THE PENNSYLVANIA STATE UNIVERSITY

SCHREYER HONORS COLLEGE

DEPARTMENT OF KINESIOLOGY

HEMISPHERIC LATERALIZATION AND INTERHEMISPHERIC TRANSFER ASYMMETRIES IN MANUAL STEREOGNOSIS

JORDAN E. SCOTT

Spring 2021

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:

Robert Sainburg
Professor of Kinesiology and Neurology
Thesis Supervisor

Jonas Rubenson
Associate Professor of Kinesiology
Honors Adviser

* Signatures are on file in the Schreyer Honors College.

TABLE OF CONTENTS

ABSTRACT

Manual stereognosis, the ability to mentally perceive dimension and depth through tactile sensation and integration, is a complex process. Studies have reported inconsistent findings, due largely to different measures of performance. Since as early as 1906, the left hemisphere has been theorized to be dominant for stereognosis (Moll, 2017). Based on this hypothesis, I predicted the right-hand should show performance advantages in manual stereognosis tasks. A secondary exploratory goal assessed the effect of opposite hand exposure on performance.

Participants of this study unimanually and blindly wielded 3D-printed cylinders of diameters ranging from 1 mm to 16 mm for three seconds. Without feedback, they selected which size cylinder they believed matched the one that they wielded. They completed 64 trials with one hand then switched hands for an additional 64 trials with the opposite hand. First exposure was defined as the hand used for the first 64 consecutive trials whereas second exposure referred to the hand used in the second round of 64 trials. MATLAB numeric computing software randomly assigned which hand went first exposure.

We recorded error magnitude (difference in true cylinder diameter (mm) minus selected cylinder diameter) to be inversely related to stereognosis accuracy. The results did not fully match the hypothesis of left hemisphere dominance. Instead, our post hoc tests (Tukey HSD) showed lowest performance in the right hand, second exposure group (mean ± SE: -1.29 ± 0.48) and highest performance in the left hand, second exposure group (0.03 ± 0.59). The results of this study support previous studies which also found left hand (right hemisphere) improvements in stereognosis (Zaidel, 1998).

I propose three possible explanations for the observed left hand improvement in the stereognostic task. First, the left hemisphere may have more ipsilateral control than the right hemisphere (Zaidel, 1998). Second, the left hemisphere may also help maintain working memory of the manipulated objects' sensory information (Miquée, 2008; Stoeckel, 2004). Additionally, I hypothesize that the right hand has greater fine-motor control which leads to a better calibration and subsequently more accurate second exposure of the left hand.

LIST OF FIGURES

ACKLOWEDGEMENTS

I would like to give a huge thank you to Dr. Sainburg. Over the past few years, Dr. Sainburg has allowed me to work on multiple projects in both the University Park and Penn State College of Medicine labs. I came to the lab group as the youngest member and with no formal research experience. However, Dr. Sainburg provided me countless insights, advice, and always included me in the lab group. Dr. Sainburg has had an established and impactful career, a successful tenure which did not need to incorporate me. Despite this, he allowed me to join the group (I don't think there was an opening even available in the lab) which has profoundly impacted my academic career. His unique research has allowed me to explore both basic science and translational/clinical work. I was told in order to not be excluded from medical schools I would need to do research. Nonetheless, I found previous labs tedious and boring. Consequently, I swore I would never join a research lab. It was until I heard Dr. Sainburg explain his research outputs that I realized research is fascinating and a task I wanted to undertake. I sincerely appreciate all you have done to help advance my academic career, Dr. Sainburg!

Additionally, I would like to thank Brooke Dexheimer for her constant and immense help throughout this whole process. Brooke has helped perform much of the heavy lifting on my thesis. From helping me with statistics, to perpetual proof-reading and edits, to making herself available and accessible at a moments whim, I could not have done this thesis without Brooke. Also, Brooke helped keep this as low-stress and high productivity as possible. Brooke has her own research and PhD coursework to complete, but she always carved time for me and genuinely cared for my thesis. For this, I am extremely thankful!

I would also like to thank Dr. Brad Wyble (Associate Professor of Psychology) and Ryan O'Donnell (Cognitive Psychology PhD candidate) for helping collaborate on this study. They helped influence our wielding apparatus design, asked constructive questions, and started this study.

I would also like to thank my honors advisor, Dr. Jonas Rubenson. He allowed me to be flexible with courses and on-top of my honors requirements. Thank you for making this entire process relaxed and efficient.

Lastly, the research reported on this thesis was supported by the National Institutes of Health Award Number R01HD059783. The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH. Thank you to all who helped make my thesis possible!

Chapter 1

Introduction

Stereognosis is the mental ability to perceive dimension and depth by tactile senses without visual feedback (Stereognosis, n.d.). The word stereognosis originates from the Greek words “stereo,” meaning solid, and “gnosis,” meaning knowledge (Schermann, 2020). This ability to discriminate haptic objects in absence of visual feedback is seemingly mundane and often underappreciated. However, stereognosis is frequently employed in daily activities. For example, it allows one to grab a quarter out of their pant pocket to pay the cashier instead of a similarly shaped button. The utility of this skill becomes apparent from those suffering the vexing battles of astereognosis. The impairment is experienced as result of common somatosensory deficits following stroke such as decreased pressure sensitivity, spatial acuity, and proprioception (Connell, 2008).

Despite the seemingly simple tasks which rely upon stereognosis, the neural underpinnings have proved complex. Hemispheric dominance has shown itself elusive to pin-down with varying results depending on the research paradigm (Zaidel, 1998). Aside from conflicting hemisphere lateralization data, interhemispheric transfer of tactile information has been remarkably complex due to neurological paradoxes and confounding variables (Tovar-Moll, 2014).

Amidst the murkiness of stereognosis, there have been two prevailing tenants. First, all studies have, in part, correlated stereognosis with parietal activation (Koch, 2011; Moll, 2017; Stoeckel, 2004; Deibert, 1999; Reed, 2004; Fabri, 2005). Secondly, cerebral hemispheres integrate tactile somatosensory input from the hand contralateral (Fabri, 2005; Roland, 1976).

The presence and/or degree to which stereognosis is controlled ipsilaterally remains controversial.

Anatomy

In 1906, Hermann Oppenheim reported one of the first pieces of evidence to locate manual stereognosis integration in the brain. He studied a patient with a left parietal lobe tumor, who presented with bilateral astereognosis. Consequently, Oppenheim proposed left parietal dominance for stereognosis function in both hands (Moll, 2017). In order for a brain function to be categorized as *dominant*, there must be a behavioral deficit on both sides of the body from a unilateral lesion, such as the case described above (Ross, 1997). However, since Oppenheim's report, few additional documented cases of bilateral astereognosis from unilateral cerebral lesion have been reported.

As technology has advanced, researchers have used functional magnetic resonance imaging (fMRI) to track neural activation during stereognosis. Participants are often asked to discriminate objects in either the left or right hand while neural activation is monitored in both the ipsilateral and contralateral hemispheres. These studies have shown persistent activation of somatosensory areas SI and posterior parietal cortex (PPC) in the contralateral hemisphere (Fabri, 2005). Earlier studies (Roland, 1976) have also shown contralateral hemisphere activation during stereognostic discrimination by tracking regional cerebral blood flow (rCBF).

Cerebral activation has also been associated in the primary motor cortex (M1) and frontopolar cortex (FPC) during manual stereognosis tasks (Fujii, 2011). Intuitively, it seems the primary motor cortex must play a role simply out of the required manual manipulation. FPC is believed to play a role in working memory of integrated information (Kim, 2015). Upon lesioning to FPC, primates displayed impaired ability to learn novel objects (Boschin, 2015). Proper working memory may be critical to stereognosis in order to evaluate and compare previously wielded objects.

While stereognosis does not involve visual feedback, it may still tap into visual cortices to create internal object recognition. The fusiform gyrus is involved in specialized functions of high-level vision and shows heightened right-hemisphere activation during stereognosis (Weiner, 2016; Fujii, 2011). While there is no visual feedback in stereognosis, this may suggest that the same neural pathways are utilized in stereognosis as high-level visual object recognition.

However, other studies (Reed, 2004) have challenged this emphasis placed upon the visual cortex instead of somatosensory association cortices. Reed (2004) instead found the most prominent activation in secondary somatosensory areas in the parietal operculum (SII) and insula. This finding is consistent with Oppenheim's earlier hypothesis of parietal imperiality for stereognosis. Although, the role and neural mechanisms of each hemisphere in stereognosis is incompletely understood.

Because previous stereognosis research has provided inconclusive and at times conflicting results, as well as the clinical importance of tactile sensory integration following cerebral infarction, this thesis aims to elucidate the responsibilities of each hemisphere in manual stereognosis. I hypothesize the left hemisphere will be dominant for stereognosis in right-handers by showing less error than its contralateral analog. This hypothesis is based upon Oppenheim's previous result of bilateral astereognosis with a left hemisphere lesion. Additionally, more recent fMRI activation studies have indicated left hemisphere predominance for stereognosis information encoding (Miquée, 2007). I therefore predict a right hand advantage for stereognosis in a unique task that assesses stereognostic resolution by wielding plastic (3D-printed) cylinders of finely graded sizes.

Chapter 2:

Methods

Participants

Participants were six neurologically intact, right-handed individuals aged 18-25. The handedness of each of the subjects was determined by a questionnaire adapted by Hull (1936). This questionnaire asked participants to self-report their preferred hand for a variety of daily tasks. Informed consent was given prior to subject participation which was approved by The Pennsylvania State University's Institutional Review Board (IRB).

Experimental Setup

Participants were seated in a chair at a table with the researcher on the other side of the table. Between the participant and researcher was a boxed apparatus, as shown in Figure 1. The apparatus contained a cutout opening covered by a curtain to allow participants to blindly wield the cylinders during the experimental task. Behind the curtain was an empty dish. The cylinders were placed in this dish each trial.

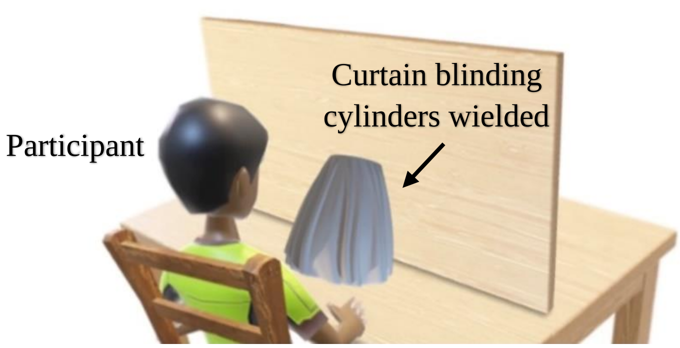

Figure 1: Blind wielding apparatus

We created sixteen 3D-printed cylinders for participants to wield during our experimental task. Cylinders were precisely measured to successively increase diameter size from 1 mm up to 16 mm (*Figure 2*). We created two sets of cylinders: one set was used by the researcher to place in the dish for each participant to wield; the other was presented in front of participants to reference their selections each trial.

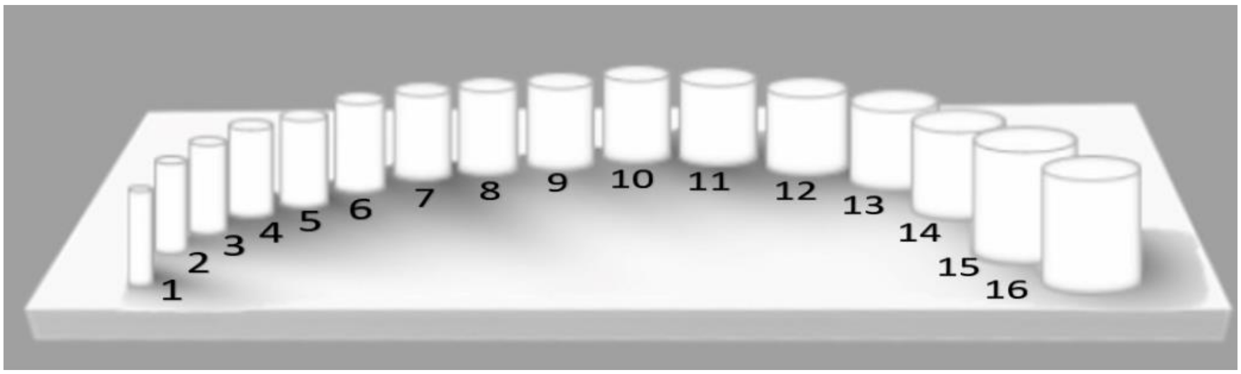

Figure 2: Cylinder array presented for participants to reference each trial with diameter size labeled (mm)

Experimental Task

Participants were seated in front of the blind wielding apparatus (*Figure 1*). A custom program created with MATLAB (2010) generated a pseudorandom order in which participants would wield each cylinder. The researcher would then place the appropriate cylinder size in the dish, which was not visible to participants. After the researcher placed the proper cylinder size on the dish, the researcher would confirm to MATLAB they had placed the correct cylinder. Upon this confirmation, a beep informed the participants to reach under the curtain to wield the cylinder with the instructed hand. The participant then had three seconds to grasp and wield the cylinder with their hand. After three seconds, the participant heard another beep which meant it was time for them to select which cylinder size they held. There was an array of cylinder options ranging from 1 mm to 16 mm diameter (*Figure 2*). They were not allowed to touch these cylinders. The participant would then provide their verbal selection to the researcher. The researcher then recorded the cylinder number in MATLAB (labeled 1 through 16, conferring the cylinder diameter). However, MATLAB only used cylinder 4 mm through 12 mm to allow room for errors above/below cylinder size. After the participant selected which cylinder size they believed they were wielding, they placed the cylinder in their hand back in the dish and awaited the next trial. This wield and select process occurred for 64 trials until a different beep occurred and the researcher instructed the participant to switch hands for another 64 trials. Thus, each participant performed 128 trials across both hands. A custom program created with MATLAB randomized the hand each participant would start the task with, thus, counterbalancing the number of participants who started the task with their left or right hand. No feedback by the researcher on the participant's trial performance was permitted.

Outcome Measures

We compared the accuracy of right and left hands across two exposure conditions. Exposure is defined as the order in which the hands completed the task. The first for 64 consecutive trials are defined as the "first exposure," while the second group of 64 trials were completed by the opposite hand, termed "second exposure.".

Error was defined as the millimeter (mm) difference between the diameter of the cylinder held by the participant and the cylinder they selected. This value ranged from 0 (the participant selected the cylinder with the exact diameter of the cylinder they were wielding) to 4 and could be a positive value (the participant selected a cylinder larger than the wielded cylinder) or negative value (the participant selected a cylinder smaller than the wielded cylinder). Thus, error was inversely related to each participant's ability to accurately perform stereognosis. Absolute error, the absolute value of each trial's error magnitude, was also used as an outcome measure to analyze each hand's performance.

Statistical Analysis

To analyze performance differences between both the hands and the exposures, we employed a repeated-measures ANOVA with two within-subject factors: hand (left, right), and exposure (first, second). This 2 x 2 ANOVA tested for main effects of exposure condition, main effects of hand, and whether an interaction occurred between these variables. Post-hoc analysis (Tukey HSD) was used to check for differences between individual levels of the factors. For each participant, mean values for each dependent variable were calculated under each level of each factor, then subjected to ANOVA using a repeated measures model in JMP (SAS Software).

Chapter 3:

Results

Error Magnitude

Figure 3 shows signed error magnitude that takes into account whether the participant selected a smaller (negative) or larger (positive) cylinder when they were not accurate. Our results indicate that when initially exposed to the task, the right hand was more accurate (mean ± SE: -0.86 ± 0.59) than the left hand (-1.21 ± 0.48) and had no bias to larger or smaller cylinder errors (mean = about zero). Interestingly, this effect was eliminated on second exposure. There was a tendency to reverse these effects, but that tendency was not significant ([$F(1, 3) = 2.6541$; $p = .2023$])

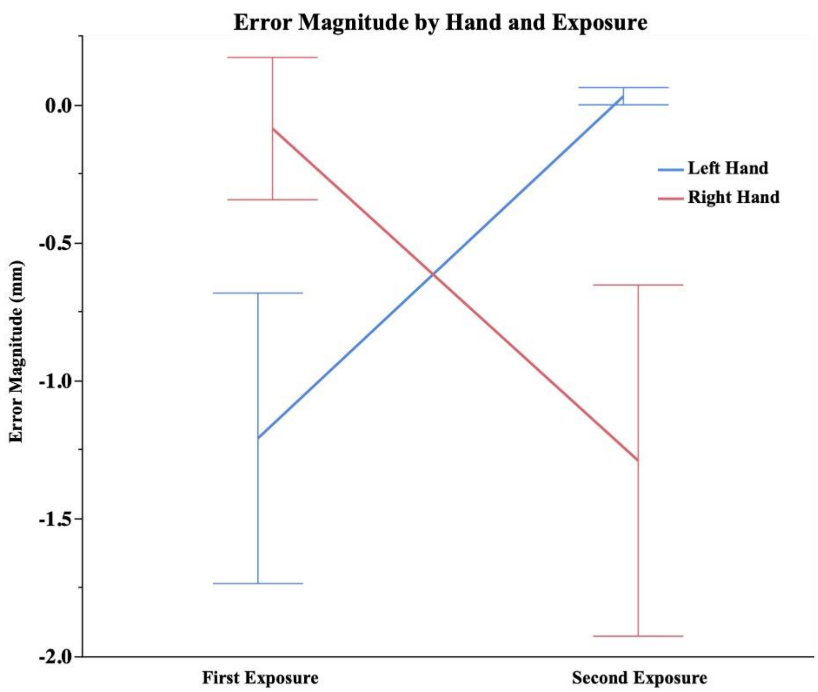

Figure 3: Error Magnitude. Error was recorded each trial of the experiment and is divided by hand and exposure.

Absolute Error Magnitude

When comparing the absolute error magnitude of both hands, the dominant hand showed greater performance on the first exposure, with lower absolute error, as shown in Figure 4. On first exposure, the absolute error of the right hand was lower (mean ± SE: 1.05 ± 0.25) than that of the left hand (1.49 ± 0.31). However, on second exposure, the dominant hand showed poorer performance when compared to the non-dominant hand (mean difference ± SE: 0.81 ± 0.49). In contrast, the non-dominant hand showed lower performance on first exposure in comparison to the dominant hand. On second exposure, the non-dominant hand demonstrated higher performance, even outperforming the dominant hand's first exposure. However, this observed interaction was not significant ($p = .2835$). Post hoc testing showed lowest absolute error magnitude in the left hand, second exposure group (mean ± SE: 0.81 ± 0.38) and the highest in the right hand, second exposure group (1.61 ± 0.31).

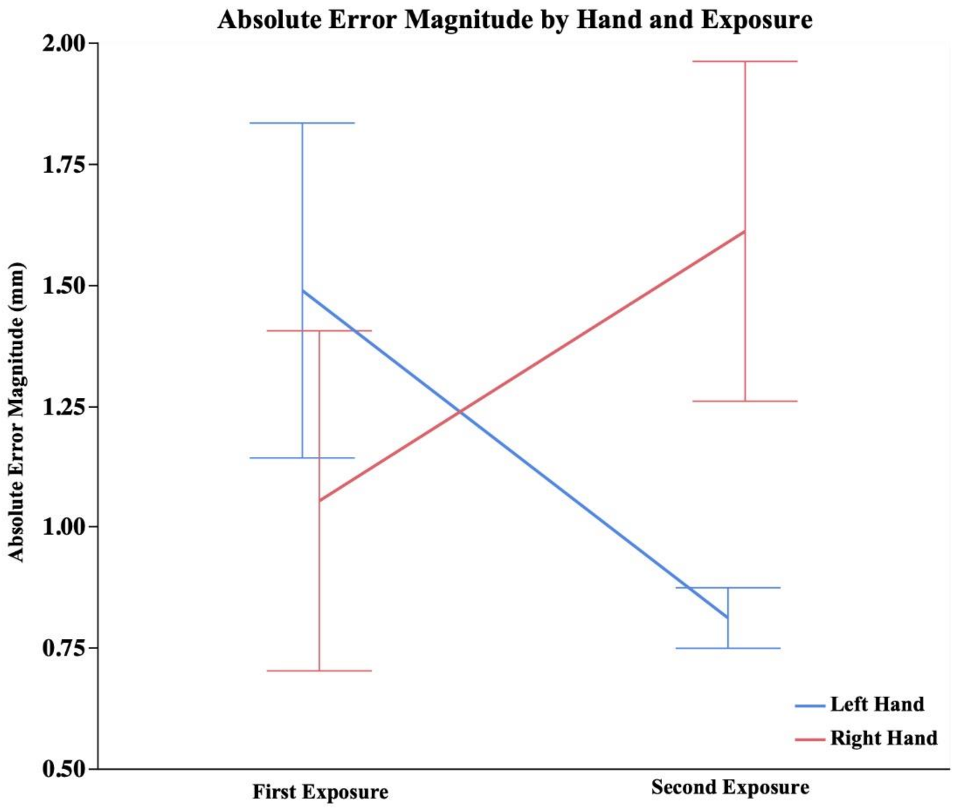

Figure 4: Absolute Error Magnitude. Cylinder selections which exactly matched the true cylinder wielded were assigned an error magnitude of 0.0. Any erroneous selections were calculated for their error by the difference in millimeter of selected cylinder diameter versus wielded cylinder diameter.

Chapter 4

Discussion

The purpose of this thesis was to evaluate the hypothesis of left hemisphere dominance for stereognosis by testing the prediction that the dominant hand (right) should show an error advantage compared to the left hand, on first exposure to the task. A secondary exploratory goal assessed the effect of opposite hand exposure on performance. However, the findings were far more peculiar than anticipated from hemispheric dominance. The right hand did prove more accurate but only upon first exposure. Interestingly, there was an apparent interaction between exposure and hand, with both hemispheres showing a shift in accuracy on second exposure (*Figure 3*). The left hemisphere became markedly less accurate on second exposure, whereas the right hemisphere showed improvement. I propose several interpretations to explain these findings.

<u>Distinct Hemisphere Strategies/Advantages</u>

Cerebral lesions and chronic split-brain patients have led researchers to theorize potential hemisphere strategies in stereognosis. However, previous data have been conflicting. Boll (1974) found patients with right hemisphere damage experienced more tactile perception impairment on both contralateral and ipsilateral side compared to left hemisphere damage. Conversely, Vaughan and Costa (1962) found increased prevalence of ipsilateral, and therefore bilateral, deficits in somatosensation for a left hemisphere lesion.

This incongruity led Zaidel (1998) to investigate possible different strategies used in each hemisphere of patients with complete and partial cerebral commissurotomy. The results of the study led Zaidel to report that the left hemisphere displayed greater ipsilateral control than the right hemisphere. Increased ipsilateral control by the left hemisphere could explain why the left hand was better on second exposure (*Figures 3, 4*). The left hemisphere may store sensory information during the first exposure performed by the contralateral right hand and utilize this input to help inform the ipsilateral left hand on second exposure.

Greater accuracy by the left hand on second exposure also appears to be partly corroborated by known fMRI studies. Discriminating objects by their oblongness has been correlated with enhanced activation of the right anterior portion of the posterior superior parietal cortex (aSPL), which suggests the right hemisphere and its contralateral hand have greater predominance for object discrimination (Stoeckel, 2004). Meanwhile, maintenance of kinesthetic information in working memory is thought to be lateralized to the left hemisphere (Miquée, 2008; Stoeckel, 2004). The left hemisphere's ability to maintain information in working memory, along with greater ipsilateral control, could help explain why the left hand was more accurate on second exposure. Other paradigms have presented precedent for the observed left hand improvement. In patients with complete commissurotomy, there was consistent improvement by the left hand but not the right hand in stereognosis tests. Consequently, it has been postulated that the right hand plays a role in constructing an image for the manually wielded object (Zaidel, 1998).

Previous researchers have also proposed models for transfer asymmetries. The "Access Model" has been used in motor control to theorize that intermanual transfer during the initial task training is stored in the dominant hemisphere no matter which hand was used for the task (Taylor, 1980). This model would suggest that the dominant hand benefits even when the non-dominant hand is used during initial training. However, if this were the case, it would be expected that the right hand, not the left, would be the limb showing improvement on second exposure.

The results of this study more closely match the “Cross-Activation Model.” This model proposes that in the initial learning with the dominant hand, a copy of the newly learned information is stored simultaneously in the non-dominant hemisphere and the aspects of the tasks which the dominant hand is adept will transfer to the non-dominant hemisphere (Parlow, 1989). The cross-activation model matches the results of left hand improvement on second exposure but fails to explain the decreased right hand accuracy on second exposure.

Callosal-Mediated Transfer

Studies have sought to interrogate the role of the corpus callosum (CC) in interhemispheric tactile information transfer. The results have not been universal, but several have suggested the anterior corpus callosum helps mediate interhemispheric transfer of tactile and other complex sensory information (Head, 1920; Lee-Teng, 1966; O’Reilly, 2013; Risse, 1978). Studies on split-brain monkeys showed an inability to transfer visual information but retained the ability to transfer somesthetic information (Lee-Teng, 1966). This has led to the unresolved hypothesis (Lee-Teng, 1966) that forebrain commissures are necessitated for communication of manual stereognostic size information between the two hemispheres. Yet, others propose it is the posterior CC that helps mediate the exchange of stereognosis information, not the anterior (Fabri, 2001; Fabri, 2004).

There are also callosal paradoxes such as Sperry’s Paradox, which describes the phenomenon of tactile transfer in split brain patients. Patients who have had surgical transection of their corpus callosum for medical procedures are unable to transfer tactile information. However, if patients were *born* without the callosum (a condition known as callosal dysgenesis or “CD”), they have preserved interhemispheric communication (Tovar-Mall, 2014). CD patients are able to achieve interhemispheric tactile communication by bilaterally linking the parietal cortices through interhemispheric tracts that cross the midbrain and ventral forebrain (Tovar-Mall, 2014). This paradox would seem to offer partial evidence of an ontogenesis theory of stereognosis.

Ontogeny

EEG evidence has suggested the ontogeny of neurophysiological mechanisms of stereognostic performance develops faster in the dominant hand. Subsequently, older subjects display more bilateral activation of homologous brain areas than is seen with children (Galperina, 2010). Interhemispheric interactions greatly enhance around ages five to six years-old (Dzugaeva, 1975). Our study involves participants of ages 18-25 years-old. However, the corpus callosum is not completely myelinated at age nineteen (Barnea-Goraly, 2005). This leads to my theory of different calibrations due to handedness.

Dexterity Altering Calibration

The dominant hand-hemisphere system has shown minor evidence to play a key role in image construction in stereognosis while the non-dominant hand-hemisphere may be critical to refining and maintaining the image constructed in memory (Zaidel, 1998). If accurate, this would help explain why the left hand performed better on second exposure. The left hand would be contralateral to the hemisphere specialized in image maintenance and memory which could lead to a more accurate conception of the object wielded.

Previous studies in our lab have explored handedness in other motor control tasks. One of the factors distinguishing dominant from nondominant performance was the efficiency of intersegmental dynamics (Bagesteiro & Sainburg, 2002). Research on fine motor performance of both hands has shown that the dominant hand outperforms the left on many standardized fine motor assessments, such as the Nine-hole Peg Test (Poole, 2005). I propose a similar concept to Bagesteiro & Sainburg (2002) but for manual dynamics, in which greater dexterous control of the dominant hand leads to increased stereognosis accuracy.

The right hand may have more efficient hand manipulation dynamics, with each manipulation serving as a sort of data point. This would lead to an increased and possibly more accurate collection of sensory information following right-handed cylinder wielding. The summation of these sensory "data" would lead to a more accurate calibration following the right hand than the left. The left hand could have had a better conception of the cylinders prior to beginning its second exposure due to possibly more and/or better sensory information from the dexterous right hand. This might lead to greater left hand accuracy on second exposure compared to first.

Other experiments have shown greater hemisphere specialization for the motor control task leads to improved interlimb transfer quality (Sainburg, 2016). Greater dexterous control of the dominant hand-hemisphere system could lead to improved interlimb transfer quality for second exposure. This could help explain why the left hand improves on second exposure. However, the right hand decreased accuracy on second exposure. The right hand decline may be because the non-dominant hand-hemisphere was less specialized for the task which conferred lower interlimb transfer quality.

Conclusion

Stereognosis research has proved itself to be complex and at times contradictory. While the results did not fully support our hypothesis that the left hemisphere would be dominant for stereognosis, the right hand did perform best on first exposure. The “improvements” seen in the left hand on second exposure could have several explanations. First, the left hemisphere may have more ipsilateral control than the right hemisphere (Zaidel, 1998). Second, the left hemisphere may also help maintain working memory of the manipulated objects’ sensory information (Miquée, 2008; Stoeckel, 2004). Additionally, I hypothesize that the right hand has greater fine-motor control which leads to a better calibration and subsequently more accurate second exposure of the left hand. However, it is imperative to express this study’s data collection was shortened due to the coronavirus pandemic. The results reported were collected from a sample size of only six participants due to the coronavirus pandemic, and many stereognosis studies have had conflicting and imprecise results. Further studies are needed to expound upon our findings.

References:

Bagesteiro LB, Sainburg RL. Handedness: dominant arm advantages in control of limb dynamics. *J Neurophysiol*. 2002 Nov;88(5):2408-21. doi: 10.1152/jn.00901.2001. PMID: 12424282.

Barnea-Goraly, N, Menon, V, Eckert, M, et al., White Matter Development During Childhood and Adolescence: A CrossSectional Diffusion Tensor Imaging Study. *Cerebr. Cortex*, 2005, vol. 15, no. 12, p. 1848.

Boll, T. Right and left cerebral hemisphere damage and tactile perception: Performance of the ipsilateral and contralateral sides of the body, *Neuropsychologia*, Volume 12, Issue 2, 1974, Pages 235-238, ISSN 0028-3932. https://doi.org/10.1016/0028-3932(74)90008-6.

Boschin, E, Piekema, C, Buckley, M. Essential functions of primate frontopolar cortex. *Proceedings of the National Academy of Sciences.* Mar 2015, 112 (9) E1020-E1027; DOI: 10.1073/pnas.1419649112

Connell, L, Lincoln, N, & Radford, K. Somatosensory impairment after stroke: frequency of different deficits and their recovery. *Clinical Rehabilitation*, *22*(8), 758–767. https://doi.org/10.1177/0269215508090674

Deibert, E., Kraut, M., Kremen, S., Hart, J. Neural pathways in tactile object recognition. *Neurology* Apr 1999, 52 (7) 1413; DOI: 10.1212/WNL.52.7.1413

Fabri M, Polonara G, Del Pesce M, Quattrini A, Salvolini U, Manzoni T. Posterior corpus callosum and interhemispheric transfer of somatosensory information: an fMRI and neuropsychological study of a partially callosotomized patient. *J Cogn Neurosci*. 2001 Nov 15;13(8):1071-9. doi: 10.1162/089892901753294365. PMID: 11784445.

Fabri, M., Del Pesce, M., Paggi, A., Polonara, G., Bartolini, M., Salvolini, U., Manzoni, T. Contribution of posterior corpus callosum to the interhemispheric transfer of tactile information, *Cognitive Brain Research*, Volume 24, Issue 1, 2005, Pages 73-80, ISSN 0926-6410. https://doi.org/10.1016/j.cogbrainres.2004.12.003.

Fujii, R., Takahashi, T., Toyomura, A., Miyamoto, T., Ueno, T., Yokoyama, A. Comparison of cerebral activation involved in oral and manual stereognosis. *Journal of Clinical Neuroscience*, Volume 18, Issue 11, 1520 – 1523

Galperina, E.I., Tsitseroshin, M.N. & Zaitseva, L.G. The ontogeny of the neurophysiological mechanisms of stereognosis: An EEG study. *Hum Physiol* **36,** 13–25 (2010). https://doi.org/10.1134/S0362119710010020

Hull (1936) A Study of Laterality Test Items, *The Journal of Experimental Education*, 4:3, 287-290, DOI: 10.1080/00220973.1936.11010014

JMP® SAS Institute Inc., Cary, NC, 1989-2019.

Kim, C, Kroger, J, Calhoun, V, & Clark, V. (2015). The role of the frontopolar cortex in manipulation of integrated information in working memory. *Neuroscience letters*, *595*, 25–29. doi:10.1016/j.neulet.2015.03.044

Koch, G, Cercignani, M, Bonnì, S, Giacobbe, V, Bucchi, G, Versace, V, Caltagirone, C, & Bozzali, M. (2011). Asymmetry of parietal interhemispheric connections in humans. *The Journal of neuroscience : the official journal of the Society for Neuroscience*, *31*(24), 8967–8975. https://doi.org/10.1523/JNEUROSCI.6567-10.2011

Lee-Teng, E, & Sperry, R. W. (1966). Intermanual stereognostic size discrimination in split-brain monkeys. *Journal of Comparative and Physiological Psychology, 62*(1), 84-89. doi:http://dx.doi.org.ezaccess.libraries.psu.edu/10.1037/h0023464

MATLAB. (2010). *version 7.10.0 (R2010a)*. Natick, Massachusetts: The MathWorks Inc.

Miquée, A, Xerri, C, Rainville, C, Anton, J. Nazarian, B. Roth, M., Zennou-Azogui, Y. Neuronal substrates of haptic shape encoding and matching: A functional magnetic resonance imaging study, *Neuroscience*, Volume 152, Issue 1, 2008, Pages 29-39, ISSN 0306-4522. https://doi.org/10.1016/j.neuroscience.2007.12.021.

Moll, J. & de Oliveira-Souza, R. (2017). Hemispheric Dominance for Stereognosis in a Patient With an Infarct of the Left Postcentral Sensory Hand Area. *Cognitive And Behavioral Neurology, 30(3), 102–115*. doi: 10.1097/WNN.0000000000000135.

O'Reilly, J. X., Croxson, P. L., Jbabdi, S., Sallet, J., Noonan, M. P., Mars, R. B., Browning, P. G., Wilson, C. R., Mitchell, A. S., Miller, K. L., Rushworth, M. F., & Baxter, M. G. (2013). Causal effect of disconnection lesions on interhemispheric functional connectivity in rhesus monkeys. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(34), 13982–13987. https://doi.org/10.1073/pnas.1305062110

Parlow S, Kinsbourne M (1989) Asymmetrical transfer of training between hands: implications for interhemispheric communication in normal brain. *Brain Cogn* 11:98–113

Poole, J., Burtner, P., Torres, T., McMullen, C., Markham, A., Marcum, M. Anderson, J., Qualls, C. Measuring Dexterity in Children Using the Nine-hole Peg Test, *Journal of Hand Therapy*, Volume 18, Issue 3, 2005, Pages 348-351, ISSN 0894-1130, https://doi.org/10.1197/j.jht.2005.04.003.

Reed C, Shoham S, and Halgren, E. (2004), Neural substrates of tactile object recognition: An fMRI study. *Hum. Brain Mapp*., 21:236246. https://doi.org/10.1002/hbm.10162

Risse, G., LeDoux, J., Springer, S., Wilson, D., Gazzaniga, M. The anterior commissure in man: Functional variation in a multisensory system, *Neuropsychologia*, Volume 16, Issue 1, 1978, Pages 23-31, ISSN 0028-3932, https://doi.org/10.1016/0028-3932(78)90039-8.

Roland PE, Larsen B. Focal Increase of Cerebral Blood Flow During Stereognostic Testing in Man. *Arch Neurol.* 1976;33(8):551–558. doi:10.1001/archneur.1976.00500080029005

Ross, E., Trimble, M., Cummings, J. 1997. Cortical representation of the emotions. *Contemporary Behavioral Neurology*. Boston, Massachusetts: Butterworth-Heinemann; 107–127.

Sainburg, R.L., Schaefer, S., Yadav, V. Lateralized motor control processes determine asymmetry of interlimb transfer, *Neuroscience, Volume 334, 2016, Pages 26-38, ISSN 0306-4522.* https://doi.org/10.1016/j.neuroscience.2016.07.043.

Schermann T, Tadi P. Stereognosis. [Updated 2020 Nov 22]. In: StatPearls [Internet]. Treasure Island FL): StatPearls Publishing; 2021 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK556003/

Stereognosis, n.d. In *Oxford Dictionary*. Retrieved from: https://www.lexico.com/en/definition/stereognosis

Stoeckel, M.C., Weder, B., Binkofski, F., Choi, H.-J., Amunts, K., Pieperhoff, P., Shah, N.J. and Seitz, R.J. (2004), Left and right superior parietal lobule in tactile object discrimination. *European Journal of Neuroscience*, 19: 1067-1072. https://doi-org.ezaccess.libraries.psu.edu/10.1111/j.0953-816X.2004.03185.x

Taylor HG, Heilman KM (1980) Left-hemisphere motor dominance in righthanders. *Cortex* 16:587–603

Thomas, J., Humphrey, G.K., Gati, J., Servos, p., Menon, R., Goodale, M. Haptic study of three-dimensional objects activates extrastriate visual areas. *Neuropsychologia, Volume 40, Issue 10, 2002, Pages 1706-1714, ISSN 0028-3932*. https://doi.org/10.1016/S0028-3932(02)00017-9.

Tovar-Moll, F., Monteiro, M., Andrade, J., Bramati, I. E., Vianna-Barbosa, R., Marins, T., Rodrigues, E., Dantas, N., Behrens, T. E., de Oliveira-Souza, R., Moll, J., & Lent, R. (2014). Structural and functional brain rewiring clarifies preserved interhemispheric transfer in humans born without the corpus callosum. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(21), 7843–7848. https://doi.org/10.1073/pnas.1400806111

Vaughn, H.G., Costa, L.D. *Journal of Nervous and Mental Diseases*, 134 (1962), p. 237

Weiner, K. S., & Zilles, K. (2016). The anatomical and functional specialization of the fusiform gyrus. *Neuropsychologia*, *83*, 48–62. doi:10.1016/j.neuropsychologia.2015.06.033

Zaidel, E. Stereognosis in the chronic split brain: hemispheric differences, ipsilateral control and sensory integration across the midline, *Neuropsychologia*, Volume 36, Issue 10, 1998, Pages 1033-1047, ISSN 0028-3932, https://doi.org/10.1016/S0028-3932(98)00057-8.

VITA

EDUCATION

2017-2021 **Pennsylvania State University** **State College, PA**
Schreyer Honors College
College of Health and Human Development
B.S. Kinesiology; Movement Science Option
Thesis: *Hemispheric lateralization and interhemispheric transfer asymmetries in manual stereognosis*

- Dean's List Fall 2017-Present

ACADEMIC HONORS

2020-Present **Academic Standards Committee Member: College of Health and Human Development.** Penn State University. State College, PA.
Student representative to hear and vote on academic integrity cases along with two faculty members.

2017-Present **Phi Eta Sigma Honor Society**. Penn State University. State College, PA..
Members must obtain a 3.5 cumulative GPA.
Members rank in at least the top 20th percentile of their class.

2017-Present **Alpha Lambda Delta.** Penn State University. State College, PA. Member.
National Honors Society for First-Year Students.
Members must obtain a minimum of 3.5 GPA during their first semester and year of college.

2017-Presnt **Dean's List.** Penn State University. State College, PA. Fall 2017-Present.
Obtained over a 3.5 GPA every semester of college.

PRESENTATION/PUBLICATIONS

April 2020 **Undergraduate Research Exhibition, participant.** Penn State University.
Present findings from personal research project, "*Hemispheric specializations in manual stereognosis*."
Create research poster and record virtual presentation.

March 2021 **Hot Topics in Medicine II, illustrator.** Penn Medicine – Lancaster General Hospital.
Illustrated the cover photos for the pamphlet flyer of Penn Medicine – Lancaster General Hospital Spring 2021 medical education conference.

RESEARCH

2019-Present **Lead Researcher.** *Exploring hemispheric specializations in manual stereognosis*.
Movement Neuroscience Lab. Penn State University. State College, PA.
Study manual stereognosis accuracy and hemispheric discriminations using 3D-printed cylinders.
Record data, analyze results, and explain findings in senior thesis.
Advisors: Robert L. Sainburg, PhD, MS, OTR; Brooke Fosaaen, OTD, PhD candidate

2019-Present **Research Assistant.** *Predicting ipsilesional motor deficits in chronic stroke patients using the Dynamic Dominance Model*.
Penn State College of Medicine, Neurology. Penn State Milton S. Hershey Medical Center (Hershey, PA).
Advisor: Robert L. Sainburg, PhD, MS, OTR
Orchestrate KineReach apparatus for kinematic data collection on chronic unilateral stroke patients.
Assist patient logistics and neurorehabilitation therapies.

2018-Present **Junior researcher**. Myocardial Ischemia and Transfusion (MINT) TRIAL. Lancaster General Hospital, Lancaster, Pennsylvania.
National Heart Blood Lung Institute sponsored clinical trial.
Multicenter study comparing two red blood cell transfusion strategies (liberal hemoglobin < 10 and restrictive hemoglobin < 8) for patients with an acute myocardial infarction and anemia.
Review electronic medical record to identify potential candidates (who have had MI and are anemic).
Principle investigator: Jeffrey L. Carson, MD. Rutgers University Robert Wood Johnson Medical School. New Brunswick, NJ.

2019 **Collaborative Institutional Training Initiative (CITI Program).**
Certified in:
Social and Behavioral Best Practices for Clinical Research
Protection of Human Research Subjects –Biomedical Course.
Animal Care and Use (ACU) Researchers (not involved in survival surgery) Basic Course

LEADERSHIP

2019-Present **Lion Ambassador.** Member. Pennsylvania State University. State College, PA.
Provide a minimum of 5 campus tours per semester to prospective and accepted students.
Communicate directly with the Penn State Alumni Network, the largest dues-paying alumni network in the world.
Organize the student section "S-Zone" for athletics.
Effectively coordinate 12 university-wide projects each school year.

2018-Present **Life Link PSU, mentor**. Penn State University. State College, PA
Volunteer work as a peer mentor to State College area special education students with the goal of "creating a road to independence."
Eat lunch with Life Link students.
Play card games with students during their breaks.

2016-2017 **Future Medical Leaders of America, Founder and President.** Lancaster Catholic High School. Lancaster, PA
Founded the idea and mission of the club to promote the curiosity, inquiry, and professional experience in all medical fields to fellow high school students.
Established club agenda and framework from scratch.
Directly contacted medical professionals to speak at every club meeting.
Reside over all meetings and funnel election of new executives.

MEDICAL

June 2019 **Medical Missions Trip to Kechene, Ethiopia**.
Mission trip through Jewish Voice Ministries International.
In charge of triage operations with 13,005 total patients served in 5 days.
Patients received free treatment for dermatology, dental/tooth extraction, minor surgery, registered nurse unit, ophthalmology, and obstetrics and gynecology at an Ethiopian government health facility.
Statistics:

- 1,102 dental patients treated, 105 eye surgeries completed, 239 minor surgeries performed, 3,883 eyeglasses distributed, 7 babies born

2019 **Centre Life Link EMS, volunteer EMT**
Provide hands-on emergency medical care to the State College community.
Gain communication skills with patient contact.

2018-Present **Nationally Certified Emergency Medical Technician**
Certification course completed at Harrisburg Area Community College.
Certified by Pennsylvania Department of Health, Bureau of Emergency Medical Services.
Passed all components of psychomotor exam on the first attempt.
Passed cognitive exam in under 80 questions.

May 2019 **Emergency Vehicle Driver Training (EVDT), certified.**
Certified in Pennsylvania to operate Class III Ambulance.
Receive instruction on emergency vehicle rules and guidelines.

June 2019 **Continued Medical Education (CME) conference, attendee.**

- *Neurology for the Non-Neurologist*: Penn State College of Medicine. June 1, 2019.

Gain knowledge on advances in stroke therapy to compound own Stroke Rehabilitation research knowledge.
Learn about advances in common neurological disorders and treatments.

2018-Present **Continued Medical Education (CME) presentations, attendee**.

- *PRBC Transfusion*. Presenter: Jeffrey L. Carson, M.D. Februrary 7, 2018. Lancaster General Hospital. Lancaster, PA.
- *Trending Topics in Nephrology*. Presenter: James A. Groff, DO. January 2, 2019. Lancaster General Hospital. Lancaster PA.
- *Topics in Infectious Disease: C. Difficile and Osteomyelitits*. Speakers: John Granger, M.D. & Michael J. Sasso, M.D. March 6, 2019. Lancaster General Hospital. Lancaster, PA.
- *The Neurologic Exam*: *It Doesn't Have to be Unnerving*. Jen Yoder, CRNP. Lancaster General Health Hospitalist Interprofessional Case Based conference series. March 20, 2021.
- *Hot Topics in Medicine II*. March 10, 2021. Lancaster General Hospital. Lancaster, Pa.

Feb. 2020 **Suturing Clinic with Army Recruiting, attendee.** Penn State University.
Instructed basic suturing techniques and review options of military opportunities for aspiring medical students.
Practiced suture on suture training pads.

2015-Present **Independent Medical Observation Experiences**, Lancaster General Hospital.
Schedule shadowing experiences in the LGH ER and Operating Rooms.
Worked with physicians in Emergency Medicine (C. Fox, MD; Seth Katz, MD; Fran Kratz, MD; Michael Reihart, DO), General Surgery (Paul Newman, MD), Neurosurgery (Christopher Kager, MD), and Orthopedic Surgery (Paul F. Carroll, M.D.).
Advisor: Michael J. Reihart, DO

2015 **Medical Volunteer Program, Lancaster General Hospital**, Lancaster, PA.
High school student selected to have the opportunity to shadow physicians.
Completed over 50 hours rounding in Emergency Medicine (C. Fox, Michael Reihart, DO), General Surgery (Paul Newman, MD), and Neurosurgery (Christopher Kager, MD)
Advisor: Michael J. Reihart, DO

PEDAGOGY

2019-Present **Head Teaching Assistant.** Biology 162 Course, Anatomy & Physiology Lab. Penn State.
Present an approximately 10-minute lecture on anatomy and physiology each lab.
Manage teaching and grading of two 20-student lab section.
Hold weekly office hours.

2019 **Teaching Assistant**. Nutrition 100 Course. Penn State University. State College, PA
Grade diet analysis projects on micro and macronutrients
Assist Dr. Cynthia Adams in course curriculum.
Host review session before each exam (3) for students to ask questions, review problems, and clarify concepts.

EXTRACURRICULAR

2019 **KPMG Ideation Challenge, presenter.** Pennsylvania State University
Collaboration with STEM and business majors to produce and present a novel idea using AI or machine learning.
Propose mechanisms to create and install the technology and detail the business benefits associated.

2017-Present **Golf Caddy.** Lancaster Country Club. Lancaster, PA.
Provide golf advice and input such as club selection and reading putting greens.
No golf knowledge prior to the start of employment, but quickly learned and consistently scored a 10/10 caddy score card.

ATHLETICS

2013-2016 **Varsity Football.** Lancaster Catholic High School. Lancaster, PA.
All-Pennsylvania Wide Receiver. Second Team.
All-Eastern PA Wide Receiver. First Team.
Four-year letter winner.
All-Lancaster-Lebanon League Wide Receiver, Section 3. First Team.
Leader in Lancaster-Lebanon League Receptions, Section 3.
All-Lancaster-Lebanon League Cornerback, Section 3. Honorable Mention.
Lancaster-Lebanon League Champion, Section 3 (2017).

2014-2017 **Varsity Baseball.** Lancaster Catholic High School. Lancaster, PA.
All-Lancaster-Lebanon League Outfielder, Section 3. First Team (2015-2017).
Four-year starter.
PIAA District 3 Champion (2017).
Lancaster-Lebanon League Champion (2017).
PIAA District 3 Runner-up (2016).

ARTWORK

- Medical Illustration.
- Portraits.
- Link to portfolio: https://docs.google.com/document/d/1-H4QjeJeHWLYryAWHx87Ta27mJ-YOgj0hnCCK9rruEk/edit?ts=5cbe950f