L., Kirazci, S., & Przybyla, A. (2014). Motor Asymmetry in Elite Fencers. *Journal of motor behavior*(ahead-of-print), 1-10.

American Psychiatric Association., & American Psychiatric Association. DSM-5 Task Force. (2013). *Diagnostic and statistical manual of mental disorders : DSM-5* (5th ed.). Arlington, Va.: American Psychiatric Association.

Annett, M. (1998). Handedness and cerebral dominance: the right shift theory. *J Neuropsychiatry Clin Neurosci, 10*(4), 459-469.

Barkley, R. A. (1998). Attention-deficit hyperactivity disorder. *Sci Am, 279*(3), 66-71.

Brandler, W. M., & Paracchini, S. (2014). The genetic relationship between handedness and neurodevelopmental disorders. *Trends Mol Med, 20*(2), 83-90. doi: 10.1016/j.molmed.2013.10.008

Broca, P. (1861). Perte de la parole, ramollissement chronique et destruction partielle du lobe antérieur gauche du cerveau. *Bulletin de la Société Anthropologique, 2*, 235-238.

Buddenberg, L. A., & Davis, C. (2000). Test–retest reliability of the Purdue Pegboard Test. *American Journal of Occupational Therapy, 54*(5), 555-558.

Coelho, C. J., Przybyla, A., Yadav, V., & Sainburg, R. L. (2013). Hemispheric differences in the control of limb dynamics: a link between arm performance asymmetries and arm selection patterns. *J Neurophysiol, 109*(3), 825-838. doi: 10.1152/jn.00885.2012

Colby, K. M., & Parkison, C. (1977). Handedness in autistic children. *Journal of autism and childhood schizophrenia, 7*(1), 3-9.

Coren, S. (1990). *Left-Handedness: Behavioral Implications and Anomalies: Behavioral Implications and Anomalies*: Elsevier.

Darrah, J., Hodge, M., Magill-Evans, J., & Kembhavi, G. (2003). Stability of serial assessments of motor and communication abilities in typically developing infants—implications for screening. *Early Human Development, 72*(2), 97-110. doi: http://dx.doi.org/10.1016/S0378-3782(03)00027-6

Eglinton, E., & Annett, M. (1994). Handedness and dyslexia: A meta-analysis. *Perceptual and Motor Skills, 79*(3f), 1611-1616.

Eliasson, A.-C., Rösblad, B., & Forssberg, H. (2004). Disturbances in programming goal-directed arm movements in children with ADHD. *Developmental Medicine & Child Neurology, 46*(01), 19-27.

Elliott, D., & Roy, E. A. (1996). *Manual asymmetries in motor performance*. Boca Raton: CRC Press.

Espe-Pfeifer, P., & Wachsler-Felder, J. (2000). *Neuropsychological interpretation of objective psychological tests*: Springer Science & Business Media.

Faraone, S. V., Biederman, J., & Mick, E. (2006). The age-dependent decline of attention deficit hyperactivity disorder: a meta-analysis of follow-up studies. *Psychological medicine, 36*(2), 159-165. doi: 10.1017/S003329170500471X

Geschwind, N., & Galaburda, A. M. (1985). Cerebral lateralization: Biological mechanisms, associations, and pathology: I. A hypothesis and a program for research. *Archives of neurology, 42*(5), 428-459.

Gesell, A., & Ames, L. B. (1947). The development of handedness. *The Pedagogical Seminary and Journal of Genetic Psychology, 70*(2), 155-175.

Gillberg, C., Gillberg, I. C., Rasmussen, P., Kadesjo, B., Soderstrom, H., Rastam, M., . . . Niklasson, L. (2004). Co-existing disorders in ADHD -- implications for diagnosis and intervention. *Eur Child Adolesc Psychiatry, 13 Suppl 1*, I80-92. doi: 10.1007/s00787-004-1008-4

Hopkins, W. D. (2013). Neuroanatomical asymmetries and handedness in chimpanzees (Pan troglodytes): a case for continuity in the evolution of hemispheric specialization. *Ann N Y Acad Sci, 1288*, 17-35. doi: 10.1111/nyas.12109

Hopkins, W. D., & Cantalupo, C. (2004). Handedness in chimpanzees (Pan troglodytes) is associated with asymmetries of the primary motor cortex but not with homologous language areas. *Behav Neurosci, 118*(6), 1176-1183. doi: 10.1037/0735-7044.118.6.1176

Hopkins, W. D., Phillips, K. A., Bania, A., Calcutt, S. E., Gardner, M., Russell, J., . . . Schapiro, S. J. (2011). Hand preferences for coordinated bimanual actions in 777 great apes: implications for the evolution of handedness in hominins. *J Hum Evol, 60*(5), 605-611. doi: 10.1016/j.jhevol.2010.12.008

Kadesjo, B., & Gillberg, C. (1999). Developmental coordination disorder in Swedish 7-year-old children. *Journal of the American Academy of Child and Adolescent Psychiatry, 38*(7), 820-828. doi: 10.1097/00004583-199907000-00011

MacNeilage, P. F., Rogers, L. J., & Vallortigara, G. (2009). Origins of the left & right brain. *Sci Am, 301*(1), 60-67.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia, 9*(1), 97-113. doi: http://dx.doi.org/10.1016/0028-3932(71)90067-4

Orton, S. T. (1937). *Reading, writing and speech problems in children*. New York, NY, US: W W Norton & Co.

Pitcher, T. M., Piek, J. P., & Hay, D. A. (2003). Fine and gross motor ability in males with ADHD. *Dev Med Child Neurol, 45*(8), 525-535.

Przybyla, A., Coelho, C. J., Akpinar, S., Kirazci, S., & Sainburg, R. L. (2013). Sensorimotor performance asymmetries predict hand selection. *Neuroscience, 228*(0), 349-360. doi: http://dx.doi.org/10.1016/j.neuroscience.2012.10.046

Reid, H. M., & Norvilitis, J. M. (2000). Evidence for anomalous lateralization across domain in ADHD children as well as adults identified with the Wender Utah rating scale. *Journal of Psychiatric Research, 34*(4), 311-316.

Rodriguez, A., Kaakinen, M., Moilanen, I., Taanila, A., McGough, J. J., Loo, S., & Järvelin, M.-R. (2010). Mixed-handedness is linked to mental health problems in children and adolescents. *Pediatrics, 125*(2), e340-e348.

Rogers, L. J., Zucca, P., & Vallortigara, G. (2004). Advantages of having a lateralized brain. *Proc Biol Sci, 271 Suppl 6*, S420-422. doi: 10.1098/rsbl.2004.0200

Sainburg, R. L. (2002). Evidence for a dynamic-dominance hypothesis of handedness. *Experimental Brain Research, 142*(2), 241-258.

Sainburg, R. L. (2005). Handedness: differential specializations for control of trajectory and position. *Exerc Sport Sci Rev, 33*(4), 206-213.

Sainburg, R. L. (2014). Convergent models of handedness and brain lateralization. *Front Psychol, 5*, 1092. doi: 10.3389/fpsyg.2014.01092

Sainburg, R. L., & Wang, J. (2002). Interlimb transfer of visuomotor rotations: independence of direction and final position information. *Experimental Brain Research, 145*(4), 437-447.

Smalley, S. L., Loo, S. K., Yang, M. H., & Cantor, R. M. (2005). Toward localizing genes underlying cerebral asymmetry and mental health. *American Journal of Medical Genetics Part B: Neuropsychiatric Genetics*, *135*(1), 79-84.

Vallortigara, G., & Rogers, L. J. (2005). Survival with an asymmetrical brain: advantages and disadvantages of cerebral lateralization. *Behav Brain Sci, 28*(4), 575-589; discussion 589-633. doi: 10.1017/s0140525x05000105

Wang, H. Y., Huang, T. H., & Lo, S. K. (2011). Motor ability and adaptive function in children with attention deficit hyperactivity disorder. *Kaohsiung J Med Sci, 27*(10), 446-452. doi: 10.1016/j.kjms.2011.06.004

Williams, S. M. (1991). Handedness inventories: Edinburgh versus Annett. *Neuropsychology, 5*(1), 43-48. doi: 10.1037/0894-4105.5.1.43

ACADEMIC VITA

Nicolette M. Morreale

Permanent Address:
29 Upton Way
Sewell NJ, 08080

Contact Information:
Mobile: 856.981.5129
Email: nwm5102@psu.edu

EDUCATION

The Pennsylvania State University, Schreyer Honors College **University Park**
College of Health and Human Development *Graduation: May 2015*
Bachelor of Science in Kinesiology - Movement Science, Minor in Psychology

Brunel University **Uxbridge, United Kingdom**
West London Study Abroad Program *Summer 2013*

RELEVANT EXPERIENCE

Motor Control, Cognition, and Neuroimaging Laboratory **University Park, PA**
Honors Research Assistant *Oct 2013 – Present*

- Conduct participant-based, honors thesis research to observe mixed-handedness in young adult ADHD patients
- Attend weekly meetings and analyze relevant peer-reviewed journal articles
- Knowledgeable and proficient in running participants through the Kinereach data collection simulator and analysis of the output variables

Weisman Children's Rehabilitation Hospital **Marlton, NJ**
Volunteer *May 2014 – Present*

- Assist with aquatic therapy program and organized activities for children and visiting siblings
- Observe a pediatric physical therapist in an inpatient rehabilitation setting

NovaCare Outpatient Rehabilitation **Ventnor City, NJ**
Summer Volunteer *June 2013-Aug 2013*

- Experienced the atmosphere of an outpatient rehabilitation setting, including insight into the treatment of diverse ages and cultures
- Observed initial evaluations and learned about computerized treatment database used in NovaCare and other facilities
- Organizational responsibilities included sanitizing beds for new patients, organizing stim pads, and cleaning towels and linens used daily

Friends Fitness Program **State College, PA**
Mentor *Sept 2012 – Dec 2013*

- Paired up with high school students who were recommended to the program because of neurological or social disorders
- Instructed and monitored an individual teen with Autism in a weekly fitness program at a local gym
- Acted as a mentor to promote physical fitness and healthy living while allowing the mentee to communicate any issues in school or at home
- Helped my individual mentee improve arm strength and enabled her to play the cymbals in her high school marching band

Sunspectrum Outpatient Rehabilitation **Sewell, NJ**
Aide *July 2011- Aug 2012*

- Assisted with treatment of outpatient physical therapy patients and office responsibilities of the facility
- Oversaw aqua therapy programs, demonstrated exercises, and timed sets

LEADERSHIP EXPERIENCE

Penn State IFC Panhellenic Dance Marathon Hospitality Committee **University Park, PA**
Member, Assistant Captain (Cadet) *Sept 2013 – Present*

- Served food to the dancers during THON weekend
- Contacted potential donors and interacted with donors and Four Diamonds families
- Raised money for the Four Diamonds Fund and the pediatric cancer research (Committee Total: $1500, THON Total: $13.3 million 2014, $13.0 million 2015)

Neuroanatomy Teaching Assistant **University Park, PA**
Teaching Assistant *Jan 2015-Present*

- Assisted with practical assessments and structure identification
- Held office hours weekly and answered questions about material
- Gained working knowledge of Clinical Neuroanatomy

Biology Peer Leader **University Park, PA**
Teaching Assistant *Sept 2012 – Dec 2012*

- Led a class of 10 students in discussions about the Biology I lecture material, retaught any topics that needed clarification
- Shared study techniques and helped all 10 students receive exam grades within the top 25% of the class

Kinesiology Club **University Park, PA**
5K Chair *May 2012 – May 2013*

- Organized a 5K race benefiting the Kinesiology club
- Raised over $1000 and had an attendance of over 100 participants in the race

PROFESSIONAL EXPERIENCE

Shelly's Breakfast Café **Ventnor City, NJ**
Food-Runner *May 2014 – Present*

- Organized orders and delivered them to the correct tables
- Dealt with various customers and employees in a high-pace pressure situation (~200 orders/day)

JoJo's Woodfire Pizza and Grill **Ventnor City, NJ**
Hostess and Counter Service *June 2013 – Aug 2013*

- Worked with other employees in order to provide quality and timely customer service
- Dealt with customers over the phone and in person on a daily basis, created a positive customer environment

Diversified Search **Philadelphia, PA**
Summer Intern *June 2010 – Aug 2011*

- Assisted with organization and verification of accuracy of healthcare networks within companies search database
- Worked on a project with the research department to organize and identify potential healthcare administrators for executive placement

ACADEMIC HONORS

- Schreyer Academic Excellence Scholarship Aug 2011-Present
- Schreyer Ambassador Travel Grant June 2013-July 2013
- Poster presentation at SCAPPS Neuroscience Conference in London, Ontario October 2014
- Phi Eta Sigma National Honors Society Jan 2012-Present
- The National Society of Collegiate Scholars Jan 2012-Present

SKILLS / INTERESTS

- Working knowledge in Microsoft Products: Excel, PowerPoint, and Word
- Knowledgeable in: MatLab, IGORPro, EndNote, SPSS
- Interests include: Exercise and fitness, Penn State Dance Marathon (THON), Soccer (participate in Intramural at Penn State), photography