LATERALIZATION LEFT OUT: THE INTERCONNECTIONS BETWEEN LANGUAGE, MOTOR SKILLS, EXECUTIVE FUNCTION, AND SOCIAL SKILLS IN PRESCHOOL CHILDREN

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Master of Science, University of Lethbridge, 2017

A thesis submitted
in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

NEUROSCIENCE

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LETHBRIDGE, ALBERTA, CANADA

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Date of Defence: June 17, 2024

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Dedication

This thesis is dedicated to all the women in my life who believed and supported me, and to the future girls and women who I hope to provide the same support.

Abstract

The goal of this thesis is to investigate the role of hand preference in preschool development using comprehensive measures to assess five dimensions: lateralized hand use, language, fine motor skills, executive function, and social competence. Early right-hand preference has been linked to better cognitive skills, but rarely studied comprehensively alongside multiple assessments of child cognitive abilities. I conducted three studies with two general goals; examine the relationship between hand preference and the four other dimension, and compare the relationships between all five areas using a single cohort of children. I found that hand preference had a small effect on child cognitive performance whereas social competence consistently appeared as a predictor of success for each cognitive skill. This result suggests that programs and interventions for enhancing cognitive function should place special emphasis on social competency.

Acknowledgments

If someone told me during my undergraduate degree that I would eventually write the acknowledgment section of my PhD dissertation, I would have laughed. It has been a long time coming, but now I cannot find the words to express my sincere thanks to Dr. Claudia Gonzalez for her belief in me, and patience over the past ten years. When I joined the Brain in Action Lab as an independent study student, I had no idea what I had truly signed up for, in the best of ways. Thank you Claudia for your support, your (many) hours of guidance and feedback, and for curating a lab that became such a special part of my life. I also must extend my deepest gratitude to Dr. Fangfang Li, who also shared a belief in me, also from my undergraduate degree when she recommended that I consider a research-based Masters program at U of C after a class project. Your hours of work, feedback, support, and your assistance with programming are all invaluable. I feel so fortunate to have worked with two phenomenal researchers as my supervisors over this degree. Thank you.

I would also like to extend my thanks to my committee members, Dr. Robbin Gibb and Dr. Matthew Tata, for your time spent in meetings with me, and the ideas that you shared that helped shape this thesis. It would not have been possible without your time. I would similarly like to thank my external examiner, Dr. Pam Bryden, for volunteering your time and insight. Again, this is not possible without you.

To the lab, and the people from the lab who made this journey so much more fun than expected, I am very grateful. Thank you especially to Lara and Daniela. I do not believe that everyone's PhD includes a US roadtrip and getting lost in San Bernadino, or weekend trips down to Portland. Thank you also for being a sounding board and another excellent source of feedback, friendship, and insight over these years.

Thank you to the many other peers and students who I worked with, directly or indirectly over the years. Whether it was sharing a project, meeting for coffee, wrangling children during data collection, or those who put in hours and hours of work to analyze or re-analyze data.

I must thank my family, who instilled the value of education and knowledge, and who I never doubted their belief in me. My grandparents, who never questioned why I would keep going to school instead of marrying or farming, the options they were faced with. My parents who supported me above and beyond what any child would expect. Your diligent bedtime reading paid off, I think. To Anita, your humour, check-ins, and friendship are so meaningful, and I feel so lucky to shout-out my sister-in-law. Leigh, as well, thank you for your friendship. Keith, thank you for your love, and your humour.

A second thank you to Claudia and Fangfang for taking me on as a student, because without my PhD, I might have never met my husband. Luke, you have only been in my life a short time, but you showed up at just the right time. Thank you for your support, your friendship, and love. And most importantly, being the wind in my sails.

A final thank you is owed to the man who is the reason I know anything is possible if you work hard, and who shared the wisdom ”The world would be a better place if everybody loved each other.” Thank you Tommy Wiseau, for your bravery, and for embracing what happens when things do not turn out how you expect, and reminding me that I should keep doing the same.

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Chapter 1

Introduction

1.1 Motivation of the thesis

At the start of the school year, preschool children are assessed across several domains to determine if they meet developmental milestones. It is well established that if a child is behind their peers in one or more areas at this stage, they may struggle to catch up even years later [73, 150, 157]. For example, a child with a receptive vocabulary below the expected norm will likely remain behind their peers at re-evaluation four years and even eight years after the initial assessment [157, 94]. It is important to note that this trajectory is not set in stone. Research also indicates that early intervention can reduce this gap [118, 142]. Complex cognitive skills like language, executive function, and social competence are each rapidly developing and challenged when a child enters school. Executive function and social competence are broad terms that each refer to a collection of related behaviours. The term executive function refers to skills that support goal achievement like working memory, inhibitory control, and cognitive flexibility, to name just a few of the components [41, 1, 177]. Similarly, social competence can refer to aspects of a child's behaviour that support positive social interactions and count as "pro-social". Definitions vary and include terms like the intrapersonal- and interpersonal-skills that support emotional management and interaction with others [111]. Some definitions of social competence include terms that directly overlap with language, such as social reciprocity of "communication [159]" or executive function, such as behavioural "flexibility [156]"). Good performance in each of these three central areas are shown to predict better academic achievement (math/reading

performance[120, 130, 4]), higher quality of life, and even relate to adult salary [130]. This highlights the life-long value of early identification of any deficits and the importance of prompt and effective programs that can help remediate any delays. The purpose of this thesis is not to identify delays or test interventions. Instead, the goal is to better understand how a wide range of skills develop simultaneously during early childhood, while paying specific attention to an often overlooked feature; hand preference. As discussed throughout this thesis, there is extensive evidence that distinct domains of development are related, which has implications for interventions. To improve the effectiveness of these interventions, it is beneficial to understand if the many skills acquired during childhood mature independently or if "scaffolding" occurs, where achievement in one area (ex. motor skills) is a prerequisite for improving another area (ex. executive function; [64, 144, 13]. If various skills are shown to rely upon one another, then there is value in detailing chronological development, which will inform the intervention best used at each age/stage. Preschool children (ages three to six years old) provide a valuable opportunity to study this development, as this group is beginning to develop a sustained attention span, making it possible to complete multiple direct assessments of behaviour in a single session, and are still rapidly improving across the listed skill set, so we would expect to see significant changes or improvements between the younger and older children included in the sample.

A notable challenge in understanding connections between different areas of development is that there are many domains, as well as limitless measures and approaches used to assess early child development within each domain [14, 38]. See Appendices A-J for a comprehensive list of examples of the diverse measures used. The studies in this thesis do not directly address this issue, but it is explicitly discussed throughout.

The goal of this thesis is to better understand the relationship between five areas of development: language, fine motor skills, executive function, social competence, and hand dominance. In this thesis, I focused on manual lateralization and its relationship to language, fine motor skills, executive function, and social competence. Previous research has

indicated that hand preference (and by proxy, neural organization [58, 64, 26]) plays an important role in early development. There is a body of literature demonstrating that children with a clear right-hand preference are more likely to display better language skills [62, 28, 110, 113, 114], better fine motor skill [16], and better executive function [63, 102]. Conspicuously absent from this list, is social competence. To my knowledge, no published study has investigated if there is a connection between manual lateralization and social development. Several studies link communicative gesture (pointing) to language development, and indirectly social competence, but these studies do not report the hand used during the social gestures [92, 25, 134, 135]. Another example is children with poor social skills (related to a disorder like Autism or ADHD) who display high rates of left-hand preference or no preference [112, 89]. Of course, in these instances, the studies do not directly link social competence to degree of hand preference. Given the multiple studies linking right-hand use for gesture to language development [66, 110, 113, 114, 169], as well as connecting language and social competence [120, 53, 97, 127, 146, 163] it is logical to investigate the link between right-hand preference and social competence.

The remaining introduction covers a theory to provide context on why I focused on manual lateralization, elaborates on current evidence of the importance of early established hand preference in infants and children, and concludes by reviewing the evidence of concurrent development of skills including receptive vocabulary, fine motor skills, speech production, executive function, and social competence in preschool children. This section is not intended to be an exhaustive background or literature review, but a brief overview connecting the following chapters to one another. Each of chapters 2, 3 and 4 includes the appropriate introduction and comprehensive description of methodologies used to address the research question and hypotheses stated at the end of this chapter. Chapter 2 is published in "Developmental Psychobiology" [167]. Chapter 3 is under review in "The Journal of Child Language Development" (van Rootselaar et al., submitted December 2023 [168]). Chapter 4 will be submitted imminently.

1.2 Why neural lateralization

There are two universal truths related to brain lateralization, one is that 90% of the population is right-handed [27, 90, 160], and second, that a similar proportion have language predominantly housed also in the left hemisphere [160, 27]. This might be a coincidence, but some argue these similarities provide insight into an important evolutionary link. Corballis first proposed the hand-to-mouth theory of language specialization in 2002 [33]. Corballis expanded on Hewes' ideas from 1973, who drew insight from sign language- an embodied communication system. Hewes argued that language as we use it today is rooted in the development of gestural communication in our evolutionary ancestors [78]. Corballis expanded this idea through research conducted in non-human primates. Non-human primates are unable to communicate verbally, so the crux of the theory is that our ancestors adapted both physically and cognitively to enable complex vocalization, which afforded a transition from gestural to verbal communication between social partners [33]. The right-hand is important to this theory because it may have enabled the switch to more effective communication [33, 8, 106]. There is evidence that in non-human primates, specialized networks in the left hemisphere are active during gestural and vocal communication that enables socialization in these animals [46]. In humans, there are a few different examples of this, one being the well known Broca's and Wernicke's areas that are specialized for speech, and found in the left hemisphere in the majority of the population [34, 86]. There is a similar connection made where typical lateralization of the brain is associated with a strong right-hand preference [27]. Non-human primate are known to show some evidence of a right-hand preference, although much like their language skills, it is much weaker and more poorly defined that what is observed in humans [46]. Humans display a strong right-hand preference for many types of tasks. One example is the left-hemisphere specialization for other manual actions, most notably the grasp-to-eat action. Studies have shown that right hand preference for grasp-to-eat is established earlier in development compared to other grasping movements [136]. Similarly, a kinematic advantage has been shown for

grasp to eat versus grasp to place actions [49]. This connection highlights the tight relationship between right hand movements and movements of the mouth (including speech). Moreover, studies have found that simultaneous movement of the mouth and hand can influence right-hand gestures and vice versa [52, 161, 55], while similar effects are not found with the left hand [164, 165, 166]. These examples begin to highlight the asymmetry that exists in complex motor planning of manual actions (grasp-to-eat), and oral motor control for speech. Even the motor control of the mouth is shown to have an aspect of lateralization. When analyzing asymmetry during speech and non-speech lip movements, the right side of the lips can react faster and open wider regardless of the intent behind the movement [174]. At risk of exhaustive repetition, the human studies discussed in this section all serve to highlight the inimitable connection between the right hand and the mouth. There is evidence that children with stronger right-hand preference during a grasping task are more likely to show adult-like speech production [62]. There are other examples, in which better performance of "higher level" cognitive skills such as language and/or executive function are associated with increased right-hand preference for pointing and grasping [63, 65, 110, 106, 113, 114, 169]. Altogether, this evidence suggests that it is advantageous to possess a strongly lateralized brain, specifically a strongly "typically" lateralized brain for the right-handed population [64, 121, 108]. During the preschool years, handedness is not yet set at adult-like rates for all manual actions [61, 141]. It is important to study the acquisition of adult-like hand preference in the context of development of other functions if it is to be predictive of performance in other cognitive domains.

1.3 Interwoven Early Skills

The goal of this thesis is to investigate how manual lateralization during preschool development interacts with the foundational skills of language, fine motor control, executive function, and social competence. In addition, my thesis examines how all these skills interact with each other through a within-subject's design. Previous studies have demonstrated

that these behaviours are related to each other. However, most of these studies have examined the relationship between two behavioural domains or occasionally among three components. When examined in pairs, there are countless examples where one domain (ex. receptive vocabulary) predicts another (ex. executive function) and vice versa. For instance, a study showed that preschool children with a larger vocabulary (assessed by the standardized Peabody Picture Vocabulary Test- PPVT) performed significantly better according to a parent-completed executive function questionnaire [146]. Some of the relationships between pairs of these cognitive skills are better established, such as vocabulary and executive function (see Appendix G), whereas social competence and fine motor skills have been seldom studied [137](see Appendix F).

One notable aspect of past research is the wide variety of tests that have been used to assess children's behaviour. These include more objective, direct child-based measures, and a proxy measure of parent-completed questionnaires, or a combination of both. Whether an direct or proxy measure is used in each study, a further complicating factor is the many options available for each type of assessment within each category of development. A valuable step to better understand child development could be to use both direct and proxy measures in a single cohort. This is a secondary goal of my thesis, but the larger goal is to understand the connections between more than two (or three) skills in a single cohort while elucidating the possible role of manual lateralization in early development. The limitations of a young child's attention span demand a narrow selection of assessments that are both quickly completed as well as developmentally appropriate for children aged three to five years old. The most common assessments of child behaviour are more objective measures for some domains, like the Stroop task to assess executive function [145], while others, like language rely predominantly on standardized tests like the Peabody Picture Vocabulary Test (PPVT; [43]). Other common measures of child behaviour are parent-completed questionnaires, which are not dependent on children's attention span, but have the limitation in that the results are based on the subjective appraisal of a parent/caregiver [145]. The difference

between direct (objective child assessment) and proxy (parent questionnaire) assessments is rarely the center of focus in developmental research. Various studies, however, have attempted to address whether one form is more reflective than the other of child competencies, the level of test/re-test reliability for these assessments, and the value of using multiple tests for one domain [10, 43, 104, 145]. Regardless of which might be true, until more studies are done to provide concrete insight, a secondary goal of this thesis is to account for and use both direct and proxy assessments of child behaviour.

1.4 Hypotheses

The following three chapters test the relationship between hand preference/hand selection and complex cognitive functions during preschool development. Language, executive function, and social competence are labelled as "higher level" because they allow humans to engage in complex thinking, reasoning, and problem-solving [64, 162]. Importantly, language, executive function, and social competence each rely on interpreting sensorimotor information and modifying behaviour according to the inputs received by the sensory organs [162]. As a child matures, their responses to the environment begin to show more sophistication in terms of expressing/ comprehending complex ideas (vocabulary), improved behavioural inhibition, and working memory (executive function), as well as a capacity for empathy and understanding of the experience of a social partner (social competence [74]). Conversely, hand preference is a partially genetic trait (but more likely epigenetic [100]), appears as early as in-utero [77], and is relatively stable through childhood, displaying adult-like preference as early as one year of age by some measures [136]. Environmental factors, however, can influence hand use, for example, if a child is holding a toy in their right hand, they will use their left hand to grasp a door handle. Fine motor skills like writing with a pencil are comparatively slower to develop than hand preference for pointing and grasping, but most of these skills reach adult-like profiles/proficiency during childhood. In contrast to hand preference, higher level cognitive skills such as executive

function and social competency continue to develop into adulthood [80]. I attempt to account for these differences in this thesis by using multiple tasks/contexts to measure hand preference alongside a comprehensive assessment of cognitive functions: language (both receptive vocabulary and speech production), fine motor skills, executive function, and social competence. One more component included in this thesis is the consideration of sex differences. Past research has shown that females outperform males in areas of vocabulary [139, 93], executive function [36, 81, 170], and social competence [139, 151] during the preschool/kindergarten years. However, there are many recent studies that report no observable sex differences in these skills [63, 54, 70]. Other studies note that boys have a wider range of performance, but the median value suggests that there may be very little difference between the performance of females and males in some of these early tasks [97]. In this thesis I compare the performance of girls and boys to explore possible sex differences in cognitive development.

Another consideration mentioned throughout the thesis in the inclusion/exclusion of children based on if they are ”typically” developing. It is challenging to define what differentiates a typically developing child from a atypically developing child. Often, a medical diagnosis is used, such as Autism. For the preschool population used in this study, many of the children are not old enough to receive an official diagnosis, but the developmental questionnaire completed by parents did ask if the child was currently being seen or waiting to see a medical professional. For the following studies in this thesis, my goal was to document behaviour representative of a random sample of children, which included children who performed poorly (or exceptionally) at some tasks, so multiple standard deviations below or above the mean. For each chapter, exclusion criteria i briefly described, but based on a clinically significant score from one of the standardized questionnaires, or from a parent-reported diagnosis. Additionally, because language is a main focus of the thesis, several children were excluded who had a language besides English listed as their first language. Several bilingual children are included where parents reported the children learned both

English and an additional language from birth.

Chapter 2 (the first study) is focused on expanding previous research that connected hand preference to speech production [62] and executive function [63]. Children who used their right hand more during a grasp-to-eat task had more adult like speech differentiation, and speech differentiation was a better predictor of right-hand preference than age [62]. Similarly with executive function, young children who exhibited a greater right-hand preference during a grasp-to-place and a grasp-to-construct task also had a better rating of executive function based on a parent questionnaire (Behavioural Rating Inventory of Executive Function, BRIEF [63]). Previous research also suggests a tight connection between right-hand preference and early language development [110, 106, 113, 114, 169]. In these studies, right-hand preference for gestural communication in infants or toddlers is linked to faster language acquisition or larger vocabulary in longitudinal studies [114]. To better understand how hand preference affects development, I selected a standardized test of vocabulary (the PPVT) that requires gestural communication to generate a vocabulary score. Specifically, the test consists of a book with four images on each page. To assess vocabulary, an experimenter read out a word and prompted the child to point to an image. I recorded which hand was used to point with, and if the child selected the correct image. If strong neural lateralization relates to better cognitive performance, then children with a stronger right-hand preference for communicative pointing should have a larger vocabulary size as shown by the PPVT. For this experiment, 112 preschool children completed the PPVT, and I recorded the receptive vocabulary score as well as percentage of right-hand use for each child.

Chapter 3 and Chapter 4 detail the investigation of the relationship between hand preference, language, fine motor skills, executive function, and social competence. In Chapter 3 I report the results of proxy measures and some direct assessments of these behaviours, whereas in Chapter 4, I focused solely on direct measures. Chapter 3 included multiple measures of hand preference- grasp-to-construct, and pointing. Like in Chapter 2, we used

the PPVT again, to generate a vocabulary score as well as the right-hand pointing percentage. My hypothesis for Chapter 3 was that if lateralization (measured through hand preference) is supportive of cognitive functions, then hand preference should be a predictor of these functions. A secondary hypothesis based on the literature review is that the complex cognitive functions would each be predictors of one another. Because we used the PPVT, my first prediction was that I would replicate the results found in Chapter 2. Second, I predicted that at least one measure of hand preference would be related to the child's performance in the cognitive tests including vocabulary, executive function, and/or social competence. Third, I predicted that each of these three functions, vocabulary, executive function, and social competence would be strong predictors of each other. To test my hypothesis, 82 children completed a block building test (RH use, fine motor skills and executive function), the PPVT (RH use, and vocabulary), and the dimensional card change sort task (executive function). I also included three questionnaires that parents completed: the Behavioural Rating Inventory of Executive Function- Preschool (BRIEF-P; executive function), the Social Responsiveness Scale-2 (SRS; social competence), and the Ages and Stages Questionnaire: Social-Emotional (ASQ:SE; social competence).

The third and final study in this thesis, Chapter 4, focused on direct measures of early childhood behaviour. This study used the same sample of children as in Chapter 3, but additional measures of behavioural tasks completed by the children were analyzed. In addition to the block building task (RH use, fine motor skills, executive function), PPVT (RH use, vocabulary), dimensional change card sort (executive function), children also completed the grasp-to-eat task (RH use), animal Stroop (executive function), speech production task (speech), and social dyadic play (social competence). The questionnaire results are not reported in Chapter 4. My hypothesis for this chapter was identical to chapter 4, where given the evidence for the importance of lateralization, preschool children with stronger right-hand preference would perform better on the cognitive tasks, and the cognitive task scores would all be significant predictors of each other. I further predicted that there would

be a relationship between vocabulary, executive function, and social competence. A secondary hypothesis was that because each task included a component of motor control and grasping/pointing, it was more likely that hand preference would be a significant predictor of performance for the direct measures of vocabulary, executive function, or social competence. An example of this includes the social play task, where children were instructed to build something together. Their social behaviour was assessed, but they also had to grasp-and-construct bricks during the social interaction.

Chapter 2

Which hand knows the "right" word? What hand selection reveals about vocabulary in pre-and school-aged children

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Published: Developmental Psychobiology

Submitted: September 9, 2020 **Accepted:** April 24, 2021 **Published:**May 9, 2021

2.1 Abstract

Research has shown that infants with increased right-hand selection for their first gestures perform better at an array of language tasks when they are tested later as toddlers. There is a smaller body of literature which focuses on preschoolers and how their right-handed movements relate to their speech and vocabulary development. Some research has established a connection between right-hand preference for grasping and speech production ability in preschool children, but the link to gestures is relatively unexplored in this age group.We investigated if lateralized gestures (pointing) are related to measures of language development (vocabulary) in a preschool-age sample. Specifically, typically developing children (aged 3–6) completed the Peabody Picture Vocabulary Test (PPVT) to assess receptive language.We recorded their hand preference for pointing during the PPVT and the incidence of mistakes (pointing to the wrong picture). Despite the length of the test, children were more likely to select a correct response with their right hand. This result suggests a relationship between lateralized communicative gestures (pointing) and receptive language. This study provides evidence for an intimate relationship between right-handed manual movement and language development. Implications of this finding include developing simple fine-motor tasks to detect and/or ameliorate delayed language development.

2.2 Introduction

Speech is an intricate motor action, particularly for an infant who is just beginning to acquire a vocabulary and combine simple babbling sounds [171]. As a result, infants often opt for a more accessible, but still effective communicative tool; gestures [2, 57]. Pointing with the index finger is a commonly used gesture which is established around 12 months of age, but infants begin to point as early as 7 months old [95, 23, 30]. Previous studies carefully examined the role that gesturing plays in the development of speech and found positive correlations between increased frequency and complexity of gestures and improved language development. Measures included vocabulary size, language comprehension, and speech production [19, 15, 17, 47, 110, 56, 135, 30] For example, younger infants who communicated concepts by combining gesture (including pointing) and single speech words progressed more quickly onto combining two words for speech [56]. In another study, authors measured hand lateralization of gesture, and found that infants who used their right hand more frequently to point also possessed larger receptive vocabularies [110]. A general trend in these studies, is that infants' communicative ability using gestures was predictive of their speech/language proficiency as toddlers. A question not answered within the cited literature is if the relationship between infant gesturing and toddler communication ability is based solely on the maturation of a communication system from gesture/hands to speech/mouth. The specific example of right-hand gestures predicting receptive language [110], is part of the evidence which suggests that the relationship between infant gesturing and language development could be related to the organization of motor control and language within the brain.

A possible explanation for the relationship observed between right-hand use and language development is the common left-hemisphere lateralization of manual actions [26, 27, 58, 136] and language [88, 148]. There is evidence of this relationship continuing through childhood and into adulthood. For instance, one indication of this relationship is that strong lateralization of hand use is correlated with language lateralization in adults [58]. In other

words, a person with a clear preference for selecting their right-hand for manual actions is more likely to demonstrate left hemisphere dominance for language processing compared to a person with a strong left-hand preference for manual actions. This shared lateralization may develop in infancy and results in a parallel trajectory of both right-hand motor skills and language development [6, 64, 122]. Gonzalez et al. [62] showed support for this suggestion. Right-handed preschool children (4 to 6-year-olds) completed two tasks: a grasping task and a speech task. The children grasped and ate small food items (cereal) and completed a second task where they pronounced words beginning with /s/ or /sh/ sounds. Children who used their right hand more for grasping, were able to more clearly differentiate between /s/ and /sh/ sounds, demonstrating more developed language skills. This lends merit to the argument that strong lateralization of function (i.e. right-hand use) may result in mutual development of functions housed in the same hemisphere (i.e. language and speech).

While the Gonzalez et al. [62] study focused on the development of speech production, another equally important language skill is speech comprehension. It appears that a general relationship exists between manual movement and receptive language. Two studies revealed a correlation between fine motor skills and vocabulary size, or reception [154, 155]. In both studies, children aged three to six years performed fine motor tasks (peg moving, bead-threading, and block-turning tasks) in addition to the widely used Peabody Picture Vocabulary Test (PPVT; [44]. Children who performed better on the motor tasks also performed better on the PPVT, indicating a more extensive vocabulary. However, it is important to note that the authors did not report which hand was used for the motor tasks. Regarding receptive language and lateralized hand use in non-infant children, we found two studies. Crow, Crow, Done, and Leask [35], compared hand selection in a writing task and vocabulary size in 11-year-olds. Children who demonstrated inconsistent selection of a hand for writing were more likely to have poor vocabulary skills [35]. A recent longitudinal study found that consistently higher right-hand use for object manipulation during a

role-differentiated bimanual manipulation task in infancy predicted better language skills (expressive and receptive) at five years of age [35]. These two studies suggest that the relationship between lateralized motor actions and vocabulary persists throughout childhood, but clearly more research is needed to firmly establish this link. Investigating this relationship beyond infancy may shed light on how motor control and language interact at different developmental stages. The relationship between lateralized hand use while pointing and receptive language ability has not, to our knowledge, been studied in preschool-aged children. To address this gap in the literature, 3–6-year-old children were given the PPVT to assess language vocabulary and the hand used when the child selected each picture during the test was documented. In this way, the PPVT is ideal for this investigation because it naturally requires children to point to an image which represents the pronounced word, measuring both their receptive vocabulary and providing a measure of hand use preference for pointing. We hypothesized that if the degree of functional lateralization is predictive of language development, children who use their right hand more would perform better on the PPVT, and therefore have a larger receptive vocabulary.

2.3 Methods and Materials

2.3.1 Participants

We tested 112 children (53 females) from the Southern Alberta area. Average age of participants was 4.27 years ± 0.83 years, with a range of 3.0 to 6.83 years. All children in this study were confirmed as typically developing through parent's responses on a questionnaire. The questionnaire required parents to specify if their child had ever been assessed and diagnosed with delays, including speech, hearing, mental and physical, as well as if the child had received any treatment to address delays in the specified areas. Additionally, all children passed the basal level of the PPVT. We did not collect handedness information for all the children in the sample, so we cannot report the number of right-handed children. However, we note that 28 children in our sample exclusively used their left hand to point

during the PPVT. This is higher than what would be expected based on the population-level left-hand dominance in preschoolers (approximately 10%, for examples see Cochet et al., 2015 [27] or Oztbrk et al., 1999[119]). All statistical tests were conducted with and without this "left-pointing" group and the results remained the same therefore, all following statistics are conducted with the full sample.

Before testing, parents/guardians provided written informed consent, accompanied by verbal consent from the children. The parents were informed that they could withdraw their child at any time without consequences in accordance with the declaration of Helsinki. The University of Lethbridge human subjects research committee approved the following procedure (protocol#2013-073). Parents provided consent for the images of their children shown in this publication.

The participants reported on in this paper were part of three cohorts investigating the development of motor and cognitive function. In two of these cohorts, children were required to complete additional tasks, such as a block construction task, and/or executive function card games (tasks that require sorting, inhibition, and working memory). This means some of the children completed additional tasks before and/or after completing the PPVT. However, analyses of the PPVT data including cohort as a factor, showed the cohorts were not different from each other ($p>0.5$), therefore they were all pooled together.

2.3.2 Procedure

For this experiment, we used the PPVT (Peabody Picture Vocabulary Test-III and IV; [45, 44]) to assess the size of each child's vocabulary. The PPVT is a validated, widely used measure of children's receptive vocabulary abilities. For the purposes of this study, it is important to note that the only change between the PPVT-III and PPVT-IV is a switch to colour pictures used in the testing booklet. As our grouped analysis did not reveal any changes or differences between the cohorts who used the PPVT-III versus the PPVT-IV, we will refer to both tests collectively as the PPVT for the remainder of the paper. To begin,

the children sat down at a table with the PPVT centered in front of them (the child's midline was aligned with the center of the testing booklet; see Fig. 2.1). This placement ensured that the children's hand preference was not biased by book placement. PPVT testing took approximately 10-25 minutes to complete. Some of the children completed additional tasks (unrelated to speech/language) before and/or after completing the PPVT.

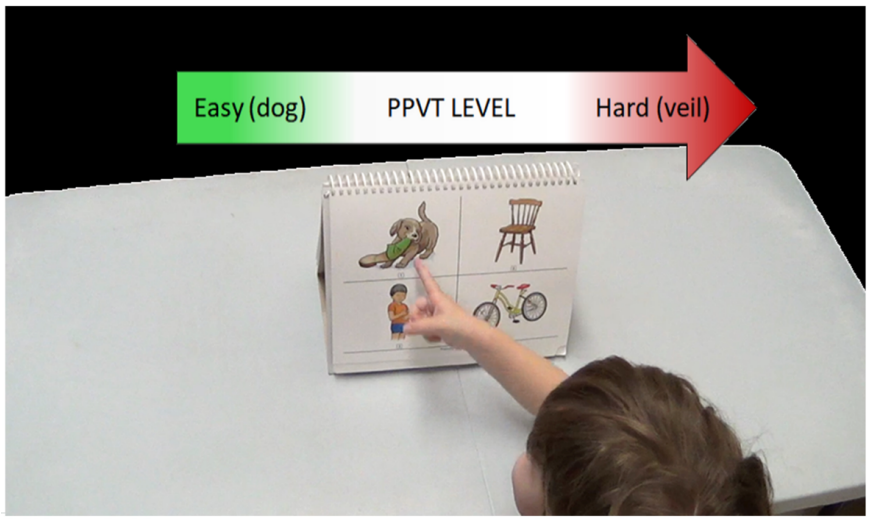

Figure 2.1: Peabody Picture Vocabulary Test (PPVT). Pictured is a child seated with the PPVT testing booklet centered in front of them. After the experimenter announces a word ("dog" in this example), the child is required to point to the corresponding picture. As the test progresses, the words increase in difficulty. The child is video recorded during this task.

We administered the PPVT in accordance with the original protocol [45, 44]. Each child completed the age-appropriate practice page before starting the actual test. The practice page consisted of four different pictures (see Figure 2.1). The experimenter read a word, and the child pointed to the picture that represented the stated word. Practice continued until the child correctly identified two pictures on the practice page. The experimenter provided positive verbal reinforcement for each correct answer in the practice phase only. During the test phase, the child saw a page containing four pictures, however the experimenter only announced one word, and after the child pointed to a picture, the experimenter would continue to the next page. As per the PPVT, each child began the test phase at the age-appropriate set of words and proceeded on with the task until reaching the ceiling level

(eight errors in one designated set of 12 words). If a child expressed uncertainty, and did not know the correct picture, the experimenter simply told them to "take a guess," selecting the image they perceived as most likely correct. From the baseline set to the ceiling set/end of the test, the words consisted of multiple categories (nouns, verbs, and adjectives), and the level of difficulty increased with each set.

The children were video recorded while completing the PPVT, using a JVC HD Everio video recorder placed directly behind or to the side of the individual, with the tripod fully extended to obtain a clear view of the hand used to point, and the picture selected by the child.

2.3.3 Data Analysis

All videos were analyzed offline. We categorized each pointing gesture produced by the child as either left- or right-handed. If the child pointed bi-manually, they were prompted to point again with a single hand. We used the total number of points and total points completed with the right hand to calculate the percent right-hand use per each child. In addition to hand use, errors in selection were recorded. Data was analyzed using R version 3.4.1. [158].

2.4 Results

To make sure that the organization of the PPVT images (i.e. the possibility that the target image is located more frequently on the right quadrants of the page) was not a factor, we examined the proportion of correct answers to either side of the page. The correct target was located on the right half of the page in nearly half the trials (48.55 percent). Furthermore, there were no differences in accuracy rate and the side of the page (70% for images on the right side of the page were correctly chosen and 73% for the left were accurately selected; $p>0.1$). This indicates that any observed differences between the right- and left-hand use are not due to the organization of the PPVT.

2.4.1 Descriptive Statistics

Table 2.1 reports the mean, standard deviation, standard error, minimum and maximum values for the children's age, percent right-hand use, standardized PPVT score, total number of points (same as total trial number), and total errors made during the PPVT. As displayed in Table 2.1, the average right-hand use percentage was 54%. Alongside the large standard deviation of right-hand use, these descriptive statistics suggests that individual children varied widely in the hand used to point to an image.

Table 2.1: Descriptive Statistics of PPVT Performance and Hand Use

	Age (months)	RH-Use PPVT (%)	Standardized PPVT Score	PPVT Levels
Mean	51.60	54.76	105.37	86.97
STD	10.22	38.01	15.33	30.43
SE	0.97	3.59	1.45	2.88
Range	36-82	0-100	69-139	24-260

2.4.2 Lateralized hand use and vocabulary size

To investigate our hypothesis, we conducted a Spearman Rho non-parametric correlation test with the full sample to determine if a significant relationship existed between the children's receptive vocabulary and right-hand use during the PPVT exam. We conducted a Spearman Rho correlation between the PPVT standardized score (number of words attempted – number of errors, adjusted for age in months; M=105.54; SD=16.34) and percent right-hand use (M=54.76; SD=38.01). The correlation was not significant (r=-0.072, p= 0.449). This result indicates that there is no relationship between right hand-use for pointing and the size of a child's vocabulary.

Before we dismissed the relationship between right-hand use and vocabulary, we considered a potential confound, the length of the test. Fatigue could have played a role as children with a larger vocabulary took longer to complete the test. In other words, it is

possible that as children progress through the levels (often taking over 15 minutes), they switched to use their left hand more often as their right hand fatigued before reaching the end of the test. In fact, the number of completed trials ranged from 24 to 260. To account for the possibility that fatigue played a role in hand use, an additional analysis was conducted only on the first level of the PPVT which all children completed (12 trials). A mixed effects logistic regression model was conducted to account the length of the test, number of trials, age, and sex. The dependent variable was accuracy (coded "1" for correct and "0" for incorrect response). The independent fixed effect variables were trial number, sex, age, and hand use, as well as the interaction between test length and hand use. The random effects were individual participants, with trials nested under each individual child.

2.4.3 Lateralized hand use and response accuracy

As indicated in Table 2.2, there were four significant factors in this model: trial number, age, hand use, and an interaction between trial number and hand use. For trial number, the negative score and significant p-value indicates that for every following trial, the child had a log-odds decrease of 0.04 for selecting the correct answer. For age, the positive score suggests that older children are more likely to select correct answers. Monthly increase in age is associated with a log-odds increase of 0.062 for selecting the correct answer. For hand use, those who preferred their right hand are more likely to select the correct answer. For every trial where the child used their right hand, there is a log-odds increase of 0.813 in selecting a correct answer. Notable, is the associated z-Score (5.285), the second highest in the model, suggesting a robust effect for this variable. Finally, the significant interaction between trials and hand-use suggests that as the trials continue, right hand use decreases, and thus the log-odds of selecting a correct answer decreased by 0.008.

Table 2.2: Results of a binomial logistic regression determining the odds of a child selecting a correct answer for the full length of the PPVT.

	Estimate	Standard Error	z-Score	p-Value
Intercept	-2.123	1.545	-1.374	0.169
Sex	-0.357	0.591	-0.606	0.545
Age (months)	**0.062**	**0.029**	**2.159**	**0.031**
Trial Number	**-0.04**	**0.002**	**-20.227**	**<0.001**
Hand Use	**0.813**	**0.154**	**5.285**	**<0.001**
Trial Number and Hand Use	**-0.008**	**0.002**	**-3.562**	**<0.001**

2.4.4 The effect of fatigue

To assess if the relationship between right-hand use and word difficulty level is driven by the child's right-hand fatigue towards the end of the test, we applied the same mixed effects logistic regression model, but included only the first twelve trials (equating to the first level in the test) for each participant. As presented in Table 2.3, nearly all factors cease to relate to the child's accuracy. Hand use becomes the only significant parameter, indicating that for each trial wherein children point with their right hand, the log-odds of selecting a correct answer increase by 1.67. The relationship between the hand selected for grasping and the odds of selecting the correct image is shown in Figure 2.2. It is a visual representation of the logistic regression and indicates per trial the odds of a child selecting a correct answer given that they use their right or left hand.

Table 2.3: Results of a binomial logistic regression determining the odds of a child selecting a correct answer for the first 12 trials of the PPVT.

	Estimate	Standard Error	z-Score	p-Value
Intercept	**0.661**	**0.133**	**4.98**	**<0.001**
Intercept	5.014	1.074	4.667	<0.001
Sex	-0.750	0.405	-1.857	0.063
Age (months)	-0.027	0.018	-1.458	0.145
Trial Number	0.030	0.057	0.523	0.601
Hand Use	**1.674**	**0.078**	**2.138**	**0.032**
Trial Number and Hand Use	-0.105	0.098	-1.076	0.281

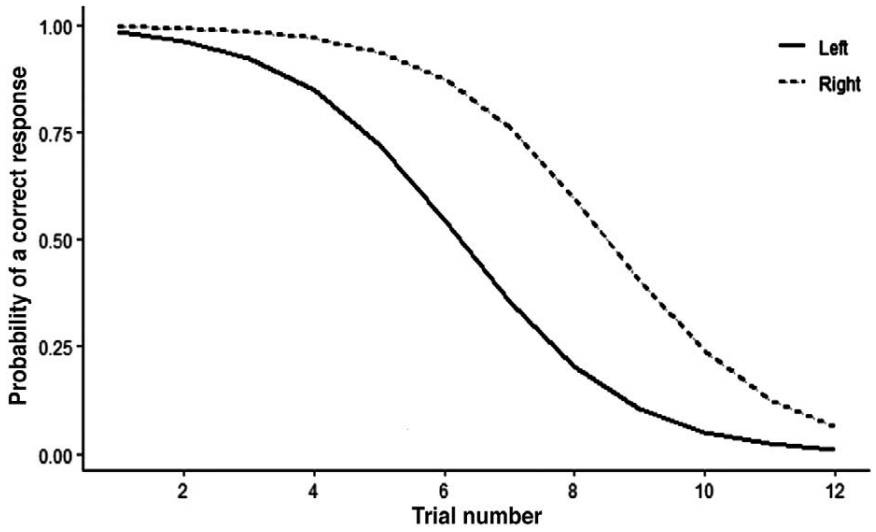

Figure 2.2: The probability of selecting a correct answers according to hand used per trial over the first level of the PPVT. The graph shows the results of the binomial logistic regression, representing any child's given probability of selecting the correct answer according to the trial number and hand used for the trial.

2.5 Discussion

According to previous literature, we expected to observe a relationship between lateralized hand use for pointing and receptive vocabulary in preschool-aged children. Specifically, we hypothesized that children with higher rates of right-hand use for pointing would possess better receptive language. This prediction was not supported, as the correlation was not significant between percent right-hand use and receptive vocabulary score. However, in depth analyses showed that when children used their right hand for the pointing task, their chance of choosing the correct answer was greater when compared to using their left hand. This relationship suggests either 1) when a child is pointing to a correct/familiar word they are more likely to use their right hand (akin to top-down processing), or 2) a child is more likely to select a correct answer if they are pointing with their right hand (akin to bottom-up processing). Given that communication begins with manual gestures before spoken language is developed, we would hypothesize that a bottom-up processing order is at the root of this result, and motor skill development is a driving force in the relationship with vocabulary. However, before discussing these possibilities further, we will address the

null result of the correlation between PPVT score and overall right-hand use.

The non-significant correlation between right hand use and vocabulary size may be attributable to both the age of the children and the variability in test length. As discussed in the introduction, there is extensive evidence in the literature of a connection between right hand use and language development, [19, 15, 17, 30, 56, 110, 134, 135] which led to our prediction of a relationship between right hand use and receptive vocabulary score. However, studies including receptive language measures [47, 110] involved infants younger than 24 months of age. While hand preference is often established during the first year, depending on the task, the dominant hand is not as consistently selected compared to older children or adults [61, 136]. It is relevant to mention that during this year long period of development (between 12 to 24 months) there is rapid sophistication of manual motor skills. Notably, children drastically refine grasping skills from birth to 12 months to include fundamentals of adult-like prehension (i.e., finger pre-shaping, appropriately timed eye-fixations), but they still clearly lack aspects of mature manual motor control [59]. It appears that in the second year of life, a shift occurs whereby at 24 months, toddlers employ grasping strategies nearly identical to that of adults [87]. It is possible that along with this maturation in grasping strategy, there is a parallel shift in the relationship between receptive vocabulary and communicative gestures. This is reflected in a study by Fagard and colleagues [47], where they established a relationship between right hand use (for simple and precision grasping) and larger vocabulary size in 18-month-old children that was absent at 24-months. The lack of relationship between receptive vocabulary and right-hand use in two-year-old children combined with our evidence suggests that the nature of the relationship between lateralized pointing and vocabulary size, changes as the child matures.

The shift in the relationship between vocabulary and lateralized hand use is reflected in our logistic regression results, where right hand use was associated with more accurate performance. If the child's understanding of language is reflected in hand selection, it is possible that as a child matures, manual movement (pointing) may assist cognitive process-

ing [32, 39] Delgado et al. [39] found that children who used pointing to solve an attentional task performed significantly worse when asked to complete a similar task without pointing. Cook and Goldin-Meadow [32] echoed these findings, showing that elementary children who were taught with gestures, and then implemented similar motions when solving a novel math problem performed better than peers who did not implement gestures. These results, combined with our findings suggest that pointing continues to facilitate learning, even after infancy. As mentioned earlier in the discussion, the results could be interpreted to support a bottom-up sensorimotor relationship between manual movement and speech. It could be argued that using the right hand during an action, facilitates cognitive process related to the task, which in turn translates to accurately selecting (and pointing to) the correct image associated with the word. Whether or not left-hand actions could lead to facilitation of other cognitive functions remains to be shown and research in this area is very much needed for a more comprehensive understanding of the relationship between action and cognition.

Notably, in the studies by Cook and Goldin-Meadow [32], and Delgado et al. [39], older children performed the task better when they naturally chose or were encouraged to implement gesture. However, there is no mention of which hand was selected for these gestures. According to our results, right-hand use relates to more accurate performance on a vocabulary task, which indicates that not only could gesture/pointing facilitate learning, but the hand chosen for those gestures may have an impact on learning outcomes. In terms of lateralization, it is possible that familiarity with the presented word results in a stronger left-hemisphere involvement when processing the information and thus creates a preference for using the right hand to select the matching image. The ideal method of confirming this hypothesis would be through using imaging techniques such as fMRI, or EEG. While we are not aware of any imaging studies which address our specific hypothesis, there are several papers that provide fuel for this proposal. In an EEG study, five-year-old children were rapidly shown strings of letters. The strength of response noted in the left temporal-occipital region significantly correlated with their letter knowledge, meaning those children with a

stronger EEG response on the left hemisphere, performed better on the letter identification task [96]. While visually reacting to letters is vastly different from the PPVT, this EEG study provides support for our proposal that the left hemisphere may play a coordinating role between manual gestures and language. Several fMRI studies conducted in adults indicate that exposure to familiar words result in greater left-hemisphere activation compared to unfamiliar words [103, 140]. Because there is evidence of this relationship in adults, it is possible that the strength of this relationship in preschool children could be indicators of academic performance later in life.

An important implication from these results is the potential to use measures of lateralized manual gestures to predict and even promote receptive language skills. Even after intervention, children struggling with receptive language delay may still fall behind their peers [126]. The results from the current study show that left-handed points are more likely to be incorrect than right-handed points. Although a causal relationship is impossible to determine, the results could suggest that more ambidextrous or left-handed children may possess a less extensive vocabulary when compared to those children that prefer to use their right hand for pointing. This idea is not novel, as other studies have found more broadly that children who are identified as left-handed may perform worse on other cognitive measures when compared to right-handed children [35, 149, 84, 85]. More studies to directly address this possibility are needed as there might be important implications for children struggling with vocabulary and other cognitive skills. Measures of right-hand use in both a pointing and fine motor movement task [62] could predict performance on receptive and productive language measures. By selecting a simple motor task from methods used both here and in the previous study [62], there is the possibility of developing a simple manual invention task which could be used in conjunction with common speech therapy practices to prevent and/or diminish language delays in children. While the scope of this specific study focuses on children who are already speaking, an additional benefit of developing a motor intervention is that it could be applied to children who are non-verbal. The previously cited studies

linking increased right-hand use and later proficient language development [66, 113] suggests this could provide a very effective training tool. Of course, more research is needed to develop such an intervention. Evidence from a longitudinal study suggested consistent preferential right-hand use for grasping and manipulating objects (i.e., removing a lid, opening a zipper) in infancy is related to language development at two years of age [113], and a recent study suggests this relationship extends from 2-3 years of age to 5-year-olds [66]. However, more information is needed to better understand the developmental trajectory of this relationship, as well as its connection to lateralized hand use and other cognitive functions. Executive function (EF) is a broad term often used as a cognitive measure. It refers to variety of skills that enable and regulate attention and emotional control (for example, inhibition, working memory, self-regulation). EF has been linked with language measures in preschool children [115], and further, it can predict vocabulary development over the span of a school year in preschool children [172]. These studies support the value of investigating an array of cognitive functions (in addition to language), to understand how early right-hand use relates to and predicts better cognitive development. Combined with the nuanced relationship between right-hand pointing (gesture) and vocabulary in our study, we believe that a full understanding of the maturation of manual motor, speech, and other cognitive systems is a necessary first step (as do other authors, for example see Michel [107]) before investigating early motor interventions which could ultimately promote not only normal vocabulary development, but also encourage EF.

In conclusion, this study examined a novel combination of developmental measures (lateralized hand use during a pointing task, and receptive language ability) in an understudied cohort, preschool aged children. The results highlight the link between right hand use and vocabulary competency. It is possible that pointing as a gestural action may influence the development of our cognitive processes. This may be a relationship that is further guided by the lateralization of speech and visual-motor control. Ultimately, it appears that dominant right-hand use may be a modulator of receptive language ability, and even cognitive

development. With further research, these findings may be important for identifying and remediating receptive language delays.

Chapter 3

Lateralization and cognitive development in preschool children: Relationships between right-hand use, language, executive function, and social competence

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Submitted: Journal of Child Language

Submitted: September 9, 2020 **Accepted:** Under revision

3.1 Abstract

Vocabulary acquisition is an important developmental skill that predicts academic success in preschool children. Previous research indicates that good vocabulary development is beneficial to other interrelated-skills, such as hand-preference, executive function, and social competence. The purpose of this study was to assess the relationship between these functions in a single sample of preschool children. We used parent questionnaires and/or tabletop assessments to measure hand preference, fine motor skills, language, executive function, and social competence in 81 preschool children. The results strengthened evidence of a connection between right-hand use for pointing and increased vocabulary accuracy. Further, we established a connection between vocabulary and social competence as well as executive function and social competence, but not vocabulary and executive function. We discuss the implications of these connections.

3.2 Introduction

When a child turns three, the number of words in their vocabulary equates to learning approximately nine new words a day over their short life [138]. Vocabulary acquisition is important not only because it transforms communication, but also because a larger preschool vocabulary is associated with both immediate and life-long benefits [71, 53, 97, 120, 124, 146, 159]. Preschool children with a larger vocabulary are known to have better executive function [97, 120, 159], social competence [53, 97, 120, 159], and mathematic skills [71]. Executive function (EF) describes the top-down processes which support goal-directed behaviour [40]. In preschool, examples of well-developed EF manifests in a child following instructions, waiting their turn, sharing, and generating new ideas. EF is often separated into several main categories, including working memory, self-regulation, inhibition/switching, and emotional control [40]. Many of the questionnaires and tasks designed to test EF claim to test one of these components, but various aspects of EF are difficult to truly isolate, and often work in concert together [40]. For example, a child that received a poor score on a working memory task might lack inhibition, so despite recalling the new rules (good working memory), they cannot inhibit an urge to point to an incorrect card. In addition to EF, another early developing skill associated with vocabulary is social emotional ability and social competence [146]. Social competence (SC) describes a child's intrapersonal and interpersonal skills which allow emotional management and help the child interact and empathize with others [111]. Children who display disruptive behaviors or do not build/maintain social relationships in an age-appropriate manner likely possess poor SC [111]. Both EF and SC are strongly intertwined with both vocabulary size and complexity [97, 120, 146, 159]. EF skills such as inhibition or emotional control facilitate successful social interactions [159]. Extensive research argues that receptive language is ancillary for both EF and SC.

Slot et al. [146] investigated the long-term benefits of a well-developed vocabulary through a longitudinal study. The results showed that language proficiency remain stable

in early preschool years (i.e., children with higher scores in vocabulary measures at the beginning of the school year remained at the top at the end of the year), and further, children with better language abilities possessed better self-regulation and social-emotional skills compared to children with more limited vocabulary. Furthermore, early language ability at the first assessment proved the best predictor of math and numeracy skills later in life [146]. Slot et al. [146] also noted gender differences, where boy's language skills were a strong predictor of their socio-emotional skills, but intriguingly this relationship was not present in girls. The stability of language skills alongside the associated increased performance reported by Slot et al. [146] suggest that it is important for children to develop a strong vocabulary even before preschool. These findings are echoed in the longitudinal study by Guez et al. [71] where preschool children with larger vocabulary and strong visuospatial skills performed better in middle- and late-elementary math abilities. While there are many known factors that influence early vocabulary development (genetics[20], family history and SES[75]), one of particular interest is the role of both functional and neural lateralization [51]. Functional lateralization refers to the division of sensorimotor/cognitive processes between the two hemispheres of the brain [64]. Some well-known lateralized functions include visually guided motor control and language, both of which are more specialized to the left hemisphere in most of the human population [37, 58]. It is hypothesized that lateralization affords benefits to an organism [51, 64, 79], and that early appearance of strong lateralization, such as a precocious hand preference in young children, indicates advantageous development [59, 117]. There is no direct proof of this hypothesis [117], but it is supported by behavioural research [64]. For example, we have shown a relationship between handedness in the development of speech, language, and other cognitive skills during the preschool age [63, 62, 64, 167]. Regarding language development and lateralization, there is strong evidence that infants with an early right-hand-preference for pointing and gesturing will have better vocabulary and language development compared to those who show weak right-hand preference [66, 110, 106, 113, 114, 169].The literature also reports

a connection between increased hand use in general for communication at 15 months of age and better language and executive function development as a toddler/preschooler [92], as well as general motor skill (both fine and gross motor abilities) predicting language and communication skills [66].

Other research suggests that much like vocabulary, hand preference plays a role in many early-developing skills (for an overview, see Michel [105]) such as visuospatial attention [129], executive function [63, 64], and even social development [97]. Given the evidence presented, it is tempting to speculate that strong lateralization for manual actions would be related to better vocabulary size, EF, and SC. Previous studies have investigated this possibility by relating hand use to one of the previously listed cognitive skills (i.e., vocabulary size, EF, SC). The goal of the current study is to examine this relationship in a single cohort of preschool children. We hypothesized that children that used their right hand more for pointing and grasping would have larger vocabularies, better EF, and greater SC. Further, we predict that there would be relationships between the cognitive measures, where vocabulary size and SC will predict EF, SC and EF will predict vocabulary, and vocabulary and EF will predict SC.

3.3 Methods and Materials

3.3.1 Participants

81 parents with a child between the ages of three to five years old (M= 52.70 months SD= ±10.69; 34 males, 68 right-handed) consented to participate in this study. We recruited 24 families from the community who completed the study at the University of Lethbridge. The remaining 64 families were recruited through three local daycares and three preschools-hereafter referred to as early learning centres (ELC) in and around Lethbridge, AB, Canada. Of the 66 families, eight families were not included in the study. This was due to: the child was too young at the time of testing (n=3); the child did not attend the program during the testing period (n=2), technical failure of the camera during the table-top activities (n=2),

or their child had a diagnosed developmental disorder (n=2). The parents completed a questionnaire confirming that their child was not diagnosed with any developmental delays and had normal hearing and normal or corrected to normal vision. All children passed the basal testing level of the Peabody Picture Vocabulary Test-V. The parents provided written informed consent, and the child provided verbal assent during the study. The University of Lethbridge human subjects research committee and the University of Alberta Ethical Review Board approved the study.

3.3.2 Materials

Questionnaires

Ages and Stages Questionnaire-Social Emotional (ASQ:SE). ASQ:SE is designed to assess age appropriate social-emotional development in children aged one month to 72 months old [152]. The questions fall into one of seven domains: self-regulation, compliance, communication, adaptive functioning, autonomy, affect, and interaction with others. The number of questions vary according to the child's age (the scores are adjusted for age), but parents responded to at least 35 questions by checking a box of "always", "sometimes", or "rarely/never", and adding a check mark if the behaviour was a concern. Examples of questions from the survey include "Does your child like to play with other children?"; "Does your child seem happy?" Each concerning behaviour that a child sometimes or always exhibits, or typical behaviour that a child sometimes or rarely exhibits is given a higher score. The scores are adjusted for age but in all cases, a lower score/score of zero suggests better/excellent age-appropriate social development.

Behaviour Rating Inventory of Executive Function-Preschool (BRIEF-P). BRIEF-P [82] is used to assess executive function in children ages three to five years old. The questionnaire includes 63 questions with the prompt: "During the past 6 months, how often has each of the following behaviours been a problem?". Examples of the questions include "Has outbursts for little reason"; "When given two things to do, remembers only the first

or last". Parents respond with "never", "sometimes", or "often" to these prompts. Each question relates to one of five domains: inhibit, shift, emotional control, working memory, and plan/organise. These domains can be combined to create broad subscales of EF including the Metacognition Index (MI), and Behavioural Index (BRI). The total raw BRIEF-P score is summed to create the global executive composite score (GEC) which summarises a child's EF. For each instance a child performs an undesirable behaviour "often" a higher score is given, and when a parent indicates "rarely" a lower score is recorded. A lower score suggests better executive function. The raw scores are transformed into standardised scores using the manual provided [143].

Social Responsiveness Scale-2 (SRS-2). The SRS-2 is a questionnaire designed to measure the dimensions of interpersonal behaviour, communication, and can be used as a screening tool for autism spectrum disorder, often associated with the scoring dimension repetitive/stereotypic behaviour [31]. There is preschool version appropriate for children ages 2;6-4;6, and a school aged version for children aged 4-18. We used both forms in this study. Parents completed 65 questions, rating how often the statements described their child's behaviour as "not true", "sometimes true", "often true", and "almost always true". Examples of the questions include: "behaves in a way that seems strange or bizarre", or "is aware of what others are thinking or feeling". These questions are associated with five domains representing social development: social awareness, social cognition, social communication, social motivation, and restricted interests and repetitive behaviours (RIRB). These domains can be combined into two main subscales: "social communication and interaction" as well as the "RIRB". All the domains are summed to create the SRS-2 composite score. A lower score indicates better, more age-appropriate social development. These raw scores are transformed into age-standardised scores using the norms provided [31].

Waterloo/Edinburgh-Oldfield Child Handedness Questionnaire (modified). The handedness questionnaire is completed by parents to indicate the hand preference of their child. Parents complete 17 questions rating how often their child might use their left or right

hand to complete a task such as “hold a brush” or “open a door”. The rating scale spans from -2 for “left hand always” to +2 for “right hand always”. There are additional questions, such as how the parent would classify the child’s handedness, either “left”, “right”, or “ambidextrous”, and if the child has had injuries or exhibited behaviour that might affect their hand preference (e.g. broken upper limb). Previous research suggests the results from these questionnaires are often not consistent or representative of hand use, but the questionnaire is a time-efficient tool to provide insight into both real and perceived lateralized behaviour in children [50].

Developmental questionnaire. The final questionnaire is used by our lab [29, 54] to report if a child met developmental milestones or to examine the extent of any developmental delays, diagnoses, or challenges. The questionnaire also collects information about the family composition, the child’s exposure to non-English language, other unique training opportunities, as well as any pre-, peri-, or postnatal complications.

Tabletop Assessments

The children located in ELC completed additional activities that are not reported here (the activities included MEGA® block construction [54], grass and snow [22, 54], block sorting (single dimension sorting task, like grass and snow), speech production task [62], social play testing (modified from [98]).

Small Block Construction. This is a measure of fine motor skill, handedness, and EF (introduced in [164]). To complete the grasp-to-construct task, the child is seated facing the middle of a table. There are 20 small building blocks (LEGO® pieces) distributed over four symmetrical quadrants in front of the child (see Fig 3.1). The child is unaware that there are four copies of each block- for a total of 5 different blocks- in each quadrant (right/left, near/far). During the task, the child is presented with a simple 5-piece model composed of one piece of each type of block, and the experimenter asks the child to make an exact match as quickly as possible. Once the child has completed the model, they are given

another model to complete with the remaining blocks on the table. This continues until a child has built four models. If the models are built correctly, the child will use all the blocks on the table. If the child is not able to reconstruct the model, they are encouraged to build something with all the blocks on the table, and allowed to build until they lose interest, or up to 5 minutes. The time to complete this task ranges from under four minutes up to 8 minutes. There are three measures we calculate from the block construction task that we roughly equate to three different behavioural analyses: hand preference (percent right-hand use), fine-motor skills (construction time), and executive function (grasping errors). To assess hand preference, we recorded the hand used for each grasp of a block, and calculated what percentage of grasps were completed with the right hand out of the total number of grasps. These methods and analyses are identical to those reported in Gonzalez et al. [63] and Gonzalez et al. [62] and Gibb et al. [54]. The measure from this task is both motor skills and EF, as represented by grasping errors. A grasping error is defined as a grasp that does not result in a correct replication of the model. This occurs in many different situations- for example, if the child drops the block after picking it up, or the child grasps a block and adds it to their model even if it does not belong on the model, or match the position on the example model. A specific example of a grasping situation where the block does not belong on the model would be if a green block is at the bottom of the model, and a blue block should be on top of the green block, and the child grasps a yellow block and places it on the green block. The yellow block is classified as a grasping error. Alternatively, if the child realises the yellow block does not belong on the model, and they grasp the block, set it down, and pick up the blue block, the grasp of the yellow block is still classified as a grasping error. As discussed in van Rootselaar et al. [164], we argued these grasps represent errors not only in construction or motor skills, but also in planning, working memory, and inhibition. These grasping errors suggest the child is either using ineffective planning when trying to replicate the model, may be unable to effectively remember the block they need to build the model, or lacking inhibition when they do not resist the urge to grab a block that

is not relevant to building the model.

Figure 3.1: Small block construction task. One of the four models is on the bottom left of the picture. The model is composed of five different blocks. At the start of the task (pictured), there is one copy of each of the five different blocks placed in four different reaching quadrants in front of the participant, for a total of 20 blocks.

Peabody Picture Vocabulary Test-V. The PPVT-V is a standardised measurement of vocabulary for anyone over the age of 2 [44]. It is administered through a testing booklet that features four images on each page (see Fig. 3.2). The experimenter states a word and asks the child to point to the picture that matches the pronounced word. If the child is unsure, the experimenter prompts the child to guess. The experimenter does not provide feedback if the child selects the correct or incorrect image but can encourage the child to continue the assessment. After the child selects an image, the experimenter will turn the page of the book and continues the test until the child makes six consecutive errors. All the errors are added together and subtracted from the level number the child achieved to calculate a raw score. The standardised score is calculated using the PPVT-5 manual to control for the age of the child. This task will take children anywhere from 10 minutes up to 30 minutes to complete.

Dimensional Change Card Sort Task (DCCS Task). This task is often referred to as

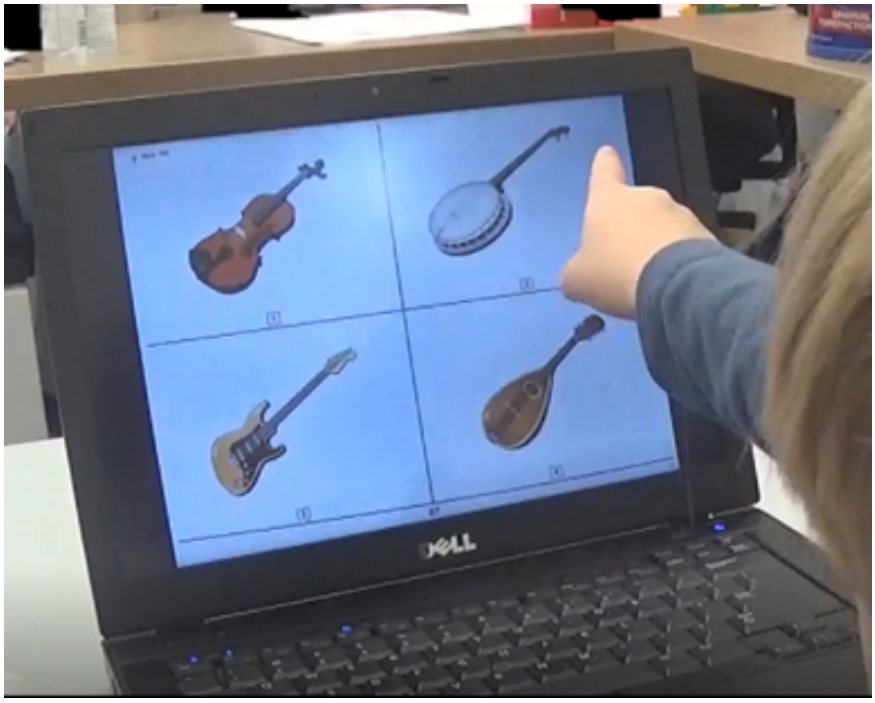

Figure 3.2: Peabody Picture Vocabulary Test-V. The child is seated in front of a computer/screen and asked to point to the image that best represents the word producer by the experimenter. For example, “banjo”.

“bunnies and boats”, or for this study, “turtles and trains”. It is a variation of the dimensional change card sort task, developed for preschool aged children [176]. This task is designed to measure EF, specifically working memory, inhibition, and task-switching. In this task, two buckets are placed in front of the child, one features a picture of a purple turtle, and the other with a picture of an orange train (see Fig. 3.3). The child is asked to play a colour sorting game and shown cards with purple trains or orange turtles. The child is expected to sort the purple trains into the bucket with the purple turtle, and the orange turtles into the bucket with the orange train. After sorting six cards, one at a time into the buckets, the child is told to change the rules to play a shape-sorting game. The child is shown the same cards but expected to sort the purple trains into the bucket with the orange train, and the orange turtles into the bucket with the purple turtle. This task takes 1-5 minutes for the child to complete. To assess EF, we calculated the percent errors from both the shape and colour sorting trials (percent error).

Figure 3.3: Dimensional Change Card Sort Task. The group on the left show the first version/rule of the game- the children must sort by colour. For example, the purple trains should be placed into the bucket with the purple turtle. The picture on the right shows the dimension change, shape. Children must switch and begin to sort by shape, so the orange turtles should be placed in the can with the purple turtle.

Animal Stroop. This test is a variation of the colour-word Stroop task [175] developed for children [59]. This assessment is designed to measure inhibition in children ages three to six years old. In this task, a child observes "normal" animal cards which consist of simple drawings of four common animals- duck, pig, cow, and sheep (see Fig. 3.4). The child is asked to name each animal three times. After completing the normal (or congruent) round, the child is shown an example of a "silly" animal. These animals will have mis-matched heads and bodies (incongruent), and the child is instructed to only name the body. The child completes four training cards, where the experimenter will give feedback and may point to the body to help the child learn the new rule. After the four training cards are complete, the child will be asked to correctly identify the bodies of the animals on twelve cards. These animals are a combination of the same animals observed during the congruent trials, for example, a pig head on a duck body. To assess EF (inhibition, working memory, shifting), we calculated the percent errors during the in-congruent trials (percent error). It took children anywhere between two minutes up to five to complete both the congruent and

in-congruent condition. The methods for this task are also reported in Gonzalez et al. [59].

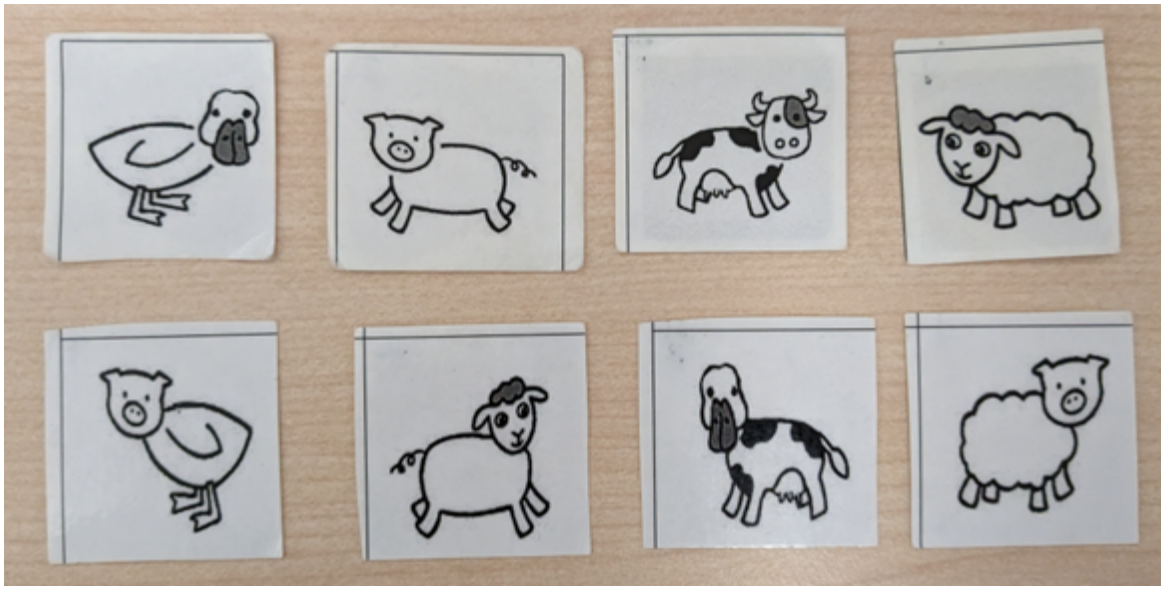

Figure 3.4: Animal Stroop. The top row shows images of the animals during the congruent condition where the child is asked to name the animal in the image. The bottom row shows cards used for the in-congruent condition where the child must name only the body of the animal. The correct response from left to right for both rows would be duck, pig, cow, sheep.

3.3.3 Procedure

As mentioned under the participants section, a portion of the children in this data set were tested at the University of Lethbridge in a lab setting. A parent was typically present in the room during testing but asked not to interrupt or interact with their child during testing. These parents were asked to complete the questionnaire package during the time their child spent at the lab. This often took parents the duration of the child testing (anywhere from one hour to 1.5 hours). For the children who completed the test at the childcare/education centres (ELC), the questionnaires were sent home and parents were asked to complete the questionnaires and return them in a sealed envelope to the school. The children at the ELC were tested in a room or hall adjacent to their classroom. The remaining testing procedures were nearly identical between all children with two exceptions- the children

who completed the experiment in the lab completed all activities in a single testing session, while the children tested in the early learning centres were tested over one to three sessions. The second difference is that the children at the ELC completed three more assessments that are not reported in this paper as they are part of a different research project. The ELC testing typically took anywhere from one hour to two hours per child but was separated into 10-45-minute-long testing sessions.

To keep the child engaged and allow rest in between assessments, the experimenter provided each child with a treasure map with several symbols on the map at the start of the session and explained that there was a surprise treasure for the child at the end of the map. To find the treasure, the child must look for matching paper images around the testing space. Once they found the matching image, the experimenter and child would complete one assessment (referred to as games), and then the child could find the next image to move onto the next assessment. At the end of each testing session, the child was rewarded with a sticker (treasure). The maps allowed the researchers to pseudo-randomize the order of the assessments. The child completed all assessments at a table set to an appropriate height with a child-sized chair. The experimenter recorded each task with a video camera for analysis. All data was scored and analysed after testing.

3.4 Results

We used Rstudio [158] to complete the analyses of the data.

3.4.1 Descriptive Statistics

The mean, SE, and minimum and maximum scores for the main variables are presented in Table 1.

3.4.2 Replication of van Rootselaar et al. (2021)

To begin the analysis, we replicated the analysis described in van Rootselaar et al. [167]. First, we used a Pearson R correlation to assess if there was a correlation between right-

Table 3.1: Descriptive Statistics

	Age (months)	PPVT Score	RH PPVT	RH Use Grasp	BRIEF-P GEC	SRS Total
Mean	52.43	112.04	70.00	63.33	51.28	45.55
STD	10.82	20.57	25.21	14.90	10.59	6.27
SE	1.22	2.34	2.85	1.69	1.25	0.77
Range	36-71.43	25-160	10.95-100	11.53-90.47	31-77	34-62

The values for the PPVT, BRIEF-P, SRS, and ASQ-SE are standardized scores.

hand use and receptive vocabulary size in preschool children. The results confirmed the null hypothesis, as there was no relationship between right-hand use for pointing and vocabulary size (r= -0.08, p =0.47).

To further investigate if the results from the current study would replicate the results described in van Rootselaar et al. [167], also 2, we conducted a mixed effects logistic regression to assess if children using their right hand to select the answer during the PPVT significantly predicted increased likelihood of a correct response. We set the model up identically with accuracy as the dependant variable (coded binomially where 1 represented a correct response and 0 an incorrect response). The independent fixed effects were hand use, trial number, age, sex, and an interaction between hand use and test length (trial number). The individual participant was included as a random effect, so the repeated trials were nested under each child. We were less concerned about fatigue as a factor because the children received several breaks during testing, and few completed the PPVT-5 in a single sitting. As shown in Table 3.2, hand use was a significant predictor of accuracy, (see Fig. 3.5).

When using their right hand, a child had a log-odds increase of 0.297 (z=1.99) for pointing to the correct image. This is comparable to the value reported in van Rootselaar et al. [167]: 0.04. The only other significant predictor of accuracy in this model was trial number. As illustrated in Figure 3.6, there is a log-odds decrease of selecting the correct answer as the child progresses through the assessment (-0.030, z= -23.14).

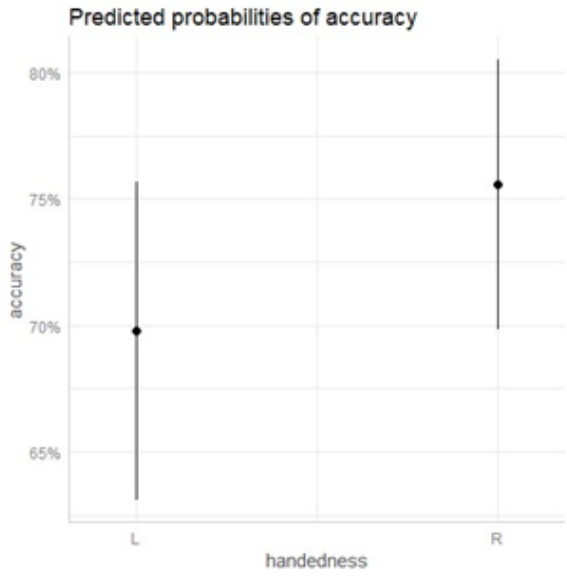

Figure 3.5: The probability of selecting a correct answer during the PPVT based on the hand used to point in any given trial.

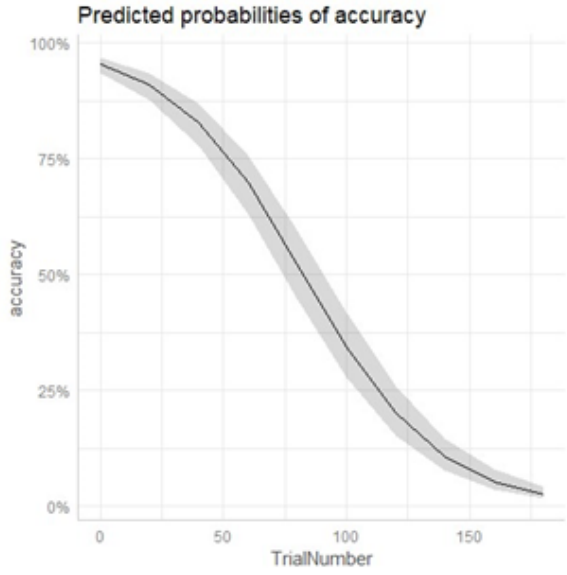

Figure 3.6: The probability of selecting a correct answer throughout the PPVT.

Table 3.2: Multiple linear regression model to predict grasping errors (percent)

height	Estimate	Standard Error	z-Score	p-Value
Intercept	**0.661**	**0.133**	**4.98**	**<0.001**
PPVT Score	**-0.004**	**0.001**	**-4.22**	**<0.001**
Phonetic Errors	**0.016**	**0.004**	**3.91**	**<0.001**

3.5 Discussion

The purpose of this study was twofold. First, we intended to replicate the previous finding that right-hand-use predicted accuracy during a vocabulary test for preschool children (Peabody's Picture Vocabulary Test- PPVT; [167]). Second, we expanded the methods from van Rootselaar et al. ([167]) to explore predictors (handedness, motor skills, language, EF, and SC) of cognitive development (language, EF, and SC) through a within-subjects design. We collected proxy measures (parent-completed questionnaires) of child EF and SC, as well as performance measures from the children: right-hand preference (pointing and grasping), motor skills, language, and EF.

We replicated the null hypothesis from van Rootselaar et al. ([167]). There was no significant correlation between right-hand use during the PPVT and children's receptive vocabulary score (as in van Rootselaar et al., [167]). In the original study the logistic regression indicated that right-hand use was a significant predictor of accuracy during the first level of the PPVT. A difference in the results of the current study is that right-hand use significantly predicted accuracy throughout all levels of the test. This discrepancy could be a result of differences between the samples. There is variation regarding the cohort's number of participants (112 children [2021] vs 84 children [current study]), age (M=4.27 years, SE= 0.97 [2021] vs M=4.36 years, SE=0.90 [current study]), ceiling level (range: 24-184 trials [2021] vs 24-260 trials [current study]), standardized vocabulary score (M = 105.37, SD = 15.33, SE = 1.45, Range = 69-139 [2021] vs M=112.04, SD = 20.57, SE =2.34, Range = 25-160 [current study]), and right-hand use percentage for pointing (M=54.76%, SD= 38.01, SE = 3.95, range = 0-100% [2021] vs M=70%, SD = 25.21, SE

= 2.85, range = 10.95-100% [current study]). A final difference is a change in methods; in the current study we administered the PPVT over two different testing sessions, whereas there was only one session in van Rootselaar et al. [167]. We made this adjustment in the current study because children completed more table-top tasks and could not sit through all the assessments at once. In summary, and regardless of these methodological differences, the repeated result that children use their right-hand to point to the correct answer suggests an undeniable relationship between active hand use and language comprehension. Notably, there is conflicting evidence from studies with preschool-aged children as to whether a strong right-hand preference directly predicts vocabulary achievement [167, 117]. Within our own research, we did not find evidence that right-hand preference for pointing directly predicted vocabulary size [167]. As explained, the results were more nuanced- each trial the child used their right-hand to point to an image during the PPVT, the odds of selecting the correct answer increased [167]. We speculated that actively using the right hand to choose an image offered the child an advantage [167]. This speculation is supported by another recent study in which increased right-hand use for gestures during a storytelling task predicted verbal semantic fluency [117]. These authors presented a similar argument where active use of the right hand for gesturing during a language task improved children's access to information during the semantic task [117].

Our second goal was to create a within-subjects design to assess the co-development of early motor and cognitive skills in a single cohort of children. Many of the studies we discussed before used two to four measures to document child development in two or three developmental areas. For example: hand preference and EF [102, 63, 66] hand preference and vocabulary [105, 114, 117, 167, 106]; vocabulary and EF [22, 97, 120, 124, 146] vocabulary and SC [53, 97, 120, 127, 146], EF and SC [7, 11, 132, 21, 120]. The novel approach of this study was to generate comprehensive measures of early childhood development in the areas of hand preference, fine motor skills, language, EF, and SC. Thus, we included early developing skills that could predict language/vocabulary. Based on our

previous work [167] and the evidence that vocabulary is a marker of success both during preschool and later in life [71], we predicted that all (or most) of behaviours would be interrelated. Second, we wanted to better define markers of development and examine the effects of handedness, fine motor, vocabulary, EF, and SC on the other "higher level" cognitive skills (EF and SC). Thus, we entered each standardized measure as a dependent variable in a regression model. We expected to observe a strong relationship between the cognitive skills- language, EF, and SC. The simplified summary of the results indicates that vocabulary size (measured by the PPVT) is predicted by SC (measured by the SRS), and vice versa, the scores from the SRS are predicted by the PPVT. Furthermore, we also found that EF (measured by the BRIEF-P GEC score) was related to both measures of SC, the SRS and the ASQ3:SE, and this relationship was bidirectional in that both measures of SC predicted the BRIEF-P GEC score. For each of these areas, better performance on one of the tests related to better performance or a better score on the related measures. These significant predictors from the stepwise regression models create a picture where aspects of language and SC are deeply interwoven in preschool children. Similarly, aspects of EF and SC seem to be intimately related.

With respect to language and SC, our findings support a large body of literature detailing the relationship between early childhood language/vocabulary and SC ([124, 97, 146, 159]. In fact, some definitions of SC include communication as a sub-category of SC itself [97]. Other assessments of SC use the term "social communication skills" (defined as the ability to use language appropriately in the classroom) in place of SC [124]. This evidence highlights how integral sufficient vocabulary can be to establishing social connections [124]. Studies also point to the idea that children who experience language delays may be viewed as sub-optimal play partners [127]. Of course, there are many factors that contribute to this relationship such as poor speech intelligibility (related to a smaller vocabulary) and lower self-esteem about communication [127]. However, another study underscores the specific role of vocabulary size in social success. When vocabulary was measured by the PPVT,

this proved to be the best predictor of social success in preschoolers [53]. Gertner et al. [53] compared preschool classrooms of children classified as one of three groups: typically developing English speakers, typically developing English as second language (ESL speakers), and a final group of children that had a speech and/or language impairment. To determine how speech and language development affected perceived social development in this configuration, the children rated their peers as a preferred playmate or less-preferred playmate [53]. The children chosen as preferred playmates were those with a more extensive vocabulary. They entered other variables into the regression analysis (age, IQ, and two other measures of language: the Reynell-Receptive test, and Reynell-Expressive test), but these variables did not significantly contribute to the model [53]. Together with the results of the current study, it appears that vocabulary size plays a pivotal role (or vice versa) in the advancement of SC.

The other bidirectional relationship in the current study occurred between EF and SC, where children with better EF also had better SC. Other studies have shown similar findings in preschool and school-aged children [21, 132, 7, 11]; see Riggs et al., [128] for a review). One study found a significant relationship between the GEC score of the BRIEF-P and a standardized social questionnaire in preschool children [7]. Many previous studies argue that it is almost intuitive that elements of EF are intrinsic to achieving SC [21]. For example, working memory allows a child to reflect on interactions and their own behaviour and to consider how they might change their behaviour for a more successful social encounter [21]. A child employs inhibition to resist grabbing a toy from another child and avoids a disruptive social inter- action [128]. Beyond correlational findings, an EF intervention study revealed children in a training group out-performed controls in both EF and SC measured at the conclusion of the study [132]. In that study, 100 kindergarten children were separated into an EF intervention group and a control group [132]. The EF intervention required educators to spend two thirty-minute-long sessions a week over several months rehearsing EF skills, either playing games to promote inhibition development (ex. Red light-green

light; see [29], or active role- playing to practice emotional regulation and switching (ex. Classic fairytales with reversed roles, Little Red Riding Hood where the wolf is good and the girl tricks the wolf; [132]). The fact that the EF intervention significantly improved the post-test BRIEF scores as well as SC performance highlights the value of EF and it's tight-knit relationship to SC. Because we found a bi-directional relationship between EF and SC, our study suggests that an intervention based on social interactions would also be effective in enhancing EF. This remains to be tested.

The results from the current study suggest that SC is at the heart of language and EF development. There are two remaining outcomes from the results to address. First, EF is not part of the relationship between vocabulary size and SC in this study. Previous research has shown the BRIEF-P is related to receptive vocabulary [99], or the PPVT is predicted by measures of EF [159]. In the current study, there is a significant negative correlation where a child with a better EF rating is more likely to possess a larger vocabulary ($r=-0.27$, $p = 0.03$). We chose regression models to explore causal relationships rather than purely correlational. We believe the regression analyses provide evidence that EF and SC are deeply imbricated, but EF is somewhat independent from vocabulary skill. Other studies also report a complex relationship between vocabulary and EF [22, 172]. In a longitudinal study, researchers found that early preschool EF performance predicted vocabulary and EF three years later, while early vocabulary did not predict EF over the years [172]. We argue that language is somewhat more dissociable from EF compared to SC, with the acknowledgement that this idea is controversial (see [92, 101, 91]). A child can acquire a vocabulary, but lack the skills of inhibition, working memory, self-regulation that are key for EF. For SC however, social interaction is nearly impossible without the assistance of a lexicon, whether it is a language or rudimentary gestures. Acquiring a lexicon is done most effectively through social interaction, and children with both a sufficient lexicon and sufficient EF skills will be more likely to develop stronger SC [172, 101] However, elucidating this is beyond the scope of the current study.

The second unpredicted outcome from the results is both the absence of right-hand-use as a significant factor in the regression models, and the discrepancy of the results between right-hand use for grasping versus pointing in the model that predicted SC. Previous work established a connection between increased right-hand-preference during a grasping task and better EF scores based on the BRIEF-P questionnaire [63]. As discussed, there is a modest body of literature detailing a direct relationship between right-hand preference and cognitive development during childhood [speech [62], vocabulary [113, 114, 169, 27] and executive function [63] However, there are studies that do not replicate or find a direct correlation between degree of right- hand preference and cognitive skills [113, 117, 120, 167, 172]. To address this apparent discrepancy, we want to highlight the notion that there is a developmental shift in hand preference across the early years of life, and it is not until later in childhood that hand preference stabilizes for all manual actions [141, 61, 136]. Furthermore, hand preference differs depending on the nature of the manual task [16, 141, 61, 136]. For example, children develop a strong right-hand preference for hand-to-mouth actions before the age of three years yet, by some accounts, show no hand preference for grasp-to-manipulate actions [136]. Infants also show significant variation in the rate of development of hand preference for pointing versus grasp-to-construct tasks [83], the same manual actions used in the current study. It thus appears that the relationship between hand preference and the intent of a manual action is more nuanced and should be considered when studying the relationship between motor and cognitive development.

In conclusion, our findings suggest that cognitive functions develop both synergistically, building upon each other, but also independently, where a well-developed skill in one area does not ensure the same success in another ability (ex. language and EF). By understanding how these skills are interrelated, there is the potential to refine a single intervention to promote development of multiple cognitive skills- vocabulary, EF, and SC.

Chapter 4

Preschool development: The intersection of motor skills, vocabulary, executive function, and social competence

4.1 Abstract

Vocabulary development has been established as a predictor of other language outcomes, executive function, and even social competence. However, the bulk of the research focuses on pairing vocabulary with one other measure and is frequently assessed through parent or teaching questionnaires. While these are excellent forms of assessment, they may provide limited insight into a child's behaviour and development. The purpose of this study was to use direct assessment of child behaviour to conduct an in-depth assessment of vocabulary, motor skills, executive function, and social competence. Fifty-nine children (33 females) ages three to five years old participated in this study. We completed at least one task per area of development. The results of multiple linear regressions suggested a complex relationship between receptive vocabulary, motor skills, executive function, and social competence. Several other variables contributed to the models, such as speech production, additional measures of executive function, and handedness. We discuss these results and highlight the value of direct assessment of behaviour when investigating child development.

4.2 Introduction

Vocabulary development is intertwined with a host of other prominent skills in early childhood, including hand preference [26, 28, 110], motor skills [65, 155, 24], executive function [69, 124, 147, 172], and social competence [159, 168]. Just a few examples from the selected studies illustrate a complex connection that begins during infancy and continues throughout the school years. For example, one-year-olds with a strong right-hand preference for pointing develop a bigger vocabulary later in life compared to children with no clear hand preference [110]. During preschool, children are more likely to select a correct answer if they use their right hand during a communication task [117] or receptive language test, like the Peabody Picture Vocabulary Test (PPVT-V; [167]). While these studies focus on right-hand preference as a predictor of vocabulary, there is evidence that motor skills are also related to better vocabulary and language development.

Early developing fine motor skills can predict vocabulary size [24]. Suggate and Stoeger [155] found that performance on several fine motor tasks (e.g., threading beads) during preschool significantly predicted vocabulary size. The relationship is even more consistent when the vocabulary test focused on words related to body-object interactions [155]. In a recent systematic review, S. L. Gonzalez et al.[65] discussed evidence that both gross and fine motor skills are linked to vocabulary development from infancy into early childhood [65]. The connection between receptive vocabulary and motor skills is less documented compared to other elements of communication like speech or vocabulary development. This may be because childhood speech development requires fine motor control (coordinating the speech articulators to accurately produce sounds), while associating a word to an object or action does not require any motor skills per se. Vocabulary assessments require minimal motor skills. However, both gross and fine motor skills afford young children an opportunity to interact with their environment, which provides ample chances to learn new words and associate them with the child's expanding world [65]. While children are using motor skills to explore their surroundings and support vocabulary development, they also

have more opportunities to develop executive function (EF).

EF is a term for multiple processes that support goal-directed behaviour, including inhibition, working memory, and self-regulation [177, 40, 64]. Vocabulary development is associated with specific measures of EF as well as global measures. For example, in a group of eight-year-old children, working memory and vocabulary size predicted each other, and vocabulary size was a better predictor of working memory than IQ [69]. In preschool-aged children, their vocabulary score on the PPVT was predicted by a battery of tabletop EF assessments including a variation of the dimensional-card-change-sort task (DCCS;[172]). Weiland et al. [172] measured children's PPVT scores and EF performance (DCCS) at the beginning and the end of the school year and found that both scores were significantly correlated at both times of assessment. Arguably, vocabulary is present in most activities where a child is applying or testing their EF skills. For example, a preschooler may not hesitate to express dissatisfaction when they are required to shift or inhibit a behaviour or narrate their intentions before executing a planned action.

A final area of early childhood development that is interwoven with vocabulary is social competence. Social competence/social skills (SC) are a complex measure that refers to a child's pro-social behaviours, like initiating and participating in interactions, communicating, and other positive traits like sharing or collaborating [159]. Because communication is often included in the definition of SC, it is unsurprising that measures of language consistently relate to early SC [159]. In preschool children, both EF (DCCS and other interactive tasks) and SC (observation-based scale) significantly predicted receptive vocabulary (measured by the PPVT; [159]). A sufficient vocabulary can facilitate effective communication, and enable development of SC.

This selection of recent studies show that vocabulary development is associated with performance across multiple dimensions (hand preference, fine motor skills, speech, EF, and SC). The full picture is not quite as harmonious, as there are examples of opposing or null results (see discussion by Bruce and Bell [18]). In a recent study we reported

that parent questionnaires, or other proxy measures of behaviour show a complex interrelationship during development [168]. Specifically, we found that receptive vocabulary of preschool children (measured by the PPVT) was predicted by a SC scale (SRS-II) [168]) and importantly this relationship was present when the SC scale was used as the dependent variable (scores on the SRS-II were predicted by scores on the PPVT). Another finding was a predictive relationship between SC and EF (as measured by the BRIEF-P questionnaire). However, the BRIEF-P questionnaire was not a significant predictor of the PPVT ([168]). These results were somewhat unexpected, as previous literature suggests strong interrelationships between each of these domains in early childhood. It is possible that we observe the nuances in development only by collecting comprehensive data that focuses on direct measures of behaviour (i.e., child performance assessment).

The purpose of the present study was to investigate the relationships between language (vocabulary size and speech production), fine motor skills, EF, and SC using direct measures of behaviour. For the present study, we included two measures of language, one measure of fine motor skill (with an EF component), two measures of EF and one measure of SC. Based on our previous study, we hypothesized that child language would be closely related to the development of each of the other functions. To build off the results from our recent report where we found a relationship between vocabulary and SC, we also investigated if any of the significant predictors of vocabulary are in turn predicted by vocabulary. The lack of a universal relationship between may represent a directionality in development, as opposed to mutual co-development. Based on the previous study, we further hypothesized that there would be relationships between vocabulary and SC, vocabulary and EF, and EF and SC. We added an additional measure that was not present in our previous publication- speech production. We hypothesized that speech production would also contribute to predicting development in these broad areas, and in turn, be predicted by skills such as vocabulary, SC, and EF.

4.3 Methods and Materials

4.3.1 Participants

A total of 81 children were recruited for this study. The data focuses on a subset of 59 children (33 females), who were present during data collection. Age range was 3-5 years old (M=4.06 years, SD = ±0.82 years). Fifty-two children were identified as white by their guardian, and the remaining seven included one child who identified as: Ojibwe, Indigenous, Filipino, Chinese, Japanese, and two of African American descent. All children were native speakers of English, and three identified as having a second native language (two knew Spanish and the third child was fluent in Japanese). We recruited children from Southern Alberta, Canada. Sixteen of the children in the study were tested at the University of Lethbridge, while the rest were tested at early learning centers and childcare centers around the city of Lethbridge. A group of children in this data set were also enrolled in the Building Brains Together curriculum, a program administered at early learning centers to target and improve EF. All data in this study was collected before the training program began. All parents provided informed and written consent, while children provided assent to participate in the study. The University of Lethbridge and the University of Alberta research ethics board reviewed the procedures and approved the study.

Twenty-two children were not included in this study for a variety of reasons. The primary reason for exclusion was missing data, where either the parents neglected to return any questionnaire information, or the child was absent during the testing period, and could not complete any of the direct measurements. This applied to 12 of the children. An additional five children where excluded due to camera error/experimenter error where the camera failed to capture audio and/or the experimenter failed to record the activity. Finally, five children were excluded due to clinically abnormal scores on the standardized questionnaires.

4.3.2 Materials

The materials and procedure discussed here are identical to those listed in Chapter 3 [168]. Parents completed a total of nine questionnaires (results reported in Chapter 3 [168]), while children completed a total of 11 assessments over one-to-three testing sessions.

Parent Questionnaires

The parents completed a developmental screening questionnaire, Behavioural Rating Inventory of Executive Function (Preschool), Behavioural Rating Inventory of Executive Function (Adult), Social Responsiveness Scale-2, Ages and Stages Questionnaire-3, Ages and Stages Questionnaire- Social Emotional, modified child handedness questionnaire (Waterloo-Edinburgh), parent protective factors questionnaire, and a questionnaire about one-on-one parental time with child. For the current study, we used the results to determine if a child was typically developing. In the included sample of 59 children, five children had scores in the mild range for the SRS-2 and/or the ASQ:SE, suggesting that they were behind their peers. Parents did not report any concerns or diagnoses in the developmental questionnaire.

Child Assessments

See the procedure section further below for information about how children were guided through each of the of the following assessments. This section includes the full list and description of the assessments. A video recorder was used to film the child during each of the following activities.

Vocabulary We administered the Peabody Picture Vocabulary Test-IV [44]. This test is a standardized assessment of child receptive vocabulary development. The test includes a booklet with four large images on each page. The experimenter is provided a list of target words, and for each page, prompts the child to point to the image that represents the word. The raw score is calculated by subtracting the total errors made on the test from the highest level the child achieved. The test is complete when the child makes eight errors in a row.

Grasping Errors The BBT uses a set of 20 stacking block pieces along with four

models composed of five unique blocks ([60]- see Gibb et al. ([54]) for a recent description of the preschool child testing procedure). The blocks are arranged in front of the child into four quadrants. Only the experimenter is aware of these quadrants/boundaries. One set of each of the five blocks are evenly spaced out in each of the quadrants. Half of the blocks are placed on the child's left, and the other half are placed on the right side of the child's midline. To turn the table into four sections, half of the pieces are set within the child's near reaching space [153], and the other half are placed in the child's far-reaching space. This task is designed so that it is equally efficient to reach and grasp with the right or left hand. After the child is seated at the table, the experimenter placed a model made of five blocks in front of the child and asked them to make an exact copy using the blocks on the table. This procedure was repeated four times, and each of the models used the same five block pieces to compose the model, just organized in a different way. If the child built all four models correctly, no blocks would be left on the table.

To score this task, a handedness percentage is calculated. Each grasp is rated as a left- or right-handed grasp. The total number of grasps are calculated, and a right-hand grasping percentage is calculated by dividing the number of right-handed grasps from the total number of grasps and multiplying by 100. An additional measure from this task is grasping errors. Grasping errors are measured by observing how the child builds the model. Each time the child grasped a block, it was considered correct or a grasping error. Grasping errors occurred one of two ways. When the child dropped a block or had to set a block down to change their grip, that grasp counted as an error. Another form of grasping errors occurred when the child exhibited poor planning and grabbed a block that did not allow them to continue replicating the model. For example, if the model showed a blue block placed on top of a red block, and the child grasped a green block and then a yellow one, they could not assemble the blocks and still replicate the model, so grasping both the green and yellow block each counted as an error. The grasping error was also calculated as a percentage of total grasps, similarly to RH use percentage.

DCCS Task A common measure of childhood EF is the DCCS task [177]. During this assessment, a child is shown cards that have two different objects printed in two different colours- here, we used turtles and trains that were either purple or orange. A child is given two small containers, one with an orange turtle, and the other with a purple train printed on the front. The child is asked to play a colour sorting game. The child is handed a small card with either a purple turtle or an orange train printed on it. There are two practice trials where the experimenter can remind the child that it is a colour sorting game and instruct the child to put the orange train card in the orange turtle container, and the purple turtle card in the purple train. After, the child completes six trials where they are handed a turtle or train card and instructed to place the card in the correct bucket. The experimenter may remind the child of the rules twice but cannot provide feedback on the child's performance. Next, the child is asked to play a shape sorting game. The child is given two practice trials again. Now, the purple turtle must go in the container with the orange turtle picture, and the child must place the orange train card in the container with the purple train. After help with the two practice trials, the child completes six more trials. At the end of the task, a DCCS error percentage is calculated by totaling the number of errors or incorrectly sorted cards and dividing the total errors by the total trials completed (12), finally multiplying by 100.

Stroop Task The final assessment of EF used in this study is known as Animal Stroop [64]. This is a child-friendly adaptation of the common Stroop task used to assess adult EF. For Animal Stroop, a child is shown a set of cards with four different cartoon images of animals printed on the cards. The child is asked to name the animal on the card (ex. cat, horse, sheep, pig). During the switch part of the task, the child is shown a set of 12 cards with the same animals on them, except the heads and bodies are mismatched (ex. a cat head on a sheep body). The child is given four practice cards, during which the experimenter explains that the child must name the body of the animal. After the child completes the four practice cards, the experimenter will no longer give feedback on the task, and simply

ask the child to name each card. At the end of the task, the total number of errors are counted, divided by 12, and multiplied by 100 to generate an Animal Stroop error percent score.

Social Play Task In this study, we developed an direct measure of a child's SC. The social play task began when two children were seated across from each other at a small table. The experimenter placed about 50 Mega-blocks^{TM} on either side the of pair, and a building plate was set in between the children. The children were instructed to build something together. The experimenter could remind children of their goal multiple times throughout the task. After the children were instructed to build something together, the experimenter started a five-minute timer. The children were filmed during the social play task, and the film was analyzed after the data collection was complete. During the task, the experimenter would ask each child at least once what they were building.

To score this task, the experimenter watched the video once for each child (at least twice in total per video). During each observation, the experimenter kept track of how many vocalizations the child initiated, and if they were directed to the other child, the experimenter, or if they were non-directed bids. The experimenter also tracked how many times the child responded to a bid from either the other child or the experimenter. Besides tracking the number of bids and who they were directed to, the bids were also scored on complexity- were the children planning what to build or going above the task requirement and engaging in pro-social behaviour by sharing information about each other unrelated to the rules of the task. In addition to bids or vocalizations, the experimenter kept track of non-verbal communication- by counting the number of times the children shared blocks with each other, gestured or pointed to an object or block, or showed something to their play partner.

Phonetic Errors To measure speech development, we used the task described in Netelenbos et al. [115]. Children completed a one-word repetition task where a small laptop computer played a word and showed a related image, and the child was required to repeat

the word into a microphone. There were 53 words in total. Each word was selected because it had a later-developing speech sound in the initial consonant position (/s/,/ʃ/, /ɹ/, /l/, /w/, /θ/). See Table 4.1. We used a digital recorder (Marantz PMD 661) to track the child's speech production with a 44.1 kHz sampling rate.

To determine production errors, an independent student listened to each production made by the child and rated each phoneme in a word as correct or incorrect. If the student could not distinguish the phoneme, the child received a score of incorrect. Each child had a percent word error rate based on the total number of words (phonemes) produced, and how many were produced incorrectly/indecipherable. Additional errors were added if a child added on phonemes that were not part of the word. To ensure consistency, a senior student listened to 20 percent of the data and provided a rating. An intraclass correlation was conducted to compare the two ratings, and we confirmed that both raters performed nearly identically, ICC [2,2] 0.863 (0.571-0.961, $p<0.001$).

Table 4.1: Wordlist for Phonetic Errors Task

Initial Sound	IPA symbol	Associated Words
l	/l/	ladder, land, lamp, lick, lid, lips, lucky charm, lunch, luggage
r	/ɹ/	rattle, ring, river, run, rubber duck, ribbon, rat, rabbit, rug
w	/w/	wizard, wax, whack, window, wonder, wig, one, wonderful
s	/s/	sandwich, salad, salmon, sick, silly, sit, sun, subway, sucker
sh	/ʃ/	shack, shadow, shallow, shin, ship, shiver, shovel, shuffle, shut
th	/θ/	thank you, thanksgiving, thick, think, thumb, thunderstorm

4.3.3 Procedure

At the start of the assessment, each child is given a "treasure map" with pictorial representations of the tasks the child should complete during that testing session. There are arrows indicating the sequential order the child will complete the assessments in. There were several variations of the maps, which allowed researchers to pseudo-randomize the order of the assessments. The child was invited to search around the testing space (usually a small classroom, office, or hallway) for an image identical to the map. Once the child found the matching image, the researcher announced the "game" or assessment the child would complete. After the child completed the assessment (one of those listed above in the materials section), the researcher produced the map, and the child searched for the picture that represented the next task. The child would complete one to five tasks per testing session, usually over five to 20 minutes of time.

4.4 Results

We used Rstudio (Rstudio Team, 2020) to complete the analyses of the data. The descriptive statistics and regression results are reported below. We did not report correlation analyses.

4.4.1 Descriptive Statistics

The mean, SE, and range of scores for the main variables are presented in Table 1. All data used in the analyses was normally distributed.

4.4.2 Multiple Linear Regressions

For the following four sections, we ran separate linear regressions to determine the best predictors of childhood outcomes in several areas: PPVT score, BBT grasping errors, phonetic errors, and social play score. For all the regressions, we used the package "olsrr" and the function "ols_step_best_subset" to select the variables that we entered into the regression

model in Rstudio. This package identifies the appropriate variables to include in the model based on the grouping that explained the most variance in the dependent variable without overfitting the data. We collected a total of 10 variables: sex, age, right-hand use during BBT (%), right-hand use during PPVT (%), BBT grasping errors (%), mean phonetic errors, PPVT raw score, Stroop errors (%), DCCS errors (%), and social play score total. For each of the four models, one of these variables became the dependent variable in the model, and the other nine were entered into the step-wise comparison using the "olsrr" package. The variables that were selected by the package are included in each of the four models in the following sections. It is important to highlight that sex was included as a variable, but it was never selected by the olsrr package, and therefore no notable effects of sex are reported in the paper.

Predictors of Receptive Vocabulary The first goal was to determine the main predictors of childhood vocabulary size (as measured by the raw PPVT score) based on nine direct measures of child behaviour. The olsrr package selected three variables that we included in the model: age (months), grasping errors (%) and social play score. The linear regression was significant ($F(3,45)=16.54$, $p<0.001$), with an adjusted R^2 of 0.49. The details are shown in Table 2. While age contributed to the model ($p=0.093$), only grasping errors and social play score significantly explained vocabulary score. Children with a larger receptive vocabulary made fewer grasping errors during the BBT task and were more likely to have a better (larger) social competence score.

Table 4.2: Results of a multiple linear regression to predict vocabulary (PPVT score)

	Estimate	Standard Error	z-Score	p-Value
Intercept	**65.101**	**25.237**	**2.580**	**0.013**
Age (months)	0.5601	0.326	1.717	0.093
Grasping Errors (%)	**-38.906**	**14.588**	**-2.667**	**0.011**
Social Play Score	**2.944**	**1.264**	**2.329**	**0.024**

Predictors of Grasping Errors Because grasping errors predicted PPVT score, we

ran a second linear regression and selected grasping errors as the dependent variable. The variables that predicted grasping errors were PPVT score and phonetic errors. The outcome of the significant multiple linear regression (F(2,45)=30.26 , p<0.001), with an adjusted R^2 of 0.55 is shown in Table 3. Children who made fewer grasping errors had a larger vocabulary, and also made fewer speech production (phonetic) errors.

Table 4.3: Multiple linear regression model to predict grasping errors (percent)

	Estimate	Standard Error	z-Score	p-Value
Intercept	**0.661**	**0.133**	**4.98**	**<0.001**
PPVT Score	**-0.004**	**0.001**	**-4.22**	**<0.001**
Phonetic Errors	**0.016**	**0.004**	**3.91**	**<0.001**

Predictors of Social Competence We continued to investigate the factors related to early language development, so we used social play score as the dependent variable in a linear regression. Social play score (F(2,37)= 7.16, p<0.001), with an adjusted R^2 of 0.38 was best predicted by age, PPVT score, phonetic errors, and grasping errors. Children with a better (higher) social play score were younger in this sample, had a better vocabulary, made fewer phonetic errors, and used their right hand more during the block building task.

Table 4.4: Multiple linear regression model to predict social play score

	Estimate	Standard Error	z-Score	p-Value
Intercept	5.604	3.209	1.746	0.089
Age (months)	**-0.110**	**0.043**	**-2.562**	**0.014**
PPVT Score	**0.045**	**0.015**	**3.067**	**0.004**
Phonetic Errors	**-0.176**	**0.061**	**-2.878**	**0.007**
Right-hand use grasping (%)	**6.589**	**2.773**	**2.377**	**0.023**

Predictors of Phonetic Errors. The final linear regression we ran was with phonetic errors as the dependent variable. The model was significant (F(3,34)= 16.74, p<0.001), with an adjusted R^2 value of 0.56. The measures that related to phonetic errors were age

(months), DCCS error (%) and social play score. Only age and social play score significantly predicted phonetic errors, where more errors were related to a younger age and worse (smaller) social play score.

Table 4.5: Multiple linear regression model to predict phonetic errors

	Estimate	Standard Error	z-Score	p-Value
Intercept	**34.694**	**5.072**	**6.841**	**<0.001**
Age (months)	**-0.354**	**0.078**	**4.523**	**<0.001**
DCCS Error (%)	0. 143	0.076	1.887	0.068
Social Play Score	**-0.852**	**0.332**	**-2.569**	**0.015**

4.5 Discussion

The main purpose of this study was to understand the predictors of early childhood vocabulary, which included fine motor skills (with EF), speech production, EF, and SC. First, we wanted to explore the contributions of multiple domains of development to vocabulary achievement using more objective measures (i.e., child behaviour). Second, in conjunction with our recent submission [168], we also wanted to determine if the relationships discovered between these dimensions existed even if the dependent and independent variable were exchanged, which would suggest co-development of these skills. Based on the previous study by van Rootselaar et al. (submitted), we predicted that measures of EF and SC would predict receptive vocabulary. We confirmed our main hypothesis, both the direct assessments of child EF and SC were significant predictors of children's PPVT score. Specifically, grasping errors and social play predicted PPVT score. When we investigated which relationships were maintained (the idependent variable was a signficant predictor of the dependent, and vice versa in a linear regression), we found that unlike the results from van Rootselaar et al. (questionnaire-based measures; submitted) here, themeasures of EF and SC were predicted by PPVT performance. It is possible that we observed these relationships because we used more objective measures of behaviour. In van Rootselaar et

al. (submitted), the parents assessed measure of EF, the BRIEF-P questionnaire, did not predict vocabulary performance. Direct measures might be more robust, and researchers should consider incorporating them into their investigations of early child development.

One outcome both of this study and the previous [168] is the strength of the relationship between grasping errors and vocabulary. Grasping errors is an assessment based on the block building task [60, 3, 54]. The BBT was previously used to measure visuospatial function, mental rotation, and hand preference across all ages [60, 3]. We recently developed an additional measure without altering the task- scoring grasping errors-to generate a representation of both fine motor coordination and EF. This method was first published in van Rooteselaar et al. [164]. Van Rooteselaar et al. [164] tracked the performance of adults on a verb and noun fluency task, as well as the adult version of the BBT. The results showed a strong relationship between verb generation/verbal fluency, grasping errors, and construction time [164]. Verbal fluency is thought to measure EF [5], as well as language skills [173]. In the current study, children completed the BBT and vocabulary task separately, but we still observed a strong relationship between vocabulary performance and this complex motor-planning task (grasping errors). During the PPVT, a child may use similar planning and complex reasoning skills to deduce which of the four images on a page are most likely to represent an unfamiliar word, much like how a child must deduce which block they need to grasp to correctly construct a model. Overall, between van Rooteselaar et al. [164] and the current study, there is strong evidence that grasping errors during the BBT (both manual errors [ex. dropping a block] and planning errors [ex. grabbing a blue block when a yellow block is required]) provide an ecological and objective performance assessment that reflects nearly all the domains of development addressed in this study. This task is easy to administer, and only requires two-to-ten minutes to complete, a small table and 40 building blocks. The most valuable aspect of this task is that it is extremely engaging and enjoyed by all ages (1-100 years, [3]; mega blocks can be substituted for children or older adults who cannot use the smaller blocks). Although not the focus of the current

study, we did investigate if grasping errors were associated with the Stroop and the DCCS, the more traditional measures of EF. We found strong correlations between them (Stroop errors [r=0.9719, p<0.001]; and DCCS errors [r=0.4135, p<0.003]).

To understand the nature of the relationship between vocabulary with EF and SC, we also used EF and SC measures as dependent variables. The best predictors of childhood EF (as measured by the BBT grasping errors) were vocabulary size and phonetic errors. With respect to SC, the regression indicated that the best predictors were vocabulary size, phonetic errors, right hand use during the BBT task, and age. Given the fact that phonetic errors appeared twice as a significant predictor of dimensions that predicted vocabulary, we ran a final regression with phonetic errors as the dependant variable. Notably, only age and SC significantly contributed to predicting phonetic errors. This is the first time in the regression results for this study that a predictor was not also predicted by the measure when the role of dependent and independent variable was switched. To be clear, grasping errors did not contribute to predicting phonetic errors. This may be related to the nature of the speech task. Despite that both grasping errors and phonetic errors reflect elements of motor coordination, only grasping errors provide multiple options for success, or a planning component. Phonetic errors were measured through a simple word repetition task that required minimal working memory and did not incorporate other EF skills such as planning.

One of the rationales for this study was to create a comprehensive assessment of early childhood behaviour and include more objective measures across multiple dimensions. Previous studies provided evidence of directionality of development between some of these variables, such as early vocabulary development supporting later EF skills [18, 92]. The data presented here allows a more comprehensive assessment of preschool development, as we found many significant correlations between the main variables [not reported in the results: phonetic errors and PPVT (r=-0.454, p<0.001); DCCS errors and grasping errors (r = 0.413, p=0.003), DCCS and PPVT (r=-0.313, p = 0.025)], but only the multiple linear regression results provided a deeper insight into the complex relationships between

early vocabulary, speech, motor, EF and SC. For example, phonetic errors and PPVT had a medium strength correlation, only slightly weaker than the relationship between grasping errors and PPVT (r=-0.648, $p < 0.001$), but a more rigorous statistical method proved that grasping errors more meaningfully predicted the behaviour outcome of vocabulary.

All the relationships in this study proved to be significant predictors of eachother, regardless of which pair is used as the dependent variable, apart from phonetic errors. It should be noted that during early development, children are rapidly acquiring skills, and development often occurs in a non-linear pattern [150]. It is possible that if we included a slightly younger cohort and/or a slightly older cohort, we may have observed more unidirectional relationships where some skills develop earlier, or plateau and are no longer as strongly related to another skill. A future study could recruit a larger sample of children and include a longitudinal element (one-year follow-up) to find further support for the results discussed here as well as expand on the ages.

A final important application of these results is that based on the interconnectedness between vocabulary, EF, and SC, then interventions for children who are diagnosed with deficits in these domains could be broader. For example, a child with diagnosed social delays could still benefit from EF interventions and vocabulary training, or vice versa [132].

In conclusion, the results of the study demonstrated a relationship between vocabulary, motor/EF, and SC. This highlights the interrelationship between these developmental domains. Arguably vocabulary, EF, and SC each rely on a high degree of planning, regulation, and working memory to successfully complete the tasks used in this study. This study truly highlights the value of a comprehensive data collection, along with use of direct measures of behaviour. Many previous studies (including our recent paper in Chapter 3;van Rootselaar et al., submitted) rely on parent or teacher report, which is valuable in that they are quick and can assess child behaviour over a longer period. The limitation is that they are based on the parent/teacher perceptions of the child's behaviour and may overlook the nuances or rapid changes in behaviour. Despite the more time-consuming nature of direct data col-

lection, future research should make attempts to incorporate them to best understand child development.

Chapter 5

Discussion

5.1 Discussion

Throughout this thesis, it is implied that when a child enters a preschool classroom, they will be challenged in multiple areas of development, whether that be through communication, fine motor skills, executive function and/or social competence. The studies featured both in this thesis and used as references all indicated that there is a high chance that if a child excels in one domain, they will be more likely to excel in the others. The purpose of this thesis was to investigate the role of hand preference in early development across four main areas; language (receptive vocabulary and speech production), fine motor skill, executive function, and social competence. The experimental design also allowed a deeper exploration of the influence that these "higher level" skills of development had on each other. Higher level cognitive processes include elements of abstract thinking, creativity, empathy, and flexible reasoning. For example, successful social play, even during preschool, often requires that a child shares ideas and understand what their partner's ideas include. This can be distinct from say, fine motor skills, which are easily tested through a concrete task devoid of creativity or abstraction.

The overarching hypothesis was that children with strong right hand manual lateralization would exhibit better performance on the various aspects of cognitive behaviours. This hypothesis is based on the hand to mouth theory that language evolved from a gestural system and the extension of this idea, whereby complex cognition is supported by functional lateralization. If lateralization, measured by hand preference, is a central support for early development, then I expected to find a relationship between hand preference and the high-level domains that were featured in this thesis; language, executive function, and social competence. These ideas are reflected in the predictions and the hypotheses shared in Chapters 2, 3, and 4. Chapter 2 investigated a pair of skills through a task with strong ecological validity. Children completed a vocabulary test (the PPVT), and I recorded hand use for pointing during the test as well as their vocabulary score. Chapter 3 used a separate sample of children to look more broadly at how hand preference during grasping and point-

ing related to language, fine motor skills, executive function, and social competence. Both direct and proxy measures were used. To complete the thesis, Chapter 4 details a similar investigation as in Chapter 3 but using exclusively direct measures with varying degrees of ecological validity. The results are reviewed in detail below.

In Chapter 2, the study had a large sample of children who completed a standardized vocabulary test, and I recorded hand use and trial accuracy, as well as overall vocabulary score. I predicted that based on previous studies connecting greater right-hand preference to better executive function and speech, children who used their right-hand more during pointing would have a better vocabulary score. The results did not support this prediction, as hand preference did not directly predict vocabulary size. Instead, a much more nuanced pattern appeared where a child was more likely to select the correct image if they used their right hand to point during the initial trials. This study aligns well with previous research that found a relationship between right-hand preference and language development [63, 24, 66, 110, 113, 114, 169]. However, this study also suggests that simply using the right-hand for all trials does not equate to a significantly larger receptive vocabulary.

Chapters 3 and 4 included a different sample of children, to further investigate the relationship between manual preference and cognitive development. Chapter 3 focused on child performance during the same vocabulary test used in Chapter 2, as well as proxy measures of executive function (BRIEF-P questionnaire) and social competence (SRS and ASQ:SE questionnaires). In this chapter I also present the results of one direct measure of fine motor skill (grasping errors during BBT) and executive function. My first goal was to replicate the results from Chapter 2 with a new sample of children. My second goal was to determine if right-hand preference for pointing and/or grasping predicted any of the recorded complex cognitive functions. A third prediction for this study was that the complex cognitive functions would also interact with each other. In Chapter 3, I successfully replicated the results from Chapter 2 in that right hand pointing predicted a successful trial in the PPVT. Hand use however, did not predict outcomes in any of the other cognitive functions. Finally,

Chapter 3 also showed a predictive relationship between all the parent-completed questionnaires: executive function (BRIEF-P) was best predicted by social competence (SRS and ASQ:SE) and vice versa. However, when vocabulary was the dependent variable (PPVT), the only questionnaire predictor was the social competence questionnaire (SRS). Executive function (as measured by the BRIEF-P) was not relevant to the model. Instead, the direct measure of executive function/fine motor skills (i.e., grasping errors) was the other predictor of receptive vocabulary. This result supports the initial hypothesis that "complex" cognitive functions are tightly connected, albeit with an asterisk noting that not all proxy assessments (e.g., BRIEF-P) are correlated with the direct measures (like the PPVT), and vice versa. See Fig. 5.1) for an overview of the regression outcomes between the PPVT language measure and the proxy measures described in Chapter 3, exluding the direct measure of EF, grasping errors, that was also described in Chapter 3.

The final experimental Chapter (4) focused on direct measures of child behaviour and used regression analyses to determine if there were relationships between hand preference (right-hand use for grasping and pointing), language (PPVT and phonetic errors), fine motor skills (grasping errors), executive function (grasping errors, DCCS task, and Stroop), and social competence (social play score). I predicted that right hand use would be more related to the direct measures of cognitive function because the output of these tasks all feature a motor component. I also predicted that the complex cognitive direct measures would predict each other. Right hand use was a predictor of social competence whereby the more a child used their right hand for grasping, the better their score in the social play task. Right hand use was not a significant predictor in any of the other regression analyses. There were two other important findings from this chapter: First, when exclusively relying on direct measures, not all complex functions were related. There was a strong relationship between social play score and vocabulary (PPVT score), and social play score and speech production. The final bi-directional relationship occurred between vocabulary and executive function- the PPVT score and grasping errors were related. The complex

cognitive functions that were not related to each other were executive function/motor skills (grasping errors) and social competence (social play score). This contrasts with the finding in Chapter 3, where social competence was a predictor of executive function. These opposing outcomes may indicate that direct assessments and proxy tools are measuring different aspects of these behaviours, like the SRS questionnaire versus the social play score. It is important to note that the predictors of vocabulary were identical to those from Chapter 3, where vocabulary was predicted by executive function (grasping errors) and social competence (social play score). Chapter 4 provided some support for previous research which found right-hand use predicted better performance, however, it was unexpected that this relationship would only exist with social competence. See Fig. 5.2) for an overview of the regression outcomes between the PPVT language measure and the direct measures described in Chapter 4. A possible explanation for the lack of relationship between right hand use and executive function or language is that when more complex regression models are used, as opposed to correlations, or models with only three variables, it is social competence that stands out as a consistent predictor of performance across measures and contexts within preschool children. This highlights the second important finding from Chapter 4, social competence was a predictor in all the models except one (not executive function).

5.2 Lateralization Gets Left Out

One of the primary purposes of this thesis was to expand on previous work connecting right-hand use to better performance on different cognitive tasks during development. As discussed in the general introduction and throughout the thesis, most studies conducted on hand preference and cognitive performance examine one or two measures of hand preference alongside one dependent variable. This thesis revealed that hand preference is not a main predictor of cognitive behaviours (measured here) in three- to five-year-olds when accounting for multiple areas of development. This is not to say that hand preference does not play an important role or reveal important stages of development. Within these stud-

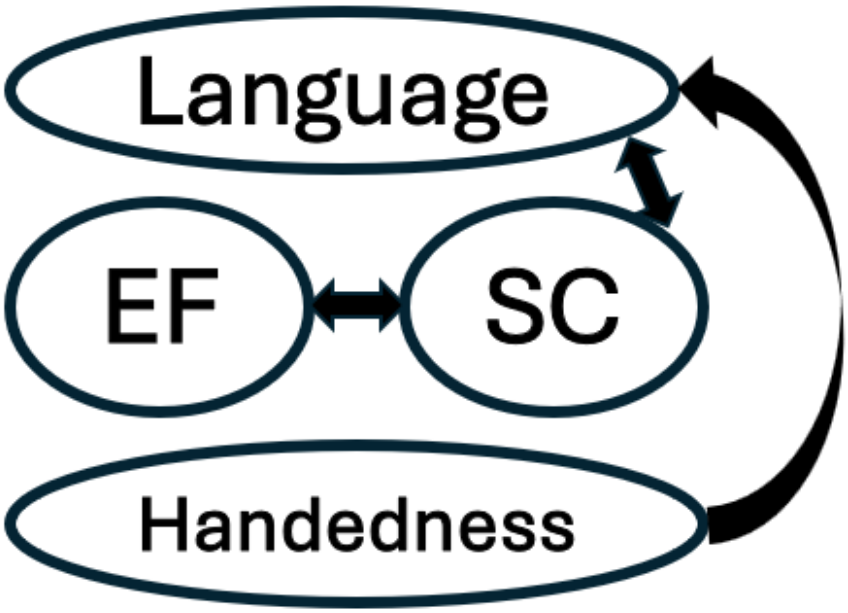

Figure 5.1: Summary of Relationships Between Proxy Measures. This arrows between the categories assessed in this thesis represent the significant relationships observed through the proxy measures (parent reports) of child performance.

ies, we did find evidence in Chapter 2 and Chapter 3 that it might be advantageous for a child to use their right hand on each trial of the PPVT [167]. More research is needed to better understand whether children used their right hand because they were confident of the meaning of the word, or because it increased their odds of guessing correctly. A future study could further test this proposal by modifying the PPVT paradigm to include non-words [167]. If children change hand use more frequently during the non-word trials compared to trials where they are pointing to common words, then it strengthens the case that there may be a relationship between right-hand use for communicative gestures and certainty/access to lexical knowledge. In addition to the role of hand preference and vocabulary (Chapters 2 and 3), there was only one other instance in which right-hand use was a significant factor. In Chapter 4 right hand use was a significant predictor of social competency, alongside two measures of language performance. Given the fact that there were multiple other linear regressions described in this thesis, and hand preference was only a significant predictor in one, this suggests that hand preference may play a smaller role than

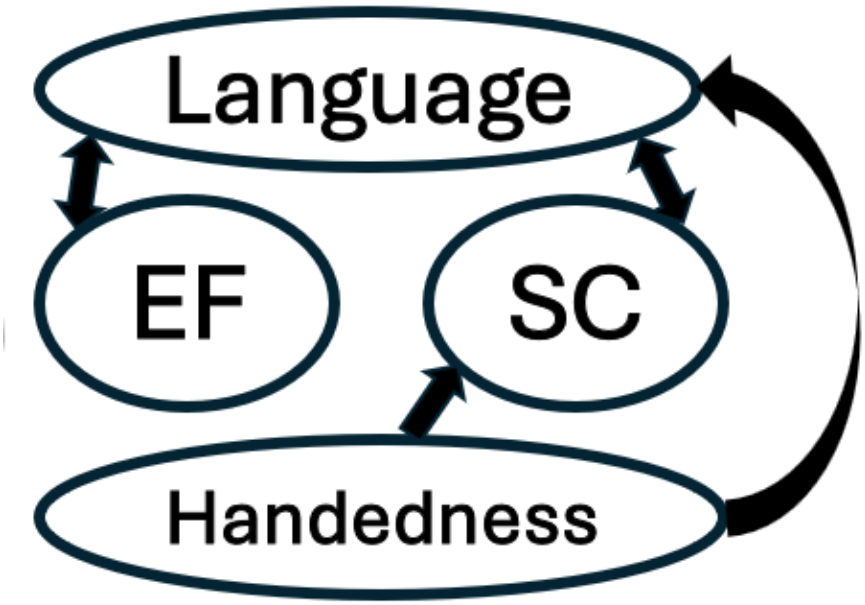

Figure 5.2: Summary of Relationships Between Direct Measures. This arrows between the categories assessed in this thesis represent the significant relationships observed through the direct measures of child performance with tabletop games and assessments.

previously described. I conducted explorative correlation analyses that are not described in Chapters 3 and 4, where I found that hand-preference was significantly correlated with social play score, speech phonetic errors, and approached significance with the DCCS task, Stroop task, and grasping errors. These results are not reported in Chapters 3 or 4, because as mentioned in those chapters, running hundred of correlation analyses are not the best statistical measure of my hypothesis.

The singular appearance of hand-preference as a predictor of social competence when using *linear regression models* is a notable result for multiple reasons. First, there are no studies that I am aware of that directly connect right-hand preference to social skills. Previous studies have linked greater right-hand preference to better language and executive function [63, 24, 66, 110, 113, 114, 169]. These studies suggest that the shared lateralization (all functions are shown to have greater activation in the left hemisphere [123, 48] and proximity of neural structures are an explanation for the connection [64, 13]. This brings up a second point of interest; social skills are not well established as being a left later-

alized function. If anything, there is evidence to suggest that social competence is more lateralized to the right hemisphere [51, 123]. Since common lateralization cannot be the reason or explanation for the relationship between hand preference and social competence, then why was there a strong connection in the results of this thesis? Though arguably untestable, an interesting possibility is that the connection between right-hand preference and social competence is a remnant of the evolutionary connection between gestural and vocal communication. This idea incorporates the hand to mouth theory shared in Chapter 1. Corballis proposed that manual gestures laid the ground for the necessary neural changes which enabled a switch to speech [33]. In non-human primates, there is evidence that social communication is lateralized to the left hemisphere [46]. This lateralization could be why right-hand motor control is still strongly related to social competence in the current thesis.

5.3 Social Competence is Key

During the 1990's the term "executive function" transitioned from rarely appearing in the literature, to front and center in the field of child development and education [42, 67]. There is extensive research that connects executive function to all the domains in this thesis. Social competence, meanwhile, has maintained a much lower profile, based on google book-reference search [67]. The research that connects social competence to these domains is notably less well-established with fewer publications on this topic A. However, in this thesis, social competence appeared as a significant predictor for all cognitive behaviours. Given the abundance of research on executive function and the other domains (fine motor skills, language, social competence), it was unexpected that executive function did not also appear as a predictor in more regression analyses (only in two out of the five regressions detailed in this thesis). Vocabulary was a predictor in slightly more measures compared to executive function (in three out of the five regressions). Together, these results suggest that despite the established literature on executive function, social competence may "play" an equally significant role in the overall development of a preschool child. However, to my

knowledge, it is only executive function that is touted as a predictor of lifelong success, life expectancy, and even lowering the risk of incarceration [120, 130, 4]. It is possible that social competence could prove to be just as effective at predicting lifelong outcomes if that research were conducted. Based on my thesis results, more research needs to focus on the role of social competence in early development. It may prove to be an invaluable tool for assessment and interventions for children who experience delays in any area of development.

5.4 Direct Versus Proxy Measures: Beyond Lateralization

Both a strength and limitation of this thesis is the range of assessments used, including direct and proxy measures. To understand which early skills are related, there is value in selecting multiple measures from a single cohort. Hence, the collection of measures used in this thesis are a strength and situate it as a novel exploration into language, hand preference, fine motor skills, executive function, and social competence. A limitation of the experimental design is the multitude of variables, which when combined with missing data, resulted in simple yet intricate statistical analyses and interpretation of the results. Data was collected during the COVID-19 pandemic, which contributed to the issue of incomplete samples. Future studies should use comprehensive assessments, but also should consider including larger sample sizes to accommodate the many variables and rates of attrition.

Studies conducted with larger sample sizes would advance understanding of a secondary issue raised in this thesis, which is the certainty that a test is measuring the desired skill (i.e., internal validity). This can be thought of in two different contexts. First, does the direct assessment score strongly correlate to the proxy measure of the same skill (e.g. does BRIEF-P score correlate with the DCCS task, grasping errors or Stroop score)? Repeated testing and use of both direct and proxy measures may eventually establish the validity of certain behavioural tasks and answer this question. Second, can an direct measure of behaviour assess a singular skill (e.g. social play task requires inhibition and emotional regulation,

which are both executive functions)? This question is difficult to tackle, it would require researchers to develop new tasks that truly isolate functions, but ideally maintain ecological validity. Potential measures of executive function could include planning/discussing how to categorize items and switching categories of objects (ex. is a lion something you find in your bedroom versus something you find in a zoo) but without physical sorting them. Potential social competence measures could include less structured and more naturalistic observations [139]. A necessity for research on early childhood development is to start considering multisensory integration and how it impacts these complex cognitive functions and observe those interactions through tasks with both high ecological validity but still viable reproducibility [68]. This is a lofty goal that will take years of concerted research to better establish and understand the role that the tasks used in these "early" experimental studies have on assessing child development.

Further research in general is needed to understand the real-life translation of performance from both direct, artificial tasks and proxy measures. If a child performed below-average on the social play task (and is more likely to have a lower vocabulary score and worse speech production), how does that translate to their ability to build relationships and show pro-social behaviour in their kindergarten classroom? Future studies can attempt to answer these questions by continuing to use standardized parent questionnaires (proxy measures) alongside these more objective tools in longitudinal designs to understand the impact and outcome of a lower score.

5.5 Less-Typical Lateralization

The studies conducted as part of this thesis did not have recruitment criteria besides age; children needed to be between 3-5 years of age at the time of testing. All children were invited to participate in the study, and only a few children were excluded from the results due to diagnosed atypical development (cognitive delay/disorder). As a result, the studies included five left-handed children, and an additional six with weak manual preference based

on parent questionnaires, behavioural measures, or both. Of the eleven children in this category, seven were also noted to have abnormal scores on the parent questionnaires suggesting below-norm executive function and/or social competence. This is a much higher rate compared to children who had a strong right-hand preference (64% versus 11%). Besides noting the higher rate of scores below the norm, the children with a left-hand preference/no preference were included in all the analyses detailed in this thesis. Earlier exploratory analyses were completed with a binomial factor (right-handed/not-right handed) that did not yield different results. The reported regression analyses were conducted with and without the group of not-right handed children, and the results remained largely unchanged- only one regression lost a significant predictor (social play score was no longer a predictor of vocabulary size). It is difficult to know if that change was due to a loss of statistical power, or if those few regressions are indicative that it is a disadvantage to have other than a strong right-hand preference. Based on the discussion above, more research is needed both in strongly lateralized and weakly lateralized children to understand how much it affects outcomes like social competence. There is a body of evidence that suggests that humans (and other animals) at the extreme ends of the lateralization spectrum may begin to show maladaptive behaviours [131], or perform worse in cognitive tasks [76, 116]. Of course, this idea is controversial [72]. To tackle this issue, researchers should be encouraged to include a diverse population of children (aka, not only normally developing children nor only right-handed children). This combined with neuroimaging techniques to measure hemispheric lateralization more precisely could provide a clearer answer to the question of what it means to have a lateralized brain.

5.6 Sex Differences

The number of females and males included in this study was relatively even. As noted through Chapters 2-4, sex was included as a potential factor in the conducted regression analyses, but was never significant. Although not reported in the chapters, t-tests were also

conducted, and I found no instances of significant differences in performance based on sex. In previous studies, it is an ongoing controversy whether or not young females have better vocabulary [139, 93], executive function [36, 81, 170], and social competence [139, 151]. Many studies include sex as a variable, and inconsistently find differences in performance of the skills measured here [109, 70, 163]. It is important to continue to consider sex as a factor and continue to challenge if there are in fact sex differences, or if these differences are because of biases from the assessments used, and/or the parents/teachers completing the assessments [109].

5.7 Future Directions

An ideal follow-up to this thesis would be to conduct a longitudinal study using similar measures, to account for both standardized performance and provide ecologically valid tasks. This study would have a large enough sample size to allow for structural equation modelling so that in addition to understanding relationships, directionality of development could be established. A larger sample size would also afford the luxury of examining the subset of children who present as not right-handed or atypical in other measures of development. For example, children with autism often present with impaired social development (American psychiatric association, [9]; [125]), but can still excel in other domains, such as vocabulary size [12, 133]. However, there are also instances of children with autism who both struggle with social competence and language [12]. Autism is also one of many disorders associated with significantly higher incidences of non-right-hand preference [89]. This example shows how atypically developing children can offer important insight into relationships between development of complex cognitive skills and sensorimotor abilities like hand preference.

5.8 Conclusion

To my knowledge, hand preference in preschool children has never been collected alongside multiple assessments of the four areas of development reported in this thesis (language, fine motor skills, executive function, and social competence). Previous studies have found that hand preference predicts performance in measures that are related to communication, such as vocabulary, speech, and executive function, when hand preference is measured and compared to one other behavioural assessment or questionnaire. The main contributions of this thesis all relate to better understanding the role of manual lateralization, and the relationship between central domains of development during the preschool years. First, I established a connection between right-hand use during a vocabulary test and performance - using the right hand increases the likelihood that a child selects the correct answer. Second, I provided novel evidence that when hand preference is measured and compared to a wide range of skills in a single cohort, it is predictive of social competence, but not any of the other complex cognitive skills. This could be related to the evolutionary development from gestural communication to vocal communication, which occurred alongside dramatic increases in social capacity and brain structure in hominids. A final contribution of this thesis is further evidence that complex cognitive functions are tightly connected. Importantly, social competence was identified as the strongest predictor of all other cognitive functions. Future research should extend these findings by including both direct and proxy measures in comprehensive studies to best understand the nature of cognitive development in young children.

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Appendix A

Studies on Hand Preference and Language in Children

List of studies cited in this thesis on hand preference and language. It is noted whether the study relied on measures that were objective (O), subjective (S), both (B), or if it was a review article (R). Also detailed are the ages of the participants, and the measures used for each study. This is not an exhaustive list, but a simplified breakdown of the literature review.

Study	O	S	B	Age Range	Measurements Used
Cochet et al., 2011	O	S		Longitudinal; 13-17 months	Play elicited gesture/pointing, MacArthur Communicative Development Inventory
Gonzalez et al., 2014	O			4-5 & 8-9 years old	Speech production (word repetition) task and RH use for grasp-to-eat task
S.L. Gonzalez et al., 2020	O	S		Longitudinal; Monthly 18-24 months, again at 5 years old	Preschool language scales (PLS-5) receptive and expressive language; role-differentiated bimanual manipulation task
Mumford & Kita, 2016	O	S		10 months old	Oxford Communicative Development Inventory Questionnaire; Pointing and grasping elicitation task
Nelson et al., 2014	O	S		Longitudinal; 6-14 months old and 18-24 months old	Bayley Scales of Infant and Toddler Development, Object grasp task, Role Differentiated Bimanual Manipulation Task

Study	O	S	B	Age Range	Measurements Used
Nelson et al., 2017	O	S		Longitudinal; Monthly 18-24 months, again at 3 years old	Preschool language scales (PLS-5) and role-differentiated bimanual manipulation task
Nicoladis et al., 2021	O	S		Longitudinal; 9-,12-18-months of age	MacArthur Bates Communicative Inventory: Words and Gestures, Play session with caregiver
Vauclair & Cochet, 2013	O	S		Longitudinal; 12-30 months	Brunet-Lezine scale (comprehension and production); pointing to images in book (like, but different from language test)
Van Rootselaar et al., 2021 [Chapter 2]	O			3-6 years old	PPVT, right hand use for pointing during PPVT

Appendix B

Study on Hand Preference and Fine Motor Skills in Children

The study cited in this thesis on hand preference and fine motor skills. It is noted whether the study relied on measures that were objective (O), subjective (S), both (B), or if it was a review article (R). Also detailed are the ages of the participants, and the measures used for each study. This is not an exhaustive list, but a simplified breakdown of the literature review.

Motor Skills	**O**	**S**	**B**	**Age Range**	**Measurements Used**
Bondi et al. 2020	O			6-11 years old	Various motor actions with left and right hands

Appendix C

Studies on Hand Preference and Executive Function in Children

The study cited in this thesis on hand preference and executive function. It is noted whether the study relied on measures that were objective (O), subjective (S), both (B), or if it was a review article (R). Also detailed are the ages of the participants, and the measures used for each study. This is not an exhaustive list, but a simplified breakdown of the literature review.

Executive Function	**O**	**S**	**B**	**Age Range**	**Measurements Used**
Gonzalez et al., 2014.	O	S		5-6, 9-10 years old	RH use for grasp-to-construct and grasp-to-place; BRIEF questionnaire

Appendix D

Studies on Language and Fine Motor Skills in Children

Studies on Language and Fine Motor Skills in Children List of studies cited in this thesis on language and fine motor skills. It is noted whether the study relied on measures that were objective (O), subjective (S), both (B), or if it was a review article (R). Also detailed are the ages of the participants, and the measures used for each study. This is not an exhaustive list, but a simplified breakdown of the literature review.

Study	O	S	B	Age Range	Measurements Used
S.L. Gonzalez et al., 2019	O	S		Longitudinal; multiple hand preference assessments for 18-24 months, and revisit at 5 years old	Role-differentiated bimanual manipulation task, Preschool Language Scales-5
Suggate & Stoeger, 2014	O			3-5 years old	Peg board task, bead threading, block turning, PPVT-IV, Body-object interaction vocabulary
Suggate & Stoeger, 2017	O			3-5 years old	Bead thread task, coin slot task, Movement ABC Task, Wechsler Preschool and Primary Scale of Intelligence

Appendix E

Studies on Executive Function and Fine Motor Skills in Children

List of studies cited in this thesis on executive function and fine motor skills. It is noted whether the study relied on measures that were objective (O), subjective (S), both (B), or if it was a review article (R). Also detailed are the ages of the participants, and the measures used for each study. This is not an exhaustive list, but a simplified breakdown of the literature review.

Study	**O**	**S**	**B**	**Age Range**	**Measurements Used**
McClelland & Cameron (2019)	R	R	R	Review of studies comparing both skills in preschool and school aged children	Wide range of measures. Also discusses issue associated with many measures.
Van Der Veer et al., (2020)		S	B	3-5 years old	Movement Assessment Battery for Children; BRIEF-P and Day/Night, Hand Tapping, Forward Corsi Block, Forward Digit Recall
Van der Fels et al., 2015	R	R	R	4-16 years old	Compared studies with various cognitive measures and motor control measures. Conflicting evidence for fine motor skills and EF

Appendix F

Studies on Social Competence and Fine Motor Skills in Children

A study cited in this thesis on social competence and fine motor skills. It is noted whether the study relied on measures that were objective (O), subjective (S), both (B), or if it was a review article (R). Also detailed are the ages of the participants, and the measures used for each study. This is not an exhaustive list, but a simplified breakdown of the literature review.

Study	**O**	**S**	**B**	**Age Range**	**Measurements Used**
Salaj & Masnjak, 2022		S		5-6 years old	Test of Gross Motor Development, ASQ:SE

Appendix G

Studies on Language and Executive Function in Children

List of studies cited in this thesis on language and executive function. It is noted whether the study relied on measures that were objective (O), subjective (S), both (B), or if it was a review article (R). Also detailed are the ages of the participants, and the measures used for each study. This is not an exhaustive list, but a simplified breakdown of the literature review.

Study	**O**	**S**	**B**	**Age Range**	**Measurements Used**
Bruce & Bell, 2022	R	R	R	Review of preschool aged children	Discusses the issues associated with the wide range of measures, and the longitudinal relationship between language and EF
Carlson & Moses, 2001	O			Longitudinal 3-4 years old	PPVT-R, Day/Night, DCCS, Grass/Snow, Tower Building, Motor Sequencing, Deceptive Pointing, Whisper, Location false belief, Bear/dragon, spatial conflict, Kansas Reflection Impulsivity Scale for Preschoolers

Study	O	S	B	Age Range	Measurements Used
Gray et al., 2022			B	7-8 years old	Goldman Fristoe Test of Articulation, Kauffman Assessment Battery for Children, Test of Word Reading Efficiency, Clinical Evaluation of Language Fundamentals, Expressive Vocabulary Test, Woodcock Reading Mastery Test, Passage Comprehension test, Working Memory Comprehensive Assessment Battery for Children, Digit Span, Location Span, Visual Span, N-back auditory test
Kuhn et al., 2016			B	Longitudinal Main Assessments at 36-, 48-, and 60-months of age	Bayley Scales of Infant Development, Woodcock-Johnson III Test of Achievement, Child-Caregiver Picture Book activity (Mean Length of Utterance & Number of Differentiated Word Roots); Working Memory Span, Pick the Picture, Spatial Conflict Arrows, Silly Sound Stroop, Something's the Same, Animal Go/No-Go
Miller & Marcovitch, 2015	O		B	Longitudinal 14-18 months old	A not B task, book presentation task, forbidden toy task, object spectacle task, imitation sorting task, gaze following task, three boxes task, MacArthur-Bates CDI questionnaire
Netelenbos et al., 2018	O	S		4-6 years old	BRIEF-P, speech word repetition task

Study	O	S	B	Age Range	Measurements Used
Pérez-Pereira et al., 2020	O		B	Longitudinal 4-5 years old, preterm and full term	Childhood executive functioning Inventory questionnaire, Clinical Evaluation of Language Fundamentals, PPVT-III, Test of Comprehension of Grammatical Structure (Spanish-CEG), Phonological Awareness
Ramsook et al., 2020	O	S		Longitudinal 4- and 5-years old	Expressive One-Word Picture Vocabulary Test, Social Communication Scale, Backwards Digit Span, DCCS, and math and learning
Slot & von Suchodoletz, 2018	O	S		Longitudinal 3-5 years old	PPVT, Heidelberger Language Development Test (HSET), Pencil Tapping task, Dimensional Card Change Sort, Forward Digit Span and Copy Hand Movement
Shokrkon & Nicoladis, 2022	R	R	R	Preschoolers	Clear relationship between executive function and language, but no clear direction

Appendix H

Studies on Language and Social Competence in Children

List of studies cited in this thesis on language and fine motor skills. It is noted whether the study relied on measures that were objective (O), subjective (S), both (B), or if it was a review article (R). Also detailed are the ages of the participants, and the measures used for each study. This is not an exhaustive list, but a simplified breakdown of the literature review.

Study	O	S	B	Age Range	Measurements Used
Gertner et al., 1994		O	B	3-6 years old, grouped into ESL, language delay, and mono-lingual typically developing	PPVT-R, Reynell Developmental Language Scales, Goldman-Fristoe Test of Articulation, Spontaneous speech (MLU); Peer Rejection/Acceptance interview
Longobardi et al., 2016		S		18-35 months old	Language Development Survey, Questionnaire on Peer Interactions in the Kindergarten

Study	O	S	B	Age Range	Measurements Used
Pakarinen et al., 2018	O	S		6 years old	Mulitsource Assessment of Social Competence Scale, PPVT-R, Letter knowledge, Phoneme Identification
Rice et al., 1991	O		B	3-5 years old	PPVT, Reynell Developmental Language Scales, Goldman-Fristoe Test of Articulation, Spontaneous speech (MLU); Peer Rejection/Acceptance interview
Slot et al., 2020		S		Longitudinal 18-36 months old; 2 assessments	Variation of MacArthur-Bates Communicative Development, (Measures of numeracy)
Van der Wilt et al., 2016	O	S		4-6 years old; found a relationship only in males	Nijmegen Test for Pragmatics, communicative functions, and conversation skills; Peer Rejection interview.

Appendix I

Studies on Executive Function and Social Competence in Children

List of studies cited in this thesis on executive function and social competence. It is noted whether the study relied on measures that were objective (O), subjective (S), both (B), or if it was a review article (R). Also detailed are the ages of the participants, and the measures used for each study. This is not an exhaustive list, but a simplified breakdown of the literature review

Study	**O**	**S**	**B**	**Age Range**	**Measurements Used**
Alduncin et al., 2014		S	B	3-5 years old, Pre-term and full-term groups	Day/Night, Bird/Dragon, DCCS, Verbal Fluency task; BRIEF-P Vineland-II and Social Competence and Behavioural Evaluation short form
Benavides-Nieto et al., 2017		S		5 years old	Observation in Early Childhood Education scale, Preschool and Kindergarten Behaviour Scale for Teachers and Caregivers
Caporaso et al., 2019	O			4-5 years old	Challenging Situations Task, Happy/Sad Stroop, Visual Counting Span, DCCS (Borders)
Hala et al., 2010	R	R	R	Review-many different ages	Features several research groups and methods used to understand relationship between executive function and social competence

Study	O	S	B	Age Range	Measurements Used
Mann et al., 2017		S	B	3-5 years old	Forward Digit Span, Picture Deletion Task for Preschoolers, Day/Night, Mischel's Delay of Gratification, Woodcock-Johnson III Test of Achievement, Scenarios for children
Riggs et al., 2006	R	R	R	Review-preschool and school age	Discuss wide range of measures, and the possible type of relationship between executive function and social competence.
Romero-Lopez et al., 2020		S		5-6 years old	BRIEF-P; Preschool and Kindergarten Behaviour Scale, Behavior Assessment System for Children and Adolescents

Appendix J

Studies on Triads of Skills in Children

List of studies cited in this thesis on triads of dimensions. It is noted whether the study relied on measures that were objective (O), subjective (S), both (B), or if it was a review article (R). Also detailed are the ages of the participants, and the measures used for each study. This is not an exhaustive list, but a simplified breakdown of the literature review.

Study	**O**	**S**	**B**	**Age Range**	**Measurements Used**
Alcock & Krawczyk, 2010			B	18-24 months old; Accounted for manual and oral motor skills, language, and had a cognitive measure	Gesture naming, gesture imitation, gesture memory, oral motor single movement imitation, speeded movements, Bayley Scales of Infant Development, Oxford CDI, MacArthur-Bates CDI, ASQ, Cognitive Questionnaire, SES screening
Gibb et al., 2021		S	B	3-5 years old; accounted for executive function, language, fine motor and gross motor, and social emotional skills	BRIEF-P, ASQ, ASQ:SE; block errors, block building time, Grass/Snow, PPVT

Study	O	S	B	Age Range	Measurements Used
Kuhn et al., 2014			B	Longitudinal 15 months and 36 months (Gesture, language, and executive function)	Picture Book Activity, Communicative Gesture Parent Checklist, Preschool Language Scale, Three Boxes Task, Snack Delay Task, Working Memory Span, Pick the Picture, Saptial Conflict Arrows, Silly Sound Stroop, Something's the Same, Animal Go/No-Go
Slot et al., 2020	O	S		Longitudinal 18- 36 months old	MacArthur-Bates Communicative Development Inventory (vocab and language), Socio-Emotional Assessment/Eval Measure (SEAM); Teacher developed questionnaire on numeracy awareness
Suggate et al., 2017	O	S		3-5 years old No relationship	Motor activity questionnaire, Movement ABC Task, Wechsler Preschool and Primary Scale of Intelligence
Teepe et al., 2017	O	S		2-4 years old	PPVT, Verbal working memory task, Hand game, DCCS, Dutch KIJK! Questionnaire
Van Rootselaar et al., submitted	O	S	B	3-5 years old	PPVT, BRIEF-P Questionnaire, SRS Questionnaire, ASQ:SE Questionnaire, Block Building Task, DCCS