

**RELATIONSHIP BETWEEN SPEECH ARTICULATION, FINE MOTOR CONTROL
AND HANDEDNESS IN ADULTS**

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HANDEDNESS

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ABSTRACT

The topic of whether or not there is a link between language and motor control in left-handed and right-handed individuals remains unanswered. Thirty-four people, fifteen of whom were left-handed and nineteen of whom were right-handed, participated in a study in which they were asked to perform a variety of speech, language, and manual tasks. Their recorded audio and videos were acoustically and perceptually analyzed. Two-way ANOVA and a General Linear Model regression were performed, which showed both manual ability and hand preference (right hand for grasping) affect speech and language production. These results lay the foundation for future research investigating language ability and manual function in adults.

Keywords: speech and language, motor control, manual ability, hand preference, diadochokinetic, lego, tongue twister

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LIST OF ABBREVIATIONS

DDK	Diadochokinetic
LegoR	Lego- Right hand use
M	Mean
PPVT	Peabody picture vocabulary test
PPT	Purdue pegboard test
PPTL	Purdue pegboard test- Left hand use
PPTR	Purdue pegboard test- Right hand use
SD	Standard deviation
TT	Tongue twister

CHAPTER 1: INTRODUCTION

Speech is a complex motor function that involves the manipulation of approximately 100 articulatory and respiratory muscles (Levelt, 1989). Many investigations, particularly in children with speech and language impairments, have highlighted the motor nature of speech. Children with Specific Language Impairment (SLI), for example, show both speech- motor and generalized motor abnormalities (DiDonato Brumbach & Goffman, 2014). According to recent studies, delays in motor development are often associated with diagnoses such as Autism Spectrum Disorder (ASD) and SLI (Leonard & Hill, 2014; West et al., 2018). These studies support the view that language and motor control are intimately linked, as individuals with an impairment in one domain (i.e., language) usually demonstrate some degree of deficit in the other (i.e., motor).

The relationship between fine motor control and speech/language has been highlighted in studies on motor control. Several speech or language impairments, for example, are associated with poor fine motor abilities (Hill, 2001; Zelaznik & Goffman, 2010; Highman et al., 2013). Children with Language disorders (LD) and Speech Sound Disorders (SSD), present with a lack of fine motor coordination skills (Varuzza et al., 2022). Sanjeevan et al. (2019) showed that children with SLI performed significantly lower on fine motor tasks compared to children with Typical Development (TD).

The connection between fine motor control and speech skills is most likely mediated by left hemisphere brain lateralized networks that support both speech production and fine motor control of the right hand (Gonzalez et al., 2014). A possible mechanism for the relationship observed between right-hand use and language development is the common left-hemisphere lateralization of manual actions (e.g., Cochet, 2016; Gonzalez & Goodale, 2009; Sacrey et al.,

2013) and language (e.g., Kimura, 1973; Somers et al., 2015). One example of this relationship is that strong lateralization of hand use is related to language lateralization in adults (Gonzalez & Goodale, 2009). By way of explanation, a person who has an obvious preference for selecting their right hand for manual actions is more likely to show left hemisphere dominance for language processing compared to a person with a strong left-hand preference for manual actions. (Alcock & Krawczyk, 2010, Hill & Bishop, 1998).

Despite the extensive literature on the relationship between speech and motor control, how exactly the two are related and how handedness mediates this relationship remains unclear. The current study is poised to directly address these questions. I predict a relationship between fine manual motor control and speech and language production, such that individuals with greater manual dexterity speak more clearly and have greater vocabulary size.

The intent of this study is to carefully examine the interaction between speech production, language, and motor skills in individuals with different hand preferences. The following introduction will review literature on measuring the production of manual actions and speech/language, and the potential role of handedness in the interaction between speech/language and manual movement control.

1.1 MANUAL ABILITY

To fully understand the complicated relationship between motor control and speech, it is important to first define fine motor control. The process of starting, directing, and purposeful voluntary movement is referred to as motor control (Latash et al., 2010). A motor skill is a function that utilizes precise muscle movements to complete a certain activity (Latash et al., 2010). Walking, or riding a bike are examples of these activities. The goal of motor skills is to maximize the ability to do the skill with the greatest level of success and precision while using

the least amount of energy and the act of completing a motor skill or activity is referred to as performance (Bondi et al., 2022).

Examining fine motor control is necessary for understanding the learning of individual motor behavior. It has recently been proven that employing different tasks to test fine motor abilities can provide different results, meaning that alternative measures of fine motor control might assess different skills and/or basic processes (Cohen et al., 2021). The capacity to coordinate muscles, bones, and nerves to make small, precise motions is referred to as fine motor control. Picking up a little object with a pincer hold (index finger and thumb) demonstrates fine motor control (Kelly & Natale, 2020). Fine motor control is a vision-influenced manual ability that requires minimal force and good precision to complete a movement. The Purdue Pegboard Test (PPT), the picking up and setting job, and the assembly task have all been used to test fine motor control in children and adults.

Fine motor skills in school-aged children are a combination of spatiotemporal processing, visuomotor integration, strength control, perceptual, and cognitive abilities (Feder & Majnemer, 2007; Tabatabaey-Mashadi et al., 2015). These interconnected abilities are an excellent illustration of network neuromotor development. Furthermore, delays and disruptions in the fine motor network are prevalent in children with special needs such as ADHD and autism (Lange-Küttner & Kochhar, 2020) and are significantly associated with low intelligence quotient (IQ), and reading scores (Mayes et al., 2018; see also Suggate et al., 2018). Given the link between poor motor ability and worse cognitive performance, it is worthwhile investigating this relationship further and the possibility of promoting fine motor skills early in development to enhance cognitive ability.

1.2 SPEECH PRODUCTION AND MANUAL ABILITY

Speech is another important function of an individual. Speech and language are the primary means of communication for humans—a sophisticated communication system that causes both cohesion and division among people; a system that allows us to structure and construct knowledge and social-cultural practice across time. Speech is an activity characterized by an auditory signal created by the speaker and transduced by the listener. Speech actions, like other motor skills, evolve with time. When it comes to the signal, speech is described as a time-varying acoustic waveform with amplitude and frequency modulation. The modulations are caused by movements of the speech organs (i.e., lungs, vocal cords, tongue, teeth, oral cavity, lips, etc.) in order to communicate the message.

Within the framework of brain specialization and evolution, there is a potential connection between speech production and motor control, specifically the fine motor control of the hands and limbs. It has been proposed for over a century that the left-hemisphere specialization for language arose from an earlier specialization of this hemisphere for control of expert motions of the hands and limbs (Liepmann., 1908). Many studies have discovered associations between various forms of motor development, notably gesture development, and language development (Bates & Dick, 2002; Goodwyn et al., 2000; Iverson & Thelen, 1999; Thal & Tobias, 1994). The discovery of remarkably strong links between gesture and language is a major finding. These two abilities are interwoven and appear to have a same neural foundation, prompting researchers to classify them as part of a closely connected "family" of abilities (Bates & Dick, 2002).

Verbal skills are highly linked to oral motor control during normal development. The capacity of typically developing toddlers to lick food off their lips, for example, is related to the

number of their verbal skills and the length of their spoken sentences (Alcock, 2006). At the same time, oral-motor skills are intimately linked to manual-motor (hand and finger) skills during normal development (Corbetta & Thelen., 1996; Iverson & Thelen., 1999). For example, rhythmicity in shaking toys is associated with competence in reduplicated babbling during infancy (Iverson & Fagan., 2004; Gernsbacher et al., 2008), and children who are able to repeat phrases and nonwords are better at pegboard activities (Bishop., 2002).

Not only motor functioning and language been linked in neuro-typical adults and children, but ample research has also demonstrated the linkage in atypical populations. Accordingly, the study of developmental abnormalities is another research field that has produced solid evidence of the relationship between physical movement and language. For example, investigating the motor bases of early language development may also provide us with information about the origins of language development difficulties, particularly SLI (Bishop, 2002), as well as language functioning in other developmental disabilities such as autism, where language skills are highly variable and appear to be dependent on children's motor abilities (Bishop, 2002; Gernsbacher, Sauer, Geye, Schweigert & Hill Goldsmith, 2008). Many studies have revealed that children with a language disability or speech impediment have motor deficiencies, including motor incoordination, than their typically developing peers (for a review, see Hill, 2001; Rechetnikov & Maitra, 2009). Another study found that children with specific Language Impairment performed fine motor activities slower than typically developing children (Zelaznik & Goffman, 2010; Sanjeevan et al., 2019).

While there may be some connections between motor development and typical language development, these relationships do not seem to be universal or apply uniformly to all forms of motor development. For example, about the link between language development and gross motor

growth which generally referred to the ability to make large limb gestures, studies (Bates, 1979; Bonvillian, Orlansky & Novack, 1983) show that there is no strong link between language development and gross motor growth. Studies, however, have revealed that gross and fine motor development were linked to language development (i.e., Gonzalez et al., 2019). Also, some studies with atypical language development discovered associations between fine motor development and language development (Hill, 2001), but others did not. In fact, a study by Bates and colleagues (1979) appeared to demonstrate a relationship going in the opposite direction which showed no associations between fine motor skills and language development. These connections were not as strong as could be determined reliably (Bates, 1979; Bonvillian et al., 1983).

Understanding the origins of language acquisition, specifically the links between non-linguistic abilities and language development may also help us understand why some children develop language much faster than others (Fenson et al., 1994). Several studies have shown comparable connections during atypical development. The oral-motor abilities of preschool autistic children, such as their capacity to extend their tongues and pucker their lips are linked to their speech fluency (Amato & Slavin, 1998). The oral-motor abilities of middle-childhood and adolescent autistic children, such as their capacity to twist their tongues and blow whistles, are connected with their manual-motor skills (Page & Boucher, 1998). Most significantly, autistic toddlers' oral-motor abilities (Thurm, Lord, Lee, & Newschaffer, 2007) and manual-motor skills (Stone & Yoder, 2001) predict preschool speech fluency better than social cognition measures like joint attention (Gernsbacher et al., 2008).

Some experts believe that the symbolic aspect of both gesture and language is what unites them. Bates et al. (1989) studied the relationship between children's use of familiar object

gestures and their language abilities. They found that language comprehension played a role in connecting gestures to language production. The study highlights how gestures and language, with their symbolic abilities to convey meaning, may interact and contribute to children's communication and linguistic development. On the same timeline, motor and linguistic abilities appear to attain shared milestones such as repeated action, symbolic usage, and combinatorial use (Bates & Dick, 2002).

The details of the Gestural Theory of Language have evolved over time, but the core concept remains that spoken language (i.e., a system of verbal gestures) is built on a foundation of manual gestures; early hominids developed manual gestures first for communicative purposes, and then gradually paired these movements with vocalizations (Corballis, 2003). Speech sounds gradually became connected with specific physical movements, and vocalizations replaced manual action as the dominant mode of communication. As a result, a set of manual signals is replaced by a repertoire of standardized symbolic sounds (i.e., language; Waters & Fouts, 2002).

1.3 HANDEDNESS AND LANGUAGE

The development of population-level right-handedness is one of the most known correlates of brain asymmetry (Gonzalez et al., 2018). Ninety percent of people identify themselves to be right-handed, preferring to use this hand for a variety of objects such as cards (Bishop et al., 1996), tools (Mamolo et al., 2006), geometric 3D shapes (Gabbard et al., 2003), toys (Sacrey et al., 2012), and blocks (Gonzalez et al., 2007). It is important to remember that among right-handed people, handedness is a consistent predictor of hemispheric lateralization of function (Netelenbos & Gonzalez., 2015). Functional exams of right-handers have revealed a left-hemisphere dominance for motor activity, which is in line with previous behavioral studies (Civardi et al., 2000).

Meanwhile, previous research has explored the role of gesturing in the development of speech and discovered significant connections between the increasing frequency and complexity of gestures and enhanced language development (Rombouts et al., 2023). A further study examined hand lateralization of gestures and discovered that infants who used their right hand to point more frequently also had bigger receptive vocabularies (Mumford & Kita, 2016). The specific example of right-hand gestures predicting receptive language (Mumford & Kita, 2016) is part of the research showing that the link between newborn gesturing and language development may be related to the brain's structure of motor control and language.

One potential reason for the observed association between right-hand use and language development is the typical left-hemisphere lateralization of manual activities (e.g., Cochet, 2016; Gonzalez & Goodale, 2009; Sacrey et al., 2013) and language (e.g., Kimura, 1973; Somers et al., 2015a). This connection appears to continue throughout infancy and into adulthood. One example of this association is that substantial lateralization of hand usage is associated with linguistic lateralization in adulthood (Gonzalez & Goodale, 2009). In other words, a person who prefers to use their right-hand for manual tasks is much more likely to have left hemisphere dominance for language processing than someone who prefers to perform manual tasks with their left hand. This shared lateralization can begin in childhood and leads to a parallel pattern of right-hand motor abilities and language development (Alcock & Krawczyk, 2010; Gonzalez et al., 2018), which Gonzalez et al. (2014) agreed on. In that study (Gonzalez, et al., 2014), right-handed preschoolers (4 to 6-year-olds) performed two tasks: grasping small objects and speaking. The child participants grasped and ate little food items (cereal) before moving on to a second task in which they were asked to produce syllables that began with /s/ or /sh/ sounds. Children who used their right hand more for grasping were able to produce a clearer

differentiation between /s/ and /sh/ sounds. This specific distinction indicates more sophisticated linguistic ability. This discovery adds to the evidence that strong lateralization of function, as found in right-hand use, can promote coordinated development of functions located within the same hemisphere, such as motor control for grasping and speaking.

While the Gonzalez et al. (2014) study focused on the development of speech production, speech comprehension is equally crucial to language ability. It appears that there is a general link between physical movement and receptive language. Two investigations found a link between fine motor abilities and vocabulary size, or reception (Winter et al., 2021; Suggate & Stoeger, 2017). Children aged 3-6 years old participated in both tasks, doing fine motor activities (peg moving, bead-threading, and block-turning tasks) in addition to the widely used Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 2007). Children who did well on the motor activities also did well on the PPVT, indicating a larger vocabulary. Also, Crow et al. (1998) investigated the relationship between hand selection in a writing assignment and vocabulary growth in 11-year-olds. Children who did not show a strong hand preference for writing were more likely to have weak language abilities (Crow et al., 1998).

There are other types of evidence supporting the association between handedness and speech, such as an increased risk of speech impairments in children with greater rates of left-hand usage (Bishop, 2002). Furthermore, children with developmental language impairment have reduced cerebral lateralization for language (Preston et al., 2010). Goez and Zelnik (2008) discovered that in a sample of children aged 5-17 years, individuals with a developmental coordination problem (DCD) demonstrated more occurrences of left-hand usage for writing, tossing a ball, and gripping a spoon, indicating a less lateralized brain. Another study found that children with particular language deficits or DCD utilized both hands together at a higher rate

during a reaching activity than control children, who mostly used their right hand for reaching and grasping (Hill and Bishop, 1998). This research on motor or language disability supports the assumption that motor control and language are linked because people who have deficiencies in one domain (i.e., motor) usually have some degree of impairment in the other (i.e., language).

1.4 GENDER AND LANGUAGE

Multiple research studies have found sex differences in a range of skills, with men having greater average ability than females in certain cases and females having higher average ability than males in others (Feingold, 1992). Male and female language skills typically display diverse patterns as a result of a mix of biological, social, and cognitive variables (Martin & Ruble, 2010). On semantic tasks such as verbal fluency and synonym production, women have been proven to outperform males (e.g., Maitland et al., 2004). This language superiority in females is frequently associated with quicker language development during childhood, when girls tend to attain linguistic milestones faster than boys (Ozcaliskan & Goldin-Meadow, 2010). This discrepancy can be related to the female brain's faster maturation rate in regions associated with language processing, such as the Broca's area in the left hemisphere. Furthermore, the importance of socialization which includes the process through which individuals learn the norms, beliefs, behaviors, and communication skills required for effective integration into society, cannot be overstated (Harasty et al., 1997).

Also, a variety of research studies give strong support for gender-based differences in language abilities, highlighting the strength of the evidence demonstrating females' greater language skills as compared to males. For example, Ma et al in 2018 investigated the effect of age and gender on voice onset time (VOT) in Mandarin speaking children and adults, concentrating on aspirated and unaspirated pauses. Gender disparities were discovered using 85

children (ages 4-18) and 13 adults: females had longer VOTs for heavily aspirated stops and shorter VOTs for unaspirated stops which reveals that gender influences VOT disparities across age and gender.

Since previous research has found gender differences in various areas of language, there is a need to control for such differences in evaluating speech production when investigating the link between language skills and manual dexterity.

1.5 PURPOSE AND HYPOTHESIS

Despite the extensive literature on the relationship between speech and motor control, how exactly the two are related and how handedness mediates this relationship remains unclear. The current research is poised to directly address these questions. I hypothesized that if skilled manual control is predictive of speech production, adults who use their right hand more for fine motor control would perform better on language tasks. Specifically, the following research questions were entertained: 1) Is there a relationship between speech production, language, and manual abilities? 2) Would right-handed people have better language and speech production than left-handed people? Importantly, this research was conducted in adult participants and specifically recruited right- and left-handed individuals.

1.6 IMPLICATIONS

This research will advance our understanding of the links between language and speech production, handedness, and fine motor control. We may, therefore, have a better understanding of the impact speech has on our actions and vice versa. The findings of the study give important insight about these functions and may have direct implications for the understanding of speech articulation. Further knowledge of speech and manual actions may help us better utilize speech in physical activities and, conversely, use fine motor activities in speech therapy. Because the

current studies will increase our understanding of the impact of fine motor skills on speech production, we could potentially use fine motor activities to improve speech delays. If the relationship between speech and fine motor control is better understood, we could increase the effectiveness of speech therapy by incorporating manual movements.

CHAPTER 2: METHODS

2.1 PARTICIPANTS

Thirty-four adults (21 females and 13 males) were recruited to participate in this study. The average age of participants was 23.6 years, with a range of 18-52 years. The number of left-handed and right-handed participants was 15 and 19 respectively. Participants were recruited using the psychology participant pool through the University of Lethbridge and using a flyer posted at the community centers in the Southern Alberta area. Participants who successfully completed the study were granted course credit or a \$25 gift card. All participants in this study were confirmed as having no known motor or speech disorder, as well as being native speakers of English. Also, participants provided informed consent prior to starting the experiment and were aware of the portion to withdraw at any time. These procedures were approved by the University of Alberta Health Ethics Board (study ID #2022-006).

2.2 STUDY DESIGN

This study required participants to engage in three different types of tasks. First, they were asked to fill out a demographic's questionnaire. They then engaged in a series of speech and language tasks. Lastly, participant's manual ability and hand preference were tested. Through these tasks, I was able to evaluate their demographic information, language and speech abilities, manual ability, and degree of handedness.

2.2.1 Demographic and handedness questionnaires

After signing a consent form, participants were asked to complete the demographic questionnaire (see Appendix A), a short version of the Edinburgh Handedness Inventory questionnaire (EHI, Oldfield, 1971; see Appendix A), for which participants were asked to report which hand they typically use for ten activities of daily living (e.g., writing: always left [-100],

usually left [-50], both hands equally [0], usually right [50], or always right [100]), and their rating would be summed to give a value from -100 (extreme left-handedness) to 100 (extreme right-handedness).

2.2.2 Language and speech tasks

Participants then engaged in a series of language and speech tasks including a Peabody Picture Vocabulary Test (PPVT™-5), a Diadochokinetic (DDK) task, and a Tongue Twister (TT) task.

The Peabody Picture Vocabulary Test™ Fifth Edition (PPVT™-5; Dunn, 2019) is a norm-referenced, independently administered assessment of receptive vocabulary based on Standard American English terms. The test is appropriate for those aged 2.5 years, and older. It assesses receptive vocabulary over the course of a lifetime and can provide important information when measuring receptive vocabulary as part of a language evaluation. The PPVT-5's great criterion-related validity is demonstrated by its significant relationships with other well-established measures of vocabulary proficiency. This combination of reliability and validity validates the PPVT-5 as a complete instrument for measuring receptive vocabulary across varied groups (Dunn, 2019).

DDK is the ability to repeat different syllables (non-words) at a high rate of production. DDK, which examines the speed, accuracy and continuity measures of speech production in single, and multi-syllables (/pʌ/, /tʌ/, /kʌ/, /pʌtʌkʌ/), is a clinical assessment for oral motor function (Ciyiltepe & Cifci, 2020). DDK tasks have been used as a speech assessment measure in various studies (e.g., Icht & Ben-David, 2021; Trafiadis et al., 2022; Gao et al., 2023) which are versatile and may be used to test numerous areas of speech production and oral motor abilities in both young children and older adults (Icht & Ben-David, 2021). For example,

Ciylitepe & Cifci, 2020 compared typically developing and stuttering children by the data of DDK measurements and they found that the syllable (/pʌ/ and /kʌ/) repetitions were quicker in typically developing children. Another research study in adults asked monolingual speakers to repeat non-word syllables as precisely as quickly as they could, which measured the effectiveness of age on DDK outcomes and discovered that people who are older have slower DDK rates (Tafiadis et al., 2022). Moreover, in the context of ensuring reliability and validity, it's worth noting that inter-rater reliability ensures a consistent evaluation of DDK task performance among different raters (when multiple raters in the current study evaluate DDK task performance). Additionally, the concurrent validity of the DDK task would find support in robust correlations between its outcomes and related measures, as highlighted by Wang et al. (2009).

For the tongue twister (TT) task, ten tongue twisters with the same length and difficulties were included as stimuli (see Appendix B). The tongue twisters used are commonly known and recognized as natural tongue twisters that are widely familiar among people. The tongue twisters were presented in a random order using the E-Prime 2. Tongue twisters are frequently used in research relating to speech and language development, phonetics, and phonology (e.g. Beirne & Croot, 2018; Wulfert & Hanulikova, 2022; Gussow, 2023). The study of tongue twister errors can give useful insights into speech production processes and also give a standardized method of assessing people's capacity to articulate certain sounds or phonemes, as well as quantify and analyze speech errors (phoneme substitutions, omissions, and repetitions or word order error and etc.). The tongue twister paradigm has mostly been used in psycholinguistic investigations to induce speech mistakes or mixes (Levelt, 1989). Shen & Janse (2020) used TT as one of the speech tasks in their study to see if there is a link between how effectively people transition between comparable syllables during speech and their executive control abilities in a population

of nonclinical young adults. In their study, participants recited hard sentences that were difficult to pronounce due to the recurrence of identical sounds or the quick alternation of consonants. The researchers found that there is a connection between higher-level cognitive processes involved in executive control (such as switching attention and mental focus) and the fine motor control required for speech production. Also, it implies people with more efficient executive control abilities may have an advantage in rapidly shifting between comparable speech sounds or consonant clusters during activities requiring maximal speech performance. In addition, Inter-rater reliability guarantees that the awarded scores stay consistent across various raters when the speech mistakes transcribed from recordings using Praat, with 100% of recordings transcribed by a second rater for reliability, and also, the TT task credibility is demonstrated by the association of task outcomes with recognized measures of verbal ability, demonstrating its validity.

2.2.3 Manual ability tasks

The first motor task included in this study was a brick-building model using Lego® blocks. A workplace was set up on a table covered in Lego® blocks for the participant to sit arms-length away in a stationary chair. The workspace was divided into four equal-sized quadrants: left near (LN), left far (LF), right near (RN), and right far (RF). Each of the four quadrants had the same set of pieces, each of which is different in size, shape, and color within the set. A Sony FDR-AX43 camera was mounted on a triple steel stand in front of the table to record participants' hand movements. By carefully examining both reliability and validity, practitioners and researchers may reliably use the Lego task to assess a wide range of cognitive, motor, and problem-solving skills in a variety of circumstances. This requires a detailed examination that compares task scores with recognized measures of related dimensions, as Strooband et al. (2023) demonstrate.

The second motor task is the Purdue Pegboard Test (PPT), created by Joseph Tiffin in 1948 (Desrosiers et al., 1995). This activity has been widely utilized by researchers for an assessment of (1) gross arm, hand, and finger mobility and (2) fingertip dexterity (Lawson, 2019). PPT is made out of a rectangular wooden board with four cups across the top and two vertical rows of 25 little holes in the center. The two outer cups each have 25 pins; the cup to the left has 40 washers, and the cup to the right of the center has 20 collars. The Purdue Pegboard (Lafayette Instruments) assessed fine manual dexterity. The pegboard had four cups at the top that contained, from left to right, pegs, washers, sleeves, and pegs. Directly below the cups were two rows of holes that ran parallel to each other at the center of the board. Adjacent to the first hole was a starting line on which subjects were asked to place the tips of their fingers before each trial. The pegboard was placed on the edge of the table closest to the subjects to ensure that the reach was comfortable, and the distance to the target was held constant for all subjects. Two distinct conditions were evaluated, with two trials completed for each condition: dominant hand, where pegs were taken from the cup one at a time and placed in the column of holes on the dominant hand side starting at the top; non-dominant hand, where pegs were taken from the cup one at a time and placed in the column of holes on the non-dominant hand side starting at the top. The number of pegs set in 30 seconds was scored in both dominant and non-dominant hand conditions. Purdue Pegboard test scores were computed for right-hand use (PPT-R) and left-hand use (PPT-L) separately. The overall score was determined by the number of pegs in each condition separately (Tiffin & Asher, 1948). In addition, comparable results across multiple administrations, the Purdue Pegboard Test (PPT) exemplifies its reliability. Moreover, the PPT consistently and accurately gauges individuals' fine motor skills and coordination abilities,

enabling precise evaluations and well-informed decisions regarding therapeutic interventions or research conclusions, thus affirming its validity (Levanon et al., 2023).

The study was conducted in one of the rooms in the Speech Production and Development lab at the University of Lethbridge (SA8326). The lab space was designed in such a manner that it was easy for researchers and participants to access all tasks in the correct order.

During the time of data collection, there were strict COVID-19 restrictions in the university and the province of Alberta, so participants had to acknowledge that they were required to take their masks off for the majority of the study for appropriate audio quality during recording. For the time that participants had their masks off for conducting the study, the researcher sat far away from the participant and wore a mask on for the entire study.

2.3 PROCEDURE

During the speech tasks, participants sat in a stationary chair with their mouths close to the microphone in front of a screen. The seating of the participants was approximately 60 cm away from the computer screen. The microphone stand adjusted close to the participants' mouths with a distance of approximately 170 mm. A Marantz Audio Recorder (model PMD661) was used for audio recording. Speech stimuli were presented through E-prime 2 (Psychology Software Tools, Inc., [E-Studio], 2012) on a laptop screen (DELL 7390, 2019) placed in front of the participant. Participants were tested individually in a soundproof room. The two speech tasks: DiadoKinetics (DDK) and Tongue Twister (TT) were delivered through E-prime. Before beginning data collection, participants were given a short introduction to the task and each participant had several practice trials at the beginning of each task.

For the DDK task, participants were asked to repeat each /pʌ/, /tʌ/, /kʌ/, and /pʌtʌkʌ/ syllables continuously without taking a breath, as quickly as possible in five seconds. The

instruction and stimuli were displayed on the screen (Laptop, E- Prime 3.0) and the stimulus order of /pΛ/, /tΛ/, /kΛ/, and /pΛtΛkΛ/ remained the same across participants. Participants were asked to repeat the stimuli after the researcher if needed. Each stimulus was performed twice (once for practice and once for the real trial), and their speech was audio recorded for analysis of accuracy.

For the Tongue Twister task, the experiment contained three practice trials and ten test trials, with each trial containing a four-word prompt. Each of the tongue twisters appeared on the screen (E-prime 2) individually and in the same order for all participants. Before the presentation of each tongue twister, a red circle sign appeared on the screen and stayed for two seconds and after two seconds it disappeared which signal for the start. After a tongue twister was presented on the computer screen, participants were given time to silently read it for two seconds and then read it aloud as fast and accurately as possible. Their speech was audio recorded.

Participants were given the Peabody Picture Vocabulary Test to assess their language skills. This is a norm-referenced receptive vocabulary measure that is administered by giving a stimulus word (by the experimenter) and asking participants to choose a graphic depiction of that word from four options. After the participant was seated in a comfortable and stable chair, the examiner ensured that the participant could view the pictures, which were arranged on the table in front of the participant, and ensured that the test was placed within easy reach of the participant. In addition, for recording the hand use of the participant during the test, the whole test was video recorded by a camera that was located in the back of the participant. Then, the participant was informed that they would be shown a series of pictures and asked to select the corresponding word from a set of multiple-choice options. The audio, which is recorded on Pratt, was played for the participant by the examiner spontaneously, one at a time. Then, the participant

was asked to point to the picture that best described the word they heard. The participants' scores were based on the correctness of the images they selected, and each correct response was counted one point. The overall score (raw score) was generated based on all accurate responses.

The Lego task (Gonzalez et al., 2009) assessed hand use for reaching and grasping. The models were forty-eight Lego pieces (ranging in size from 6.5 cm × 3.2 cm × 2.0 cm to 3.0 cm × 3.0 cm × 2.0 cm) that together made six different sample models. The samples were prepared by the researcher ahead of time, and one sample at a time was presented to the participant for reproduction. The participants were instructed to sit facing a table with a workspace measuring 70 cm deep by 122 cm wide covered in Lego pieces. The workspace was divided into four equal-sized quadrants: left near (LN), left far (LF), right near (RN), and right far (RF). Each of the four quadrants held an identical set of pieces, with each piece being unique in size, shape, and color (see Figure 2). In this task, the participant was expected to recreate six pre-made models. Each model was made from one set of pieces (the same set in each quadrant), so all models had the same components but different configurations. Each participant was given the same six models in different sequences.

During the Lego task, the experimenter first explained to the participant that the objective of the task was to construct a model that resembles the given model. The researcher gestured to a pre-made model at the far end of the block array, aligned with the subject's midline, across from the participant. Participants were asked to complete the replica as quickly as possible, and their actions were video recorded. Participants were allowed to pick up the original model at any point during the task and manipulate it in any way to understand its configuration. When the first duplicate was finished, the researcher removed it and replaced it with the next (in the same spot).

After completion of all three replicas, all pieces on the tabletop were used, and then the other three premade models' pieces were available on the table for the same process.

Afterward, the participants were engaged in the Purdue Pegboard Task, a well-known measure of manual dexterity (Lawson, 2019). To ensure optimal performance, each participant was seated comfortably and securely on a chair, and the examiner made certain that the pegboard was positioned at an appropriate distance to allow easy access to the pegs and holes without requiring excessive arm stretching. Additionally, participants were instructed to rest their forearms on the table where the pegboard was placed. (See Figure 3 for an illustration of the task setup.) Then, the examiner explained the test and materials and asked the participant to have a practice round without timing and scoring. Following that, the examiner started the timer and asked the participant to use one of their hands (dominant hand or non-dominant hand—start randomly for each participant) to pick up the pegs and place them one by one into the holes on the board thirty seconds (right-hand, right holes, left-hand, left holes), and then after the task is completed, the examiner asked the participant to repeat the task with another hand (dominant hand or non-dominant hand) in the same time limit (30 seconds).

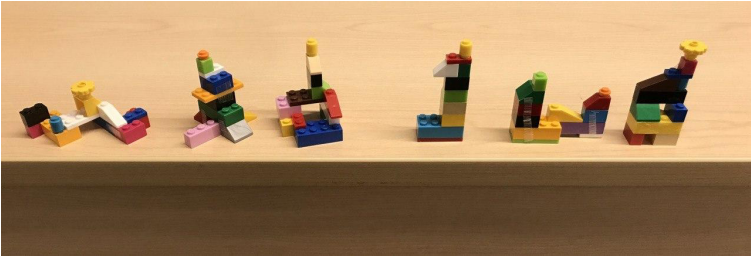


Figure 1: The high- and low-demand mental rotation Lego models (left and right, respectively)

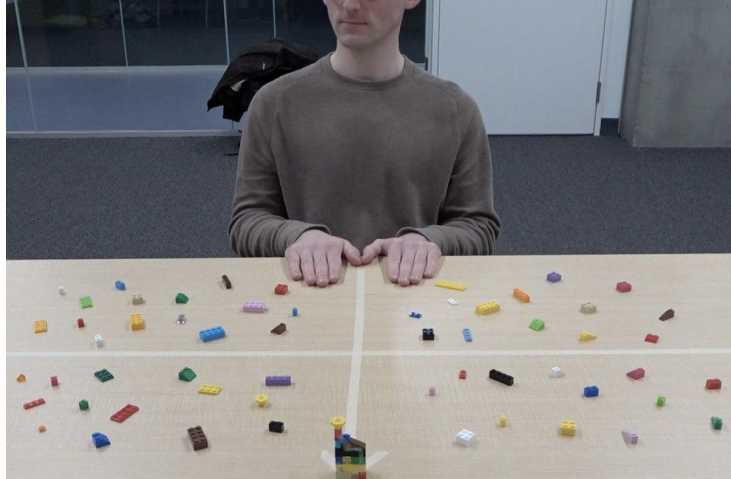


Figure 2: A workspace covered in Lego pieces



Figure 3: Participant initiated a left-hand use pegboard (PPTL) task

2.4 ANALYSIS

2.4.1 Language and speech Tasks

Participants completed the speech tasks on an Asus laptop in E-Prime 3. Participants' responses to these tasks were recorded via a microphone. All the speech recordings were analyzed in Praat (Boersma & Weenink, 2017).

For the DDK task, the number of repetitions by Praat Software was counted for each syllable (/pʌ/, /tʌ/, /kʌ/, and /pʌtʌkʌ/) separately and then the total number was used to calculate the Mean number of repetitions per second. In the current study, the mean number of repetitions (total number of repetitions/ total duration in seconds (5 seconds)) was used in the analysis.

Regarding the TT task, each repetition in a trial was segmented so that the duration of each set of words was measured. The duration for all repetitions was calculated for each participant. Also, the number of repetitions and the number of speech errors were logged for each participant. Speech errors that contain all types of errors (ex: phoneme substitution, phoneme insertion, phoneme deletion, word repetition, or vowel distortion) were counted. Only the total number of errors was included in the analysis which means that if a participant consistently said the wrong word that word deemed as an error.

In PPVT-5, the number of correct responses by participants was counted (raw score), and then according to the normative scheme, the raw score was converted to the standard score. The standard score was used in the analysis, which is used to gauge participants' performance compared to the average performance of others in the same age group.

2.4.2 Manual ability and handedness tasks

For the Purdue pegboard task, the number of pegs that each participant put in the holes with left-hand (PPT-L) and right-hand (PPT-R) in thirty seconds were counted separately. And in the Lego task, the number of times that participants used the right- and left-hand for picking up the Lego bricks was recorded. In the current study, the percentage of right-hand use (right-hand use/(right-hand use + left-hand use)*100) was used in the analysis.

2.4.3 Statistical Analysis

To address the study goals, the data were analyzed using Analysis of Variance (ANOVA) and General Linear Model (GLM) regression using a R software. To assess differences between right- and left-handers, as well as female and male participants, a two-way ANOVA was utilized.

Three separate GLMs were used for the analysis, one for the PPVT task, one for the DDK task, and one for the TT task. The equation used for this model in the General Linear Model (GLM) regression analysis for three different speech tasks (dependent variables) and three different manual ability tasks (independent variables) in R can be seen below.

```
summary(glm(DDK~Age+Gender+Handedness+LegoR+PPTL+PPTR,data=df))
```

```
summary(glm(PPVT~Age+Gender+Handedness+LegoR+PPTL+PPTR,data=df))
```

```
summary(glm(TT~Age+Gender+Handedness+LegoR+PPTL+PPTR,data=df))
```

CHAPTER 3: RESULTS

This chapter presents the findings of the speech and motor tasks analyses. The primary purpose of this thesis was to determine if a relationship exists between fine motor control and language, particularly, speech production. I hypothesized that right-handed people would have better language and speech abilities. A three-step analysis was conducted: Section 3.1 summarizes the descriptive statistics for language and speech production as well as data on manual ability. Data for each variable was described for both genders and handedness categories together and separately. Section 3.2 outlines the results of a two-way ANOVA in which we explore gender and handedness differences for the language and manual ability data. Section 3.3 reports the results of a General Linear Model (GLM) to understand the relationship between language and motor abilities.

3.1 DESCRIPTIVE STATISTICS

The purpose of the following section is to summarize how the language and speech production and motor data were distributed across both genders (female and male) and both handedness groups (left- and right-handers). The variables are divided into three categories: 1) demographics: responses to the Edinburgh questionnaire, gender-typicality questionnaire responses, and age; 2) language measures, and 3) manual ability measures. The language measures include the Peabody Picture Vocabulary Test (PPVT) and two speech production tasks: the Diadochokinetic (DDK) task, and the measure of Tongue Twister (TT) task. Manual ability measures included participants' performance on the Purdue Pegboard Test (PPT) and the Lego task.

3.1.1 Gender, handedness, and age

Descriptive statistics for the mean and standard deviations of these measurements were reported by participants based on the demographic questionnaire which can be found in Appendix A. Table 1 contains the demographic results for these variables. The study comprised a sample of 34 participants. Their age ranged from 19 to 52 years with a mean age of $M = 23.6$ years ($SD = 6.9$). The sample included 13 males (38%) and 21 females (62%). Nineteen (56%) identified as right-handed and fifteen (44%) identified as left-handed. Table 1 shows the handedness results according to the Edinburgh handedness questionnaire. Scores in this questionnaire range from 100 (always right) to -100 (always left). Right-handed participants had a mean score of 88.8 ($SD = 15.5$); left-handed participants' mean score was -70 ($SD = 37.4$). Table 1 presents the distribution of participants across different genders (female and male) and handedness (right-handed and left-handed).

Table 1

Mean and Standard Deviation for Age and Edinburgh Inventory Scale by Gender and Handedness

Variable			Left-handed	Right-handed
Age	Female	22.6 (7.39)	21.7 (4.06)	23.4 (9.65)
	Male	25.4 (6.12)	25.2 (3.70)	25.5 (7.50)
	Total	23.6 (7.39)	22.9 (4.17)	24.3 (8.65)
Edinburgh	Female	11.9 (87.5)	-73.8 (32)	89.8 (18.4)

	Male	29.8 (81.17)	-62.5 (50)	87.5 (11.6)
	Total	18.8 (84.5)	-70 (37.4)	88.8 (15.5)

3.1.2 Language measures

Table 2 illustrates the mean for the three language variables separated by gender and handedness. For the Peabody picture vocabulary test, the mean PPVT score was 107 (SD = 11.7) with females scoring M = 103 (SD = 10.3) and male participants scoring M = 113 (SD = 11.8). Right-handed participants scored M = 108 (SD = 11.8) and left-handed participants M = 105 (SD = 11.7). Table 2 shows these data further broken down by gender and handedness.

The mean diadochokinetic (DDK) score was M = 4.10 words/sec (SD = 0.83) with a mean for female speakers of M = 3.99 (SD = 0.79), and male speakers of M = 4.27 (SD = 0.89). Right-handed speakers scored M = 4.39 (SD = 0.82) and left-handed participants scored M = 3.73 (SD = 0.7). Broken-down data by gender and handedness can be found in Table 2.

The mean for the number of errors in the tongue twister task was M = 17.9 (SD = 7.53) with females scoring M = 20.3 (SD = 7.28) and male participants scoring M = 14 (SD = 6.42). When separated by handedness, the mean for right-handed participants was M = 17.1 (SD = 6.59) and, for left-handed participants was M = 18.9 (SD = 8.7). A breakdown of the mean of speech tasks can be found in Table 2.

Table 2*The Mean and Standard Deviation of Speech Variables by Gender and Handedness*

Variable	Task			Left-handed	Right-handed
Speech Production	PPVT	Female	103 (10.3)	101(10.2)	105 (10.3)
		Male	113 (11.8)	114 (10.3)	112 (13.3)
		Total	107 (11.7)	105 (11.7)	108 (11.8)
	DDK	Female	3.99 (0.79)	3.66 (.71)	4.29 (.78)
		Male	4.27 (0.89)	3.86 (.75)	4.53 (.92)
		Total	4.10 (.83)	3.73 (.7)	4.39 (.82)
	TT	Female	20.3 (7.28)	21 (9.35)	19.6 (5.14)
		Male	14 (6.42)	14.8 (6.06)	13.5 (6.99)
		Total	17.9 (7.53)	18.9 (8.71)	17.1 (6.59)

3.1.3 Manual ability measures

As can be seen in Table 3, the average number of pegs inserted into the Purdue board when participants used the right hand was $M = 15.1$ ($SD = 2.46$) and when using the left hand was $M = 14.9$ ($SD = 2.35$). The female mean score when using the right hand was $M = 15.5$ (SD

= 2.79) and when using the left hand was M = 14.8 (SD = 2.55). The male mean score when using the right hand was M = 14.4 (SD = 1.71), and M = 15.2 (SD = 2.08) when using the left hand. The full descriptive statistics can be found in Table 3.

Table 3

The Mean and Standard Deviation of Motor Variables for Male and Female by Handedness

Variable	Task		Gender		Left-handed	Right-handed
	PPT	R				
Manual Ability	PPT	R	Female	15.5 (2.79)	14.6 (3.17)	16.3 (2.24)
			Male	14.4 (1.71)	14 (1)	14.6 (2.07)
			Total	15.1 (2.46)	14.4 (2.61)	15.6 (2.27)
		L	Female	14.8 (2.55)	15.5 (3.06)	14.1 (1.87)
			Male	15.2 (2.08)	16.6 (1.95)	14.2 (1.67)
			Total	14.9 (2.35)	15.9 (2.72)	14.2 (1.74)

3.1.4 Lego right hand use

The results of Table 4 show that the mean percent right-hand use on the Lego task was M = 56.1 (SD =30.8). Females' right-hand use was M = 57.1 (SD = 31.3) and males was M= 54.5

(SD =31.4). The mean right-hand use for right-handed participants was M= 74.8 (SD= 20.3) and for left-handed participants was M = 32.4 (SD= 24.9). Data broken down by gender and handedness is presented in Table 4.

Table 4

The Mean and Standard Deviation of Motor Variables for Male and Female by Handedness

Variable	Task	Gender		Left-handed	Right-handed
Manual Ability	LegoR	Female	57.1 (31.3)	33 (27.6)	79.1 (11.7)
		Male	54.5 (31.4)	31.2 (21.3)	69 (28.3)
		Total	56.1 (30.8)	32.4 (24.9)	74.8 (20.3)

3.2 INFERENCE STATISTICS: TWO-WAY ANOVA

To examine the effects of gender and handedness in the language and motor tasks, a two-way analysis of variance (Two-way ANOVA) was conducted. The independent variables were gender (female, male) and handedness (right-handed, left-handed). The dependent variables for the language tasks were the scores on the PPVT, the mean number of syllables/ per second produced during the DDK task, and the number of errors in the TT task. The dependent variables for the motor tasks were the number of pegs inserted onto the board with the right and the left hand, and the right-hand use during the Lego task. The significance level was set at $p < 0.05$. The results of this analysis are reported in the following section.

3.2.1 Peabody Picture Vocabulary test (PPVT)

A main effect of gender was found in the PPVT scores ($F(1, 33) = 5.45, P = 0.02$). The results show that male participants have a greater ($M = 113$) mean vocabulary size compared to female participants ($M = 103$). No main effect of handedness was found ($F(1, 33) = 0.63, P = 0.43$) nor a significant interaction between gender and handedness ($F(1, 33) = 0.73, P = 0.39$)

Table 5 and Figure 4 show the results of the analysis.

Table 5

Two- way ANOVA- Speech Task- PPVT

	SS	Df	MS	F- Value	P-Value
Handedness	77	1	77.4	.63	.43
Gender	666	1	665.8	5.45	.02*
Interaction	90	1	89.7	.73	.39
Within	3665	30	122.2		
Total	4498	33			

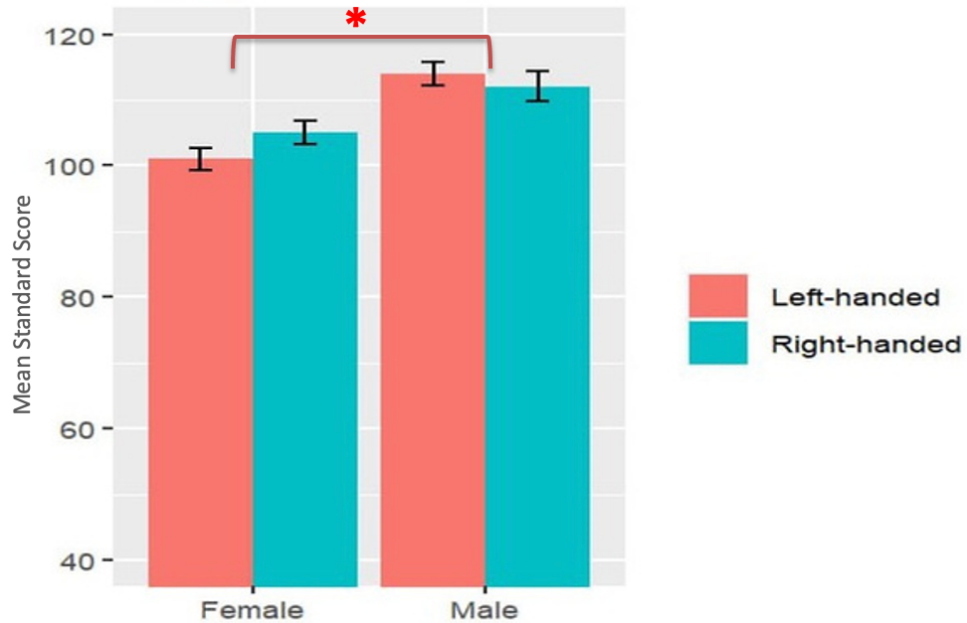


Figure 4: Distribution of PPVT scores by Handedness

3.2.2 Diadochokinetic (DDK)

No significant gender differences were found in the DDK score ($F(1, 33) = .61, P = 0.44$). But there was a significant difference between left and right-handed participants ($F(1, 33) = 5.84, P = 0.02$). According to Figure 5, right-handers perform better than left-handers in the DDK task, which indicates greater oro-motor skills in right-handers. No significant interaction between gender and handedness were found ($F(1, 33) = 0.004, P = 0.95$). Table 6 and Figure 5 show these results.

Table 6

Two- way ANOVA- Speech Task- DDK

	SS	Df	MS	F- Value	P-Value
Handedness	3.68	1	3.68	5.84	.02*
Gender	.38	1	.38	.61	.44
Interaction	.002	1	.002	.004	.95
Within	18.9	30	0.63		
Total	22.96	33			

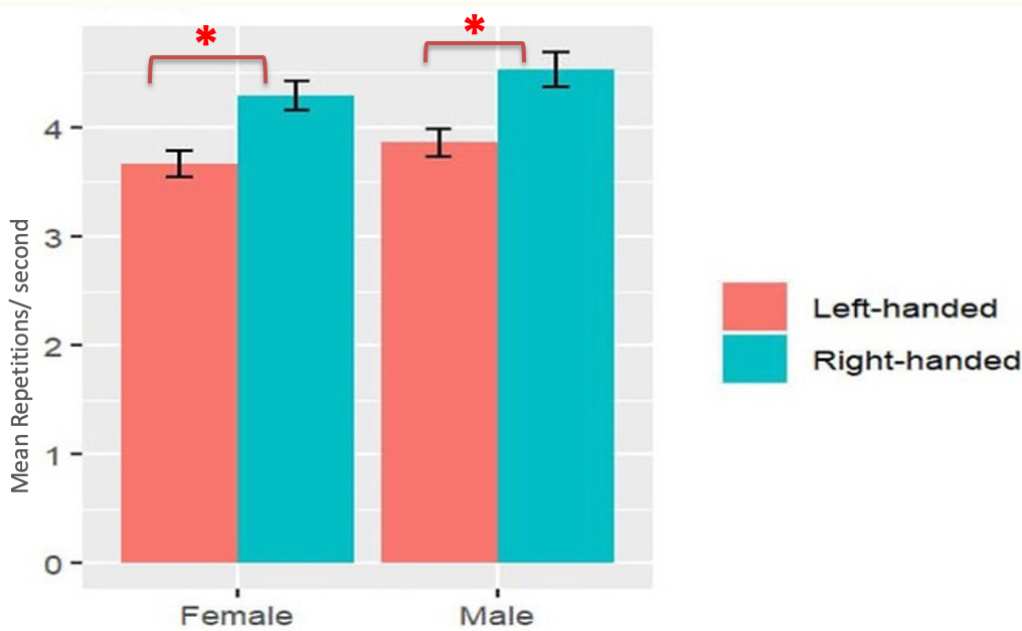


Figure 5: Distribution of DDK scores by Gender

3.2.3 Tongue Twister (TT)

There was a significant difference in the number of errors in the TT task between female and male participants ($F(1, 33) = 5.89, P = 0.02$) whereby females ($M=20.3$) made more errors rather than males ($M=14$). There were no significant differences in terms of handedness $F(1, 33) = 0.57, P = 0.45$ or in terms of an interaction between gender and handedness ($F(1, 33) = 0.00, P = 0.99$). Table 7 and Figure 6 show these results.

Table 7

Two- way ANOVA- Speech Task- TT

	SS	Df	MS	F- Value	P-Value
Handedness	29.6	1	29.6	.57	.45
Gender	302.5	1	302.5	5.89	.02*
Interaction	.0	1	.01	.00	.99
Within	1539.3	30	51.31		
Total	1871.4	33			

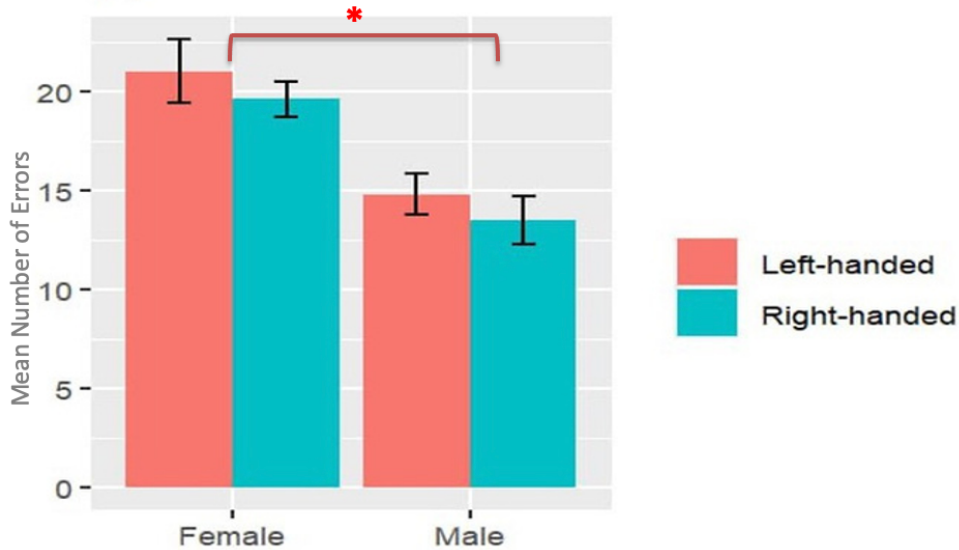


Figure 6: Distribution of TT scores by Handedness

3.3 RELATIONSHIP BETWEEN LANGUAGE AND MANUAL ABILITY

A generalized linear model (GLM) regression analysis was conducted to examine the research question, which is whether language ability can be predicated by manual dexterity. In particular, this model estimates the amount of variance explained by manual ability when predicting an individual’s speech and language capability

Three GLM models were constructed, one for each of the speech and language measures. For each model, the dependent variable was the PPVT score, DDK score, or TT errors. The independent variables were manual abilities as measured by right- and left-hand use in the pegboard task, and right-hand use in the Lego task. By GLM regression, the possibility of an association between dependent variables (PPVT, DDK, and TT) and independent variables (LegoR, PPTL, and PPTR) were tested. Additionally, gender and age were included as covariate (control variables) in the GLM regression because of the results of the two-way ANOVA demonstrating the influence of gender or handedness differences on speech production.

The results of these models can be found in Table 8, which provides information on the estimated coefficients, standard errors, t-values, and p-values for each independent variable.

3.3.1 Peabody picture vocabulary test (PPVT) and Manual ability

Although the results of Table 8 show no significant result between PPVT and manual ability tasks, it provides some interesting findings. The results indicated that there is a positive gender effect on the PPVT score (Coef. = 8.46, P= 0.048), suggesting a higher PPVT value for male participants compared to females. It means male speakers have a larger vocabulary size with an average of 8.46 higher scores than females.

Table 8

General Linear Model (GLM) regression for PPVT (comparison level was indicated in parentheses)

Independent Variable	Coefficient (Coef.)	Standard Error (Std.Err.)	t- value	p- value
Age	.54	.28	1.90	.066
Gender (Male)	8.46	4.09	2.06	.048*
LegoR	.02	.07	.29	.772
PPT-L	-.54	1.13	-.48	.632
PPT-R	.34	1.04	.32	.74

3.3.2 Diadochokinetic (DDK) and Manual ability

The results indicate that among all manual tasks, just PPT-R shows a main effect in DDK (Coef. = .16, P= 0.037). Specifically, with one unit of increase in PPT-R (i.e., one more peg being put in the hole when asked to use their right hand), their DDK value increases by .16 (i.e., they are able to produce an additional .16 syllables per second). According to Table 9, LegoR and PPT-L show no significant coefficient with DDK.

Table 9

General Linear Model (GLM) regression in DDK

Independent Variable	Coefficient (Coef.)	Standard Error (Std.Err.)	t- value	p- value
Age	.03	.02	1.76	.08
Gender (Male)	.39	.29	1.34	.189
LegoR	.003	.005	.63	.532
PPT-L	-.07	.08	-.87	.390
PPT-R	.16	.07	2.18	.037*

3.3.3 Tongue Twister (TT) and Manual ability

The results indicated that there is a negative effect of gender on TT score (Coef. = -6.00, P= 0.023), with male participants having higher DDK scores than females. The results suggest that male speakers made fewer errors in the tongue twister task, and thus performed better than females. We also found a main effect of the LegoR task in TT (Coef. = -.10, P= 0.026) which means that with one unit of increase in LegoR (i.e., one more grasp of a piece of Lego with their

right hand), their TT value decreases by .10 (i.e., they are able to perform -.10 number of errors).

According to Table 10, PPT-L and PPT-R show no significant coefficient with TT.

Table 10

General Linear Model (GLM) regression in TT

Independent Variable	Coefficient (Coef.)	Standard Error (Std.Err.)	t- value	p- value
Age	-.17	.17	-1.01	.319
Gender (Male)	-6.00	2.49	-2.40	.023*
LegoR	-.10	.04	-2.34	.026*
PPT-L	-.46	.69	-.66	.510
PPT-R	-.09	.63	-.14	.888

CHAPTER 4: DISCUSSION

4.1 GENERAL DISCUSSION

The current thesis was designed to investigate the interrelationship among language, speech production, manual ability, and handedness. Based on previous research, I hypothesized that 1) right-handers would have better language and speech production and 2) better manual dexterity would be associated with greater language and speech production abilities. In addition, because multiples levels of speech and language ability were measured, the current study further investigated the specific levels of linguistic processing that might be related to motor skills and handedness.

Two hypotheses were made in the introduction with respect to the research question. The first hypothesis, based on previous studies in speech production and motor development (see Ireland, 1907; see Bates & Dick, 2002; see Gonzalez et al., 2018), was that there would be a relationship between language/speech production and manual ability. We predicted that people with greater manual ability would also show better language and speech skills. The second hypothesis was that right-handed adults would have better speech production compared to left-handed adults. This hypothesis is in line with prior studies that have shown the superiority of the left hemisphere of manual activities (see Gonzalez & Goodale, 2009; Cochet, 2016) and language (see Somers et al., 2015). For example, one study on speech articulation which measured the acoustic distance between the “s” and “sh” sounds when the child produced the names of objects, showed that if the distance between the two sounds is greater, the more the youngster utilized the right hand in a fine motor task (Gonzalez et al., 2014). Another study using a similar Lego task than the one used here, found a positive correlation between right-hand use for precision grasping and language lateralization (i.e. the more language was

lateralized to the left hemisphere when individuals used their right hand to grasp the Lego pieces; Gonzalez & Goodale, 2009). These results lend support to the findings of the current study's research question, which is also in line with Dimitrova et al (2020) findings that right-handed gestures may predict the vocabulary size in speech. While the exact reason for this link is not clear, several studies showed a positive relationship between handedness and structural brain differences in regions associated with language processing (see Foundas et al., 2004). The researchers utilized MRI scans to look at the asymmetry of speech-language areas in right- and left-handed people. Foundas et al. (2004) observed that the association between handedness and brain structural variations is more apparent in right-handed people, where certain brain areas connected to language processing demonstrate a significant leftward asymmetry. This pattern is less prevalent in left-handed people, and the direction of asymmetry is related to their writing position. The work gives information on how handedness may contribute to structural brain abnormalities and their possible significance to language processing.

The value of this project lies in our endeavor to achieve a comprehensive understanding of the various levels of linguistic processing. Undoubtedly, the landscape of language and speech tasks is vast, with numerous options available for assessment. In light of my research objectives and the need for tasks that are particularly suited for adults, I carefully selected three unique measures: the Peabody Picture Vocabulary Test (PPVT), Tongue Twisters, and Diadochokinetic Rate (DDK). I deemed these tests as the most suitable choices for my study. By utilizing these specific measures, my research did not solely focus on articulation; instead, it was designed to gain a holistic overview of the language profiles.

To evaluate the links between language, fine motor abilities, and handedness, I included both left-handed and right-handed participants in this study. Left-handed people frequently

demonstrate various brain lateralization patterns that might impact language processing, as well as distinct approaches to fine motor skills (Johnstone et al., 2021). While the majority of people are right-handed and have a left-hemisphere dominance for language, left-handers have more variable lateralization patterns (i.e., left/right-hemisphere dominant for language; Johnstone et al., 2021). I expected to acquire a better grasp of these complex relationships by analyzing both groups. Furthermore, taking handedness into account in my research, allowed for sensitivity analysis and guaranteed an inclusive representation of the human population. This approach adds to a more thorough analysis of language and fine motor skill development by emphasizing the importance of handedness as a significant variable in future studies. In this area of study, there is a notable lack of adult-focused research, particularly in the areas of language, fine motor abilities, and their interactions with handedness. While numerous studies have examined language development and fine motor skills in children and adolescents, the adult population, particularly regarding the influence of handedness, remains significantly underrepresented in the literature.

I used a Two-way ANOVA to compare means across gender and handedness and a General Linear Model (GLM) regression to further investigate relationships between the language and motor variables. Although the results of these analyses were not conclusive with respect to the link between the different language measures and manual ability assessments in adults, they did provide some insights which will be detailed in the following sections.

4.1.1 Gender differences

The results showed that male participants performed significantly better in the PPVT and TT tests. This finding was further supported by the GLM regression analysis. Interestingly, this result contradicts the papers that show gender differences in speech abilities that favor females

(see Ma et al., 2018; see Yu et al., 2015). For example, in previous studies by Harrison & McLeod, 2010, it was demonstrated that male gender is a risk factor for SLD (Harrison & McLeod, 2010), and a study of 9854 Israeli Jewish children aged 2 to 3 years born in 1980 discovered that speech and language disorders were more prevalent in male children (Bendel & et al., 1989). Although some studies show that females' performance in speech production is better compared to males, there are some studies that showed no sex differences (see Klatt & Klatt, 1990, Munson et al., 2006; Dunn and Dunn, 2007). One difference of note between the current thesis and previous research is that the majority of these reports are in children, and there are few studies investigating sex differences in language ability of both, production and receptiveness in adults. Another factor that could account for our results is that in our sample, we had a limited number of males, and some of the ones we recruited might have been those with exceptional language skills. Also, it is noteworthy to mention that within our research sample sourced from the psychology pool, females demonstrated a higher degree of representation in comparison to males. So, it is possible that our results showing better performance in males is an isolated finding requiring further investigation that includes a larger sample size and varied demographics (i.e., not only university students).

4.1.2 Handedness differences

The Two-way ANOVA revealed only one handedness difference, right-handed participants scored better in the DDK task. This finding supports our original hypothesis but interestingly, the GLM regression analysis suggests that rather than handedness per se (grouping participants according to the Edinburgh handedness questionnaire), it is the degree of right-hand use that relates to the language tasks. Developmental studies in infants and children whose handedness has not been formally established but that display higher rates of right-hand use for

pointing and grasping show better language ability (Nelson et al., 2017; Cochet et al., 2011). The Gonzalez et al., 2014 study aimed to investigate the relationship between motor performance and executive function (EF) in children. Two age groups of children completed grasping tasks involving Lego blocks to construct various models. The researchers indicated that both right-hand use and right-space use during the tasks were predictors of enhanced executive function. In other words, children who exhibited more right-hand dominance (regardless of handedness), tended to have better EF scores which aligned with the results of the current study as the thread of motor lateralization. Particularly, right-hand use is associated with improved cognitive functions and suggests that motor lateralization may play a role in supporting higher-order cognitive abilities. This alignment implies that a more lateralized brain, favoring right-hand use, might have broader implications for various cognitive functions in right-handed individuals.

4.1.3 Language and manual ability

The GLM regression analysis revealed that being a male is associated with a significant increase in vocabulary size. As mentioned earlier, this was a surprising result, as previous studies have shown no sex differences or a female advantage in some aspects of language (see Klatt & Klatt, 1990, Munson et al., 2006; Dunn and Dunn, 2007). Again, it will be important to diversify and increase the sample size before any conclusions can be made about gender and vocabulary size.

Central to the research question, the GLM demonstrated a relationship between manual dexterity and the DDK. Participants that placed more pegs when using the right hand, obtained better scores in the DDK. In a previous study by Melby and others (1987), it was demonstrated that the correlation between pegboard and PPVT scores in children was positive and significant, which aligns with the current finding.

Results of the GLM also revealed a significant link between hand preference for grasping and speech production. Participants that used their right hand more often to pick up the Lego blocks, made fewer errors in the tongue twister task. This result supports a previous developmental study that demonstrated that children that used their right hand more often to pick up objects had better speech production (Gonzalez et al., 2014). It also aligns with other research that has demonstrated significant relationships between fine motor skills, manual actions, and speech production (see Scott et al., 2009, Westerhausen et al., 2010). In closing, the findings of the study showed a substantial association between manual dexterity and speech production, adding to the expanding body of data demonstrating the link between fine motor skills and linguistic ability.

4.2 LIMITATIONS AND FUTURE CONSIDERATION

There were a number of limitations to the research that was conducted for this thesis. The first important limitation is the limited sample size, which may restrict the ability to generalize the results. The current study's small sample size also reduces the power of statistical analysis, which means that actual effects may have been overlooked due to insufficient statistical power. To confirm and extend the findings of this study, more research with a larger sample size is required. In addition, the majority of participants recruited were U of L students. University students are not a representative sample of the population. Furthermore, another limitation of this research was the difficulty in recruiting left-handed participants. Left-handed people are known to be a minority in the population, accounting for around 10% of the overall population. As a result, obtaining an acceptable sample size of the left-handed participants was difficult. The small number of left-handed participants within the study's target population remained a significant challenge. As a result, caution should be exercised when interpreting the findings for

the broader left-handed population. Additionally, an unequal representation of female and male participants is another limitation. Due to the sample's gender imbalance, with significantly more female participants than males, the study's ability to adequately analyze and create conclusions regarding gender differences and interactions may be limited, as gender can influence different variables, including behavior and actions, which could potentially impact the results.

Likewise, a limitation of utilizing a Tongue Twister task in the study is the potential confounding effect of participants' familiarity or experience with tongue twisters. This familiarity and expertise in handling tongue twisters could potentially impact a participant's performance. Further studies could consider assessing participants' prior exposure to tongue twisters and control for their level of familiarity or skill to better isolate effects.

4.3 CONCLUSION

The present study contributes to investigating the association between speech production and manual ability. Specifically, this thesis investigated how handedness and speech production link together. Although the findings from this research were inconclusive, they were suggestive. Despite having such a small sample size, we found some significant results and relationships. The first major finding was the existence of a relationship between fine motor control and language, particularly speech production. While Diadochokinetic and PPVT showed no association with manual ability, the findings from Tongue Twister and Lego indicated a significant association. The results from this study and an investigation into previous studies (see Overby et al., 2012 & Butler et al., 2023) seem to highlight that fine motor skills, such as the control and coordination of hand and finger movements, have a significant impact on language abilities and development.

The second major finding was that right-handed people have better language and speech abilities. These differences between right-handed and left-handed participants were in PPVT and TT, suggesting that hand preference, like previous studies, may influence language and speech production abilities (see Bruckert et al., 2021 & Markou et al., 2017).

The third major finding from this research is the sex difference in vocabulary size and in speech production as measured by the TT test. The existence of gender differences in speech production highlights the possibility of sociocultural influences, individual variations, or environmental factors. Kent & Vorperian (2013) discussed their observations from various aspects of speech and language where there is a difference between males and females. Because our sample size was small and almost exclusively composed of university students, the male advantage found here needs to be further corroborated.

Future research should be conducted in which the sample size of participants is bigger. This would provide more representative results. With a larger sample size, future studies can provide a comprehensive understanding of the association between speech production, handedness, and manual ability. In addition to increasing the sample size, future studies also should strive to include an equal number of left-handed and right-handed participants which leads to certain results about motor asymmetries and potential variations in the neural mechanisms underlying speech and manual abilities.

In conclusion, while there are still many questions about the relationships between language, speech abilities, fine motor control, and handedness, this present study gives some insights into how manual ability and hand preference (right hand for grasping) can affect speech production in an adult population. Specifically, adults that have better manual ability with the right hand as measured by the pegboard task, were able to produce more utterances as measured

by the DDK task. Furthermore, participants that used their right hand more for picking up Lego blocks, made fewer mistakes in a tongue twister task. These results lay the foundation for future research investigating language ability and manual function in adults.

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Appendix A

Questionnaires

Demographic Questionnaire



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Please fill out this brief questionnaire and hand it in along with the consent form.

Name: _____ Date of Birth: _____ Age: _____ Sex: _____

Email address: _____ Telephone number: _____

What is (are) your first language(s)? _____

If your first language is not English, when did you start to learn English? _____

Do you speak any additional languages? _____

Where were you born? _____

What is your ethnicity? _____

Do you consider that your speech, language, and hearing are within normal limits?

Y ___ N ___ If no, please describe _____

What is your dominant hand for writing? Left Right

What is your overall dominant hand? Left Right

Would you be ok if we contact you for follow-up questions? Y N

Would you like to be included in our subject pool mailing list for future experiments? Y ___ N ___

Thank you for participating in this study!
Hadis Honarvari
Department of Psychology
University of Lethbridge

The Edinburgh inventory Oldfield, R. C. (1971)

Edinburgh Handedness Inventory—Short Form

Edinburgh Handedness Inventory - Short Form

Please indicate your preferences in the use of hands in the following activities or objects:

	Always right	Usually right	Both equally	Usually left	Always left
Writing	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Throwing	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Toothbrush	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Spoon	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

Scoring:

For each item: Always right = 100; Usually right = 50; Both equally = 0; Usually left = -50; Always left = -100

To calculate the Laterality Quotient add the scores for the four items in the scale and divide this by four:

Writing score	<input type="text"/>
Throwing score	<input type="text"/>
Toothbrush score	<input type="text"/>
Spoon score	<input type="text"/>
Total	<input type="text"/>
Total ÷ 4 (Laterality Quotient)	<input type="text"/>

Classification:	Laterality Quotient score:
Left handers	-100 to -61
Mixed handers	-60 to 60
Right handers	61 to 100

Appendix B

List of tongue twisters

1. Soup Talk Sack Tape
2. Moss Knife Noose Muff
3. Sauce Beak Sock Base
4. Case Port Bed Moon
5. Mass Pub Mob Pass
6. Bus Farm Nook Soup
7. Bed Cough Card Beef
8. Moat Nap Mop Nut
9. Fort Pass Fuss Peat
10. Sum Fin Foam Sign