Language and Literacy Development as Revealed Through the Bilingual Brain

by

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Abstract

Reading is a dynamic process that varies as a function of environmental and cognitive factors. This dissertation study asked, h*ow does bilingualism influence literacy acquisition, within and across children's two languages, and through brain development?* To answer these questions, the dissertation focuses on theoretical frameworks that suggests early-life bilingual experiences influence the concomitant neural architecture underlying language and cognition. Through two separate studies, I explore the relationship between bilingual children's dual-language experiences, neural organization for spoken language comprehension, and literacy development in 132 Spanish-English bilingual children ages 7-12. The design and method of the dissertation includes functional Near-Infrared Spectroscopy (fNIRS) neuroimaging during two language comprehension tasks, as well as, behavioral language and cognitive assessments in both languages. In the first study, I found that bilingual children's language and literacy skills fall within a continuum of shared and unique abilities across languages, and that reading in one language supports reading in another, at the word- and passage- level. In the second study, I found that bilinguals who are equally proficient in both languages show more neural responses to tasks of language comprehension, and this makes a contribution to children's literacy skills. Findings show how variations in child experiences influences neural organization for language and literacy. This interdisciplinary approach has the potential to yield exciting insights into the brain and behavior of the developing child and carries theoretical implications for understanding acquisition in typical development and in language disorders, across different populations of learners.

Chapter I

Introduction

Learning to read is not only an important milestone of early childhood development, but fluent reading and comprehension skills are essential for success in the modern world. Yet, many young learners fail to meet the U.S. national standards in reading achievement and young bilingual learners are disproportionately represented in this low-achieving group (U.S. Department of Education, 2016). Given the rapid growth of language diversity across the country, appreciation for bilingualism as a common early life experience is as important as ever. In this dissertation, I address the following overarching questions: *how does bilingualism influence literacy acquisition, within and across children's two languages? How does bilingualism influence the brain organization for processing language?*

The dissertation builds upon the field's findings that child language ability is foundational for learning to read. Thus, a critical component of the dissertation is building the link between the development of children's spoken language comprehension and reading comprehension, in bilingual development. Literacy acquisition is dependent on children's abilities to understand and manipulate the sounds in spoken words (phonological awareness), understand the meaning of words (semantics), and translate words or units into orthographic representations (word decoding; Perfetti & Hart 2002; Perfetti, Liu, & Tan, 2005). Reading acquisition is further facilitated by changes of the developing brain, such as the emergence of the neurocognitive pathways that support literacy skills (Perfetti et al., 2006, 2007; Pugh et al., 2001). By considering the diversity of bilingual experiences and proficiencies in each language, we can ask key developmental questions of how early childhood experience with two language systems has the potential to impact learning outcomes within and across the two languages.

Theoretical perspectives on bilingualism

Theoretical behavioral perspectives on child bilingualism has long debated critical questions asking to what degree, in what domains, and at what point in development are children's language knowledge independent or interdependent. Research has shown that bilinguals' two languages are always active and interact behaviorally, and in the brain (Kroll Dussias, Bice, & Perrotti, 2015). Yet, the nature of these interactions in literacy development are not as well understood. Two theoretical frameworks are prominent in understanding cross-linguistic interactions in bilingual development (Genesee, Geva, Dressler, & Kamil, 2006). Theoretically, understanding cross-linguistic influence will help us to grasp the nature of bilingualism and how learning two (or more) languages deviates from learning only one. Practically, it can inform pedagogy and educational interventions both bilingual and monolingual literacy development.

The *linguistic Interdependence Hypothesis* (Cummins, 1979; 1991) posits that a core of skills is common to both languages such that learning in one language can advance learning in the other. Support for this hypothesis has been shown in the development of various aspects of language and literacy skills in bilingual children (e.g. Gottardo & Mueller, 2009; Lesaux et al., 2010; Melby-Lervag & Lervag (2011, 2014); Oller & Eilers, 2002; Proctor, August, Snow, Barr, 2010; Proctor, Harring, & Silverman, 2017), including a recent longitudinal study by Leider, Proctor, & Silverman (2018) on the role of immigrant generation status as a moderator for linguistic interdependence.

The *Contrastive Analysis Hypothesis* (Connor, 1996; Ellis, 1994; Lado, 1957; Odlin, 1989) posits that the cross-linguistic transfer of specific skills depends on the structural similarities of the two languages. Further, acquisition of one language may benefit from the knowledge of the other or learning of one may impede learning of the other (Costa & Sebastián-Gallés, 2014). Bilingual acquisition of two languages can vary across the different domains of linguistic processing (Bialytok, Craik, Luk, 2012; Genessee, 2001). For example, bilinguals' phoneme boundaries (e.g. a shift in the phoneme space) differ from that of monolinguals, as a consequence of using two languages. This is not to say that bilinguals cannot have two phonological repertoires, one for each language (Garcia-Sierra et al., 2012). Spanish and English share many structural features (e.g. common orthography, phonology) that support a positive cross-linguistic transfer of word-reading skills (Bialystok, Luk, & Kwan, 2005). While shared alphabetic knowledge may help young Spanish-English readers decode words in English (*avocado)* and Spanish (*abogado*), the mapping of printed words to specific word meanings often vary given a language (avocado = fruit, abogado = attorney/lawyer). Similarly, children's lexical and syntactic properties in one language may juxtapose the lexical and syntactic properties of the other (e.g. Runnqvist, Gollan, Costa, & Ferreira, 2013; Proctor et al., 2010; Geva & Siegel, 2000). In Chapter 2 of this dissertation, I investigate to what degree language and literacy skills relate to support bilingual children's reading comprehension, an area of literacy less explored in bilingual development.

Sociocultural factors and heritage language use in the home

Sociocultural environment surrounding multiple language use plays a major role in bilingual acquisition (McCardle & Hoff, 2006). However, the mediating roles of these factors in bilingual child reading comprehension have been generally unexplored. Effects of parental socioeconomic status (SES) on children's language development are strongly associated with the quantity and quality of linguistic input in the home (Oller & Eilers, 2002; Pace et al., 2017; Schwab & Lew-Williams 2016). Parents from more advantaged backgrounds tend to talk more with their children and use more complex and responsive language (e.g. extensive vocabulary, longer sentences, more complex grammar) compared to parents from less advantaged backgrounds (Hart & Risley, 1995). Quality of language use in the home is a strong predictor of children's language skills (Merz et al., 2015; Pace et al., 2017; Ramirez-Esparza et al., 2014).

Research has demonstrated that children from homes in which a language other than English is primarily spoken and children who come from low SES backgrounds have different language trajectories than their middle-class monolingual peers (e.g., Brooks-Gunn, Rouse, & McLanahan, 2007; Hernandez, Denton, & Macartney, 2007; Hoff, 2013). Given that language minority status is confounded with SES in the U.S., it is hard to tease apart the effects of language minority status on children's reading and academic development. Examining the associations among socioeconomic background, home language use, and children's reading skills may shed some light on the effects of dual-language exposure on trajectories of English language development in children from language minority homes. In addition to parental socioeconomic status, this dissertation takes into account bilingual language use, specifically children's heritage language use, as a key contextual factor influencing childhood bilingualism and literacy development (Pearson, 2007).

Heritage language (a language other than English, linked with a speaker's ethnic and cultural background; Valdés, 2001) fluency is not only a necessity for verbal communication within family structures, but it is an essential socialization component of children growing up in immigrant or non-English speaking homes. Children of bilingual and bi-cultural backgrounds, especially children from immigrant families, face challenges of adaptation in both their culture of origins and culture of the new country. Importantly, their native language use and proficiency is a critical aspect of how bilingual children develop a sense of identity and belonging (Phinney & Ong, 2007; Rivas-Drake et al., 2014; Umaña-Taylor et al., 2014), and associate with particular ethnic group(s) within the larger society (Phinney, Romero, Nava, & Huang, 2001). Immigrant parents often rely on heritage language use to teach their children about social norms and attitudes of their culture (Pearson, 2007). Critically, children's heritage language fluency is associated with children's ethnic identity (Arredondo, Rosado, & Satterfield, 2016; Kim & Chao, 2009), overall positive relationship with parents (Phinney et al., 2001; Oh & Fuligni, 2010), school effort and future educational, and occupational aspirations (Kim & Chao, 2009).

Thus, the use of the heritage language has a positive effect on many developmental outcomes, including the growth of reading in a second language. Children's early experiences with books in their heritage language have been shown to predict reading comprehension skills in a second language in early elementary grades (Goldenberg, Reese, & Rezaei, 2011). However, as children get older and enter school, children become increasingly dominant in the community language (Najafi, 2011) this leading to considerable variation in their proficiency levels attained in each of their languages. How does every day bilingual language use influence children's literacy development? In Chapter 2 of this dissertation, I investigate to what degree language experiences in the home support children's developing reading skills.

Neurocognitive processes in the bilingual brain

How does bilingual exposure influence children's neural organization for language, a core component of successful reading acquisition? Theoretical neurocognitive perspectives suggest that structural and functional brain development arises as a result of complex interactions between neurobiology and individual experiences (*interactive specialization hypotheses*; Johnson, 2011). *Neuroemergentism*, a new theoretical framework, posits that bilingual experiences also influence the neural specialization for language (Hernandez et al., 2019). Specialization for language in early development is often characterized by increasingly left-lateralized and localized activations that lead to a more coordinated network of regions involved (Price, 2012; Dehaene-Lambertz et al., 2006; Werker & Hensch, 2015).

For example, learning to read is a dynamic process that directly influences brain development as a function of varied environmental and cognitive factors. Word reading requires one to recognize word sound and meaning in print. Stronger neural specificity for word sounds (phonology) includes stronger activation in left superior temporal gyrus (STG) than in middle temporal gyrus (MTG), and vice-versa for meaning (lexical morphology; Weiss, Cweigenberg, & Booth, 2018). Further, reading comprehension requires one to recognize sentence structure and meaning in print. Stronger neural specificity for sentence structure (syntax) includes stronger activation in left dorsal inferior frontal gyrus (dIFG/BA 44) than ventral IFG (vIFG/BA 47), and vice-versa for sentence meaning (semantics; Hagoort & Indefrey, 2014). In Chapter 3 of this dissertation, I will extend this line of work to examine how bilingual proficiencies influence the brain specialization for spoken language comprehension in relation to children's developing literacy skills.

Specific Aims & Hypotheses

In this dissertation, I assess the behavioral and neural processes underlying emergent literacy skills in early-exposed Spanish-English bilingual children (ages 7-12) and investigate how the functional organization of the bilingual developing brain is shaped by bilingual languages experiences and proficiencies. The design and method of the dissertation includes functional Near-Infrared Spectroscopy (fNIRS) neuroimaging during two language comprehension tasks, as well as, an extensive battery of behavioral language and cognitive assessments in both languages.

In Chapter 2, I begin by examining the varying nature of dual-language experiences (i.e. language use) and proficiencies in Spanish-English bilingual children in relation to children's reading comprehension outcomes in each language. To test how Spanish and English language and literacy variables are related, I first run an exploratory factor analyses of the relevant underlying constructs (e.g. phonological awareness, word reading, and spoken language proficiency) using variables measured in Spanish and English. I then use structural equation modeling (SEM) to test pathways between children's bilingual experiences, language proficiencies, and reading comprehension outcomes. In Chapter 3, I examine children's brain activity during two experimental paradigms of English auditory sentence processing, tapping into semantic and morphosyntactic knowledge. I then examine the associations between children's bilingual language proficiencies, brain activity underlying spoken language comprehension, and English reading comprehension.

<u>Aim 1 (Study 1)</u>: *To uncover the impact of bilingual experiences on children's reading comprehension.* An important methodological component of Aim 1 is the operationalization and

measurement of children's daily language use in the home, specifically children's Spanish language use. Previous research has shown that higher SES is associated with higher quantity and quality of language use, which in turn relates to stronger language and reading skills (e.g. Pace et al., 2017; Hart & Risley, 1995; Romeo et al., 2018). Similarly, greater bilingual language use in the home may also provide an enriched linguistic environment in support of children's developing literacy skills (Paradis, Emmerzael, & Sorenson Duncan, 2010). Research has shown that time and opportunity to hear and use each of their languages impact the performance of bilingual learners (Bedore, Peña, Joyner & Macken, 2011; Gutiérrez-Clellen & Kreiter, 2003; Paradis et al., 2010). This evidence leads us to predict that bilingual children's experiences in English will yield better English reading proficiency (independence), and, more balanced bilingual experiences will also yield better English proficiency (interdependence).

Aim 2 (Study 1): To uncover language-specific and shared aspects of literacy in the bilingual learner. Words are comprised of meaning and sound. In learning to read, children must discover those units in print. Theoretical perspectives on dual language acquisition pose that bilinguals' two languages interact (Kroll et al., 2014). Here we ask, how does this interaction yield language-specific as well as language-shared knowledge to support emerging bilingual literacy. Two theoretical perspectives, the linguistic interdependence hypotheses (Cummins, 1979; Proctor et al., 2010) and contrastive analyses hypothesis (Connor, 1996; Ellis, 1994; Lado, 1957; Odlin, 1989), suggests that the sound-to-letter mapping skills would be strongly associated across the two languages. This association would be especially robust for speakers of two typologically-similar orthographies, such as Spanish and English (Bialystok, Luk, & Kwan, 2005; Proctor, Harring, and Silverman, 2017). This evidence leads us to predict that word decoding skills focused on recognizing sound in print, should be maximally shared or otherwise common across bilingual children's two languages.

Unlike sounds and alphabetic sound-to-letter correspondences, word meanings are more language specific (Proctor et al., 2010; Geva & Wang, 2001). The theoretical perspectives on bilingual language and literacy therefore pose that bilinguals' ability to understand print is linked to their proficiency with meaning (semantics) and structure (morphosyntax) of the given language (Melby-Lervag & Lervag, 2014). Prior review on the cross-linguistic transfer of spoken language comprehension, comprised of semantics and syntax knowledge, further suggest that there are only small associations between oral language skills in the child's two languages (Melby-Lervag & Lervag, 2011; 2014). This evidence leads us to predict that reading comprehension skills will be dependent upon children's language-specific semantic and morphosyntactic proficiency.

<u>Aim 3 (Study 2)</u>*: To examine the impact of bilingual proficiency on children's neural architecture for language.* Neurodevelopmental frameworks (e.g. Hernandez et al., 2019) suggest that children's bilingual language experiences and proficiencies influence the functional neural architecture supporting language processes. A developmental increase in language proficiency is often associated with an increase in left temporal and a decrease in left frontal activations (e.g. Liu & Cao, 2016). Yet, bilinguals tend to show heightened attention and sensitivity to linguistic input, which is associated with left IFG functionality (Arredondo et al., 2018; Jasinska et al., 2017; Kuo & Anderson, 2010; Petitto & Kovelman, 2003; Raizada et al., 2008). This evidence leads us to predict that bilingual children's experiences in English will yield greater activation in left temporal regions and reduced activation in left frontal regions as a

signature of more advanced proficiency and neural specificity for English. Critically, children with greater dual-language proficiency (i.e. balanced English and Spanish) should yield stronger left frontal activation during tasks of language comprehension.

Chapter II

Study 1. Reading Comprehension in Spanish-English Bilinguals

Given the rapid growth of language diversity within communities around the nation, it is becoming increasingly important to understand not only how young bilinguals learn to read in each of their languages, but also how aspects of dual-language knowledge contribute to literacy within and across languages (Hammer et al., 2014). Literacy acquisition is reliant on children's abilities to understand and manipulate the sounds in spoken words (phonological awareness), understand the meaning of words and sentences in language (semantics and grammar rules), and translate words or units into orthographic representations (word decoding; Perfetti & Hart 2002; Perfetti, Liu, & Tan, 2005). The goal of the present study is to examine these key antecedents of literacy in Spanish-English bilingual children and how they interact within and across the two languages to support the development of children's reading comprehension. Specifically, this dissertation study examines how Spanish language and literacy knowledge influences the development of English reading comprehension in a group of early-exposed Spanish-English bilingual children ages 7-12.

The ultimate goal of reading is the comprehension of text. Yet, there is limited understanding of literacy development in young bilinguals beyond single word reading (Melby-Lervag & Lervag, 2014). Previous work has shown that word-level reading skills develop along similar trajectories when comparing monolinguals to bilingual readers (Lesaux & Siegel, 2003; Lesaux, Koda, Siegel, & Shanahan, 2006) and across bilingual children's two languages (August & Shanahan, 2010; Durgunoglu, 2002; Lesaux et al., 2006). However, the findings on reading comprehension are quite different. Results consistently show that in comparison to their monolingual English-speaking peers, reading comprehension is an area of weakness for English language learners (ELLs; August, Carlo, Dessler, & Snow, 2005; August & Shanahan, 2010; Reese, Garnier, Gallimore, & Goldenberg, 2000). Across schools in the U.S., children of all language backgrounds are being assessed on English reading comprehension as a key benchmark for elementary literacy and academic success across school subjects (National Center for Education Statistics, 2017). In some states, this benchmark and can determine whether students may be retained a grade level based on sub-par reading scores or may even be at risk of being categorized as language impaired (Bedore & Pena, 2008; U.S. Department of Education, 2017). Thus, there is a critical social, developmental, and educational demand to better understand the effects of diverse language experiences on bilingual children's literacy development beyond single-word reading.

Two established theoretical models guide the current work on bilingual reading development. First, the Simple View of Reading model (SVR) posits a concise framework describing the processes and skills involved when readers comprehend texts (Gough & Tunmer, 1986; Hoover & Gough, 1990). On the simple view, reading comprehension consists of word decoding (letter-to-sound mapping) and linguistic comprehension (often measured as a combination of vocabulary and listening comprehension skills; Melby-Lervag & Lervag, 2014). Several studies have tested the utility of the SVR model in Spanish-English bilinguals and found consistent within-language results linking English linguistic comprehension and word decoding skills to English reading comprehension (e.g. Gottardo & Muller, 2009; Lesaux et al., 2010; Proctor et al., 2006, 2005). Yet, only a small number of studies have empirically examined these components in Spanish and English togethernd modeled the cross-linguistic interactions that influence reading comprehension (Nakamoto, Lindsey, & Manis, 2008; Proctor et al., 2010). To test how Spanish and English variables interact to predict English reading comprehension, we turn to a second theoretical account that guides our understanding of bilingual language development (Genesee, Geva, Dressler, & Kamil, 2006).

The *linguistic interdependence hypothesis* of second language acquisition posits that children develop a certain underlying set of skills that is common to both languages such that learning in one language can facilitate learning in the other (Cummins, 1979, 1991). The strength of the cross-linguistic transference is dependent on the structural similarities of the two languages (e.g. when both languages are alphabetic or share many cognates) and the particular linguistic skill in question (e.g. grammar knowledge; see Genesee et al., 2006; MacSwan & Rolstad, 2005). Based on this account, Proctor et al. (2010) propose an interdependence framework where the cross-linguistic associations between specific language domains fall within a *continuum* (see continuum of "problem spaces" by Snow & Kim, 2006). Proctor and colleagues suggest that alphabetic and word-level knowledge inhabit a relatively small problem space while constructs such as language comprehension (e.g. meaning making) occupy larger spaces that require more intensive instruction and a broader range of knowledge for mastery of the domain. Additionally, cross-language transfer may stem from an implicit understanding of the underlying components of language and literacy and an awareness at the metacognitive/metalinguistic level of how languages are similar or different in certain aspects (Genesee, Lindholm-Leary, Saunders & Christian, 2006; Durgunoglu, 2002; 2017).

Bilingual acquisition is not only influenced by many factors at the individual level (e.g. age of bilingual exposure or years of exposure; Berens, Kovelman, & Petitto 2013; Goldenberg, 2008), but is also dependent on broader sociocultural factors (e.g. access to literacy, community support, family language use; Lesaux, Vukovic, Hertzman, & Siegel, 2007; Pearson, 2007). In many bilingual communities, children's primary language use at home differ from the language of instruction and language used to measure academic achievement in schools. A growing body of research continues to demonstrate that bilingual learners with well-developed first language and literacy skills are more likely to acquire their second language to higher levels (Dressler & Kamil, 2006; Genesee et al., 2006). Therefore, children's different home language should be viewed as a resource to be encouraged and used rather than as a barrier (Durgunoglu, 2017). To this end, children's bilingual language use outside of the school offers unique opportunities to use context dependent and independent language and foster critical thinking skills, such as being able to draw inferences and make meaning, thereby facilitating cross-language interdependence (Durgunoglu, 2017; Durgunoglu & Verhoeven, 2013; Uccelli et al., 2015).

This dissertation study expands on previous models of reading development by considering a few proximal and distal contextual variables known to be linked to language and literacy development. In the present study, I include a quantitative measure of children's language input and output in Spanish to assess the direct relations between children's home language experiences and the development of literacy skills in young bilinguals. Children's everyday bilingual language exposure and use is key to understanding the varying ways in which literacy skills develop. For example, previous work by Bohman and colleagues (2010) shows that in young Spanish-English bilinguals entering U.S. schools (increased exposure to English), children's language input in the home was a significant predictor of the development of semantic knowledge, while children's language output was important for performance in both semantic and morphosyntax domains, in both English and Spanish (Baron et al., 2018; Bedore et al., 2016). The authors discuss how using a language (i.e. output) forces the learner to process the language in a way that only hearing it (i.e. input) might not.

Indices of socioeconomic status (SES), such as parental education level and income have been described as distal variables that directly affect proximal language and literacy practices at home, such as amount and richness of language stimulation (Duncan & Brooks-Gunn, 2000; Hoff, 2003, 2006; Raviv, Kessenich, & Morrison, 2004), as well as, encouragement of bilingual competence (Pearson, 2007; Oller & Eilers, 2002). In monolingual and bilingual populations, SES is shown to significantly correlate with measures of literacy, including decoding, phonological awareness, and reading comprehension (Noble, Farah, & McCandliss, 2006).

In the present study, I aim to assess the nature of bilingual literacy acquisition by focusing on early-exposed Spanish-English bilingual children that vary in their dual-language experiences and proficiencies. Although the primary language of schooling is English for most, the bilingual sample studied here have exposure to written Spanish in the home or in afterschool programs and are primarily balanced in proficiency across the two languages. To effectively evaluate key associations in the development of bilingual literacy acquisition, I use structural equation modeling (SEM) to test within and cross-language effects of bilingual experiences and proficiencies on the development of English reading comprehension.

I first ran an exploratory factor analysis (EFA) to determine whether measures of Spanish and English language knowledge should be represented as single, cross-linguistic latent constructs or as separate, language-specific latent constructs in relation to reading comprehension. Previous work has demonstrated strong evidence for cross-linguistic transfer between phonological awareness and word decoding skills (Bialystok, Luk, & Kwan, 2005; Melby-Lervag & Lervag, 2011). Given that Spanish and English are alphabetic languages that share a common orthography, I predicted that measures of phonological awareness in Spanish and English will load together as one latent variable. Findings on the associations between spoken language measures largely show little to no evidence of cross-linguistic transfer in models of reading development (Melby-Lervag & Lervag, 2011). Based on previous literature (Gottardo & Muller, 2009; Lesaux et al., 2010) and the linguistic interdependence hypothesis (Cummins, 1979), I predicted that measures of spoken language comprehension, assessed using semantic and morphosyntax knowledge in each language, will load separately as language-specific latent variables.

I then tested how these latent constructs of language and literacy are directly and indirectly related to reading comprehension in both languages. I predicted that spoken language proficiency and word reading skills within each language would be significantly related to reading comprehension in that language (SVR model of reading, Hoover & Gough, 1990). Additionally, based on the findings from Proctor et al. (2010) showing support for the language interdependence continuum, I predicted that language knowledge and experience with reading in Spanish will significantly contribute to reading comprehension in English.

Method

Participants

132 Spanish-English speaking bilingual children participated in the study (69 females, age range = 6 years 8 months - 11 years, 8 months, $M(SD)_{age}$ = 8.75 (1.41), see Table 1).

Selection criteria for participants were the following: those who were receiving daily exposure to both languages, those who were first exposed to Spanish from birth and to English between birth and the age of five and have at least two continuous years of daily English exposure prior to participation. At least one parent was a native Spanish speaker and reported consistent use of Spanish at home with their child(ren). For all participants, English was the primary language of instruction at school while some participants (N = 13) received one to two hours of Spanish language and reading instruction at school. About one-third of the participants (N = 35) attended a Spanish heritage language-learning school once a week for 2-to-3hours, which included daily Spanish language and literacy homework. Twenty-five participants were born outside of the United States in a Spanish-speaking country. All participants were exposed to English before the age of five. All children had normal hearing, no known neurological conditions, or learning impairments.

Procedure

Prior to the lab visit, parents completed a 24-item questionnaire to determine the child's eligibility for participation (e.g. no developmental delays, etc.) and a language experience questionnaire detailing the child's daily use of each language within and outside of the home (see Measures for more detail). Questionnaires were completed over the phone with a native Spanish speaker, in the language of the caregiver's choice. During the lab visit, participants completed assessments of language and literacy in Spanish and in English (counterbalanced) with a native speaker of that language. Most assessment sessions were video or audio recorded with parent's permission for later coding and analysis. Families were recruited through advertisements in local communities within the greater southeast areas of Michigan and received monetary compensation and a small gift bag for participation.

Measures

Bilingual Language Experiences. To examine a child's everyday bilingual language experiences, parents competed the Bilingual Input Output Survey (BIOS; Peña, Gutierrez-

Clellen, Iglesias, Goldstein, & Bedore, 2014) describing the *quantity* of the child's home and school language use to the best of their ability. This questionnaire asked parents to detail a typical weekday and a typical weekend day of the child on an hour-by-hour basis, including the language(s) the child is exposed to in and outside of the home and the amount of input and output of each of the languages (e.g. how many hours approximately). Additionally, the questionnaire broadly tapped into the settings in which the child might be using one or more languages. For example, while watching television a child might be receiving input only in English, whereas during dinnertime, a child might be receiving input in Spanish and English and producing both Spanish and English. Considering the input and output in each language, the BIOS calculations result in an overall number of hours of use and a relative percentage of experience in each language for each child. Given that most bilingual participants are exposed to and use English the majority of the time (e.g. at school, at home with siblings, etc.), I used the approximate number of hours a child speaks Spanish in typical week as a key variable of interest and direct measure of heritage language experience.

Sociocultural Variables. To capture several components of parent and family sociodemographic variables, parents completed a 43-item questionnaire regarding the child's language and literacy environment (e.g. reading habits, number of books in the home), family socioeconomic information (e.g. parental educational, household income), and parental perceptions of economic and cultural socialization, including the John D. and Catherine T. MacArthur Foundation Research Network on Socioeconomic Status and Health questionnaire (retrieved from: www.macses.ucsf.edu) as related to subjective social status, educational attainment, and occupational status (see Appendix A).

Assessments of Language and Literacy

Assessments of language and literacy included three Woodcock-Johnson III Normative Update (Tests of Achievement, Woodcock, Mather, McGrew, & Schrank, 2001) and Batería III Woodcock-Muñoz Normative Update (Pruebas de Aprovechamiento, Woodcock & Muñoz - Sandoval, 2004.) subtests: *Sound Awareness (SA), Word Identification (ID), and Passage Comprehension (PC)* in English and Spanish, respectively. Basal and ceiling were established for each subtest and raw and standard scores (*M* = 100, *SD* = 15) are reported when appropriate.

Participants also completed two subtests of the Bilingual English Spanish Assessment – Middle Elementary (BESA-ME; experimental version of the BESA for an older age group, Peña et al., 2018): *Semantic Knowledge* and *Morphosyntax Knowledge*, in both languages. The BESA is an assessment normed specifically with Spanish-English bilinguals ages seven to twelve from varying regions in the United States (Peña, et al., 2018).

Phonological awareness, the ability to understand and manipulate the spoken units in a language, was measured using Woodcock *Sound Awareness (SA)*. Participants completed all four subtests of this assessments (48 items in English and 52 items in Spanish total) measuring phonological processes of Rhyming (e.g. "What rhymes with "*moon"?)*, Deletion (e.g. "Say *swimmer* without *–er"*), Substitution ("If you replace the word *sun* in *sunny* with *fun,* what word would it be?"), and Reversal (e.g. "If you say the sounds in the word *back (b-a-k),* and then say them backwards, what word would it be?"). Difficulty in the task ranged from phonemic to syllabic level sound discrimination and manipulation. Individual components SA in both languages were included as separate observed variables in the factor analyses.

Bilingual word reading skills. The ability to recognize and read words was measured using Woodcock *Word ID (WID)* in English and in Spanish (total of 76 items in each language). Participants were required to read single words aloud with correct pronunciation in one attempt and were explicitly given instructions to read the word as a whole and not letter-by-letter or sound-by-sound. If the latter were the case, the item was marked incorrect. Given that both English and Spanish are alphabetic languages and share a common orthography, we computed an aggregate "balance" score of word reading skills using the raw scores from English and Spanish Word ID in the following manner: (English-Spanish)/(English+Spanish). This results in scores ranging from -1 (Spanish dominant) to 1 (English dominant) where a score of 0 indicates equal proficiency in word reading across the two languages. The present study did not assess pseudo-word reading as part of alphabetic knowledge given that previous work has shown that an SVR model with decoding defined as word recognition is more powerful than one where it is defined as phonetic analysis (Johnston & Kirby, 2006).

Reading comprehension, the ability to read and understand connected text, was measured using Woodcock *Passage Comprehension (PC)*. Participants read short cloze sentences and identified a word out-loud that best fit the passage (total of 47 items in each language). Initial test items provided picture cues to assist the children in supplying the missing words and increased in order of difficulty.

Spanish and English language comprehension was measured using the *Semantic and Morphosyntax Knowledge* subtests of the BESA-ME. The *Semantic Knowledge* subset measures acquisition of semantic breadth and depth in order to tap into how children organize and gain access to their lexical system (Peña, Bedore, & Rappazzo, 2003). Participants are shown pictures and asked questions that tap into semantic knowledge such as category generation (e.g. Tell me all the zoo animals you can think of), similarities and differences (e.g. What makes these two gifts alike?), analogies (e.g. Legs are to table as wheels are to ______), and functions (e.g. What do lungs do?). Children's correct responses are credited in either English or Spanish on some parts of the Semantics subtest (Bedore et al., 2005; Peña, Bedore, & Rappazzo, 2003; Peña, Bedore, & Zlatic-Giunta, 2002). There were equivalent but not translated items on the Spanish (26 total items) and English (23 total items) versions, with equivalent item difficulty.

The *Morphosyntax Knowledge* subtests examines grammatical morphemes and sentence structures that are typically challenging for children with language impairment in English or in Spanish (Gutiérrez-Clellen & Simon-Cereijido, 2007). On the Cloze Task, examiners read a complete sentence while pointing to a picture. They then read a second sentence corresponding to another similar picture that the child completed using the targeted morphosyntactic markers (e.g., possessives in English, clitics in Spanish). Sentence Repetition comprised the second part of the morphosyntactic test and was used to test more complex forms (e.g. preterite, conjunctions) that cannot be elicited using Cloze Tasks. In Sentence Repetition, children simply repeated the sentence spoken by the experimenter. In Spanish there were 19 cloze items and 32 sentence repetition items and in English there were 18 cloze items and 28 sentence repetition items.

The BESA-ME subtest *Semantic Knowledge* in each language was included as an observed variable and individual components of the *Morphosyntax Knowledge* subtest (Cloze Items and Sentence Repetition) were included as separate observed variables in the factor analyses.

Verbal working memory was assessed using the Wechsler Intelligence Scale for Children V - Memory for Digit Span, *Forward, Backward* and *Sequencing* subtests (WISC–V; Wechsler, 2014). Children repeated a sequence of numbers spoken aloud by the interviewer in forward, backward, and ascending order where the length of each sequence of numbers increases as the child responds correctly. Children completed two trials in each length (digit span) sequence of numbers starting from a two-digit sequence. Incorrect recall of the sequence for both trials within a digit span length resulted in termination of the assessment. Raw scores for each subtest were calculated out of possible 18 trials for each series.

Data Analysis

Data analysis was computed using Mplus8 (version 1.6; Muthén & Muthén, 2012–2018). We used full-information maximum likelihood (FIML) for obtaining estimates of the parameters. FIML maximizes the use of existing data points and accounts for missing data without deleting cases listwise or pairwise (Byrne, 2001; Muthén & Muthén, 2010). The largest amount of data missing is no more than 20% for any given variable, within the accepted bounds (Klein, 2010).

The goodness of fit of the estimated models were evaluated according to the following indicators: chi-square statistics, comparative fit index (CFI), Tucker-Lewis Index (TLI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR; McDonald & Ho, 2002; Schreiber et al., 2006). The chi-square ratio (χ^2/df) statistic adjusts for the chi-square statistic's sensitivity to sample size and the complexity of the model (Byrne, 2001). Chi-square ratios smaller than or equal to 3 indicate good model fit (Schreiber et al., 2006). CFI and TLI values above 0.90 indicate adequate model fit while values above 0.95 indicate a very good fit (Hu & Bentler, 1999; Kline, 2015). SRMR and RMSEA values at or below .08 are considered a good fit (Hu & Bentler, 1999; McDonald & Ho, 2002; Kline, 2015).

We used a two-step approach to structural equation modeling. First, we used an exploratory factor analysis (EFA) to determine the appropriate factor structure of the measurement model. Second, we constructed a structural equation model (SEM) to confirm the factor loadings from the measurement model (confirmatory factory analysis, CFA), and analyze the within and cross-language associations of the latent constructs and observed variables, and their contributions to reading comprehension in both languages. construct.

Exploratory factor analysis (EFA) of latent variables. Table 4 displays the fit statistics and Table 5 displays the factor loadings for observed variables on latent constructs for the following measurement models (see also Figure 1). All factor loadings from the observed variables to the latent constructs were significant.

Language Skills Latent. To identify a factor structure of language skills, broadly, we computed an EFA with estimated two to four factor-structures across measures of phonological awareness, semantic, and morphosyntax knowledge in both languages. While the fit statistics revealed that the four-factor model (Table 4, Model C) was the best fit model initially, a closer examination of factor loadings (Table 5) showed that Rhyming subcomponent of *Sound Awareness* in Spanish and English clustered together to form a fourth factor on its own. Based on this clustering pattern, a three-factor model with latent constructs of Phonology (comprising of all Spanish and English *Sound Awareness* subcomponents), and English and Spanish language comprehension (English LC, Spanish LC comprising of BESA-ME language assessments in each language) separated by language showed to be the most appropriate measurement model with very good fit indices (Table 4, Model B).

Socioeconomic Status (SES) Latent. Similarly, we also computed an EFA on the overarching construct of socioeconomic status to capture a composite of parent and family sociodemographic variables. SES is a multifaceted construct that is difficult to capture by a single index (Duncan & Magnuson, 2012). Given that structural equation modeling allows for testing of the relationships between latent constructs, we used several components of SES in the model that have been shown to influence language skills (Hoff, 2018; Huttenlocher et al., 2010;

Noble et al., 2006). The EFA included variables of objective (e.g. parental education and household income) and subjective (e.g. McArthur Ladder Scale perception of social status at community and national levels) measures of SES, with estimated one to two factor-structures.

The EFA revealed that all indicators of SES loaded onto a one-factor model (see Table 5, Model D). However, Model D did not converge. Thus, we ran a second EFA with the indicator measuring subjective social status at the community level, Subjective Status – Community, removed. This indicator had the lowest factor loading on the latent SES variable relative to other indicators and did not correlate as strongly with other SES variables (see Table 3). Model E was the best fit model for the latent construct of SES.

Structural Model. Next, direct and indirect paths between latent constructs and observed variables of interest were tested (Model F). Number of hours speaking Spanish was entered into the model as an observed variable of language experience, the balance score of Spanish-English word reading was entered as an observed variable of dual-language word reading skills, and Spanish and English reading comprehension were entered as individual observed variables. Analyses used raw scores from all language and literacy assessments and controlled for age (regression coefficients between age and all latent variables of language skills, bilingual word reading skills, and English reading comprehension were significant, $p < .001$). We did not control for age of English acquisition as all participants were early exposed bilinguals, most of them before the age of four and all before the age of five (Bedore et al., 2016). Correlations among latent variables of phonological awareness and language comprehension were included in the model. Direct paths tested are shown in Figure 2 and results for indirect paths tested are shown in Table 6.

Results

As seen in Table 2, on average, participants had age appropriate language and literacy scores in English and Spanish across all assessments. Paired sample *t*-test across assessments reveal significant differences between Spanish and English, especially in reading comprehension and BESAME measures of semantic and morphosyntactic knowledge. English assessment scores are higher than Spanish across all measures ($p < .01$) as would be expected of bilinguals with English-dominant schooling and neighborhood environments that are typical of the demographic make-up of southeast Michigan; see Table 1.

Correlations among study variables, controlling for participant age and gender, are reported in Table 3. Parental education significantly correlated with almost all measures of language and literacy across both languages. Household income, specifically, correlated with BESA-ME spoken language measures in English and Spanish but not with literacy measures of phonology, word reading, and reading comprehension. Parents' subjective measure of social status, at the community and national levels, significantly correlated with children's English but not Spanish BESAME language measures. The number of hours children speak Spanish positively correlated with Spanish morphosyntax knowledge and negatively correlated with English morphosyntax knowledge. BESA-ME and Woodcock assessments used as indicators for latent variables are correlated within and across languages to varying degrees (see Table 3), indicating reciprocal relations between language and literacy abilities in Spanish and English, some of which are captured by the path coefficients in the structural model.

Factor analyses and latent constructs

We first ran a factor analyses and then tested a structural model with paths predicting language specific and cross-language contributions to examine how varying linguistic abilities contributed to reading comprehension in Spanish and English. The SEM analyses confirmed a three-factor model of language skills in English and Spanish, with language specific and language general components loading onto latent constructs (see Figure 1 for factor loadings). English and Spanish phonological awareness indicators all loaded onto one general latent construct suggesting that phonological awareness ability should be considered as single, cross-language construct underlying general phonological language skills. On the other hand, Spanish and English oral language skills, comprised of semantic and morphosyntactic knowledge within each language, loaded as separate language-specific constructs, suggesting that items measuring these skills should be represented as separate latent constructs within this structural model.

Predictors of bilingual reading comprehension

The full structural model (Model F) yielded a good model fit (χ^2 (209) = 325.43, $p <$ .001, CFI = .94, TLI = .93, RMSEA = .06, SRMR = .06). Standardized ß-coefficients among all direct paths tested are shown in Figure 2 and indirect paths tested are reported in Table 6. The model explained a large percentage of the variance in children's English (R^2 = .87, $p < .001$) and Spanish (R^2 = .82, $p < .001$) reading comprehension outcomes.

We observed a small but significant effect of Spanish reading comprehension on English reading comprehension. Spoken language knowledge had a direct effect on reading comprehension in both languages and also related to bilingual word reading skills. Bilingual word reading skills had a direct effect on Spanish reading comprehension, but not English reading comprehension. Similarly, phonological awareness, had a strong effect on bilingual word reading skills and a direct effect on Spanish reading comprehension. The relation between phonological awareness skills and Spanish reading comprehension was significantly mediated by bilingual word reading skills (see Table 6).

We also observed significant contributions of children's sociodemographic variables and Spanish language use on reading comprehension outcomes. Socioeconomic status had a direct effect on phonological awareness ability and both Spanish and English language knowledge, and an indirect effect on bilingual word reading skills and Spanish and English reading comprehension. The number of hours of a child speaks Spanish in a typical week had a direct effect on Spanish spoken language comprehension and an indirect effect on Spanish reading comprehension.

Discussion

The Simple View of Reading (SVR) framework has long described reading comprehension as a product of word decoding and listening comprehension, where both are necessary for reading success and neither is sufficient by itself (Hoover & Gough, 1990; Lervag, Hulme, & Melby-Lervag, 2018). Theoretical frameworks of bilingual development add to this view and suggest that in young bilingual readers, proficiencies across the two languages interact under certain domains and make a cumulative impact on literacy development (Genesee, Geva, Dressler, & Kamil, 2006; Durgunoglu & Verhoeven, 2013; Proctor et al., 2010). The goal of the present study was to test the associations between bilingual children's language and literacy skills within and across languages in the development of reading comprehension. Specifically, I asked, how do children's Spanish and English language proficiencies interrelate to support children's reading comprehension? Based on prior theoretical accounts of reading development in bilingual learners (interdependence theory, Cummings, 1979), I predicted that children's language and literacy skills in Spanish will contribute to reading comprehension in English, the primary language of instruction in this bilingual sample.

I present three main findings that adds insight into the SVR model in Spanish-English bilingual development: first, bilingual children's language and literacy skills fall within a continuum of shared and unique abilities across languages; second, reading in one language supports reading in another at the word- and passage- level; third, bilingual children's sociocultural context and experiences, including familial SES and the number of hours a child speaks Spanish in and outside of the home, make significant contributions to bilingual language and reading outcomes. Findings from this dissertation study inform broader theoretical perspectives that guide literacy research highlighting how variations in bilingual language abilities shape literacy development and its underlying components (Melby-Lervag & Lervag, 2011; 2014).

Continuum of shared and unique language abilities

In an exploratory factor analyses of children's bilingual skills of phonological awareness and semantic and morphosyntactic knowledge, I found a three-factor model that represented shared and unique language abilities. Observed measures of phonological awareness in Spanish and English loaded together onto one latent construct suggesting one shared ability across the two languages. The results of the current factor analyses are consistent with the field's findings that phonological awareness skills transfer readily and relate to reading across languages, specifically when the two writing systems are similar (Bialystok, Luk, & Kwan, 2005; Melby-Lervag & Lervag, 2011; 2014; Proctor et al., 2010). Phonological awareness is commonly considered language-independent linguistic knowledge tapping into broader metalinguistic/metacognitive abilities (August, McCardle, & Shanahan, 2014; Bialystok, 2002), although, a few studies have modeled phonological skills in bilinguals as separate but highly related predictors of reading development (see Branum-Martin et al., 2006; and Gottado & Mueller, 2009; Nakamoto, Lindsey, & Manis, 2008). In the present study, I find that phonological awareness ability was related to both English and Spanish broader language comprehension and best characterized as a separate language-general construct.

The factor analyses also established that measures of spoken language comprehension, assessed with bilingual semantic and morphosyntactic knowledge, were best represented as two latent constructs separated by language. Findings in the literature suggest there is a lack of overlap, often interpreted as less cross-linguistic transfer, on oral language measures across bilinguals' two languages, especially when oral language is assessed using vocabulary scores (Melby-Lervag & Lervag, 2011; Pena, Bedore, & Zlatic-Guinta, 2002). In the present study, I measured spoken language comprehension using assessments that tapped into language skills beyond vocabulary, bilingual children's breadth and depth of English and Spanish semantic and grammar knowledge. In fact, children's responses on the semantic knowledge assessment allowed for code-mixing by giving children credit for a correct response in either language (Penã et al., 2018). Previous studies examining the cross-linguistic transfer of spoken language skills have shown large variations in results between studies, often finding little to no overlap across languages (see meta-analyses by Melby-Lervag & Lervag, 2011). This is often interpreted in terms of the complexity of the oral language domain and the many subskills involved underlying language knowledge (Cobo-Lewis et al., 2002; Durgunoglu, 2002; Gottardo & Mueller, 2009). In general, language comprehension as conceptualized in the SVR model, represents all of verbal ability including vocabulary, syntax, inferencing and the construction of mental schemas, and are less likely to be represented as a common underlying process (Gottardo, Yan, Siegel, & Wade-Woolley, 2001; Proctor et al., 2006; 2010).

Bilingual reading at the word and passage levels

Together, bilingual children's spoken language comprehension in each language and phonological awareness ability directly related to bilingual word reading skills. Children with greater phonological awareness abilities were better at reading words in both English and Spanish. While Spanish and English word reading skills both rely heavily on phonological awareness and letter knowledge, the two languages differ in their orthographic transparency in sound-to-letter mappings. A balanced measure of word reading thus allowed us to test direct effects of phonological awareness as well as unique effects of Spanish and English broader language knowledge on bilingual word reading, tapping into lexical and sublexical processes of phonology, semantics, and orthography (Plaut, 2005).

English language comprehension directly predicted word reading balance and English reading comprehension. As expected, bilingual children with stronger English proficiency were better at word-reading and reading comprehension in English. We also observed that children with greater Spanish language comprehension were more balanced readers at the word-level and were better at reading comprehension in Spanish. In reading words, children often rely on the use of semantic and/or wider language comprehension resources when grapheme-phoneme correspondences are less predictable, such as the case in English (Nation & Cocksey, 2009; Ricketts et al., 2016). In these cases, fluent reading may depend on experience with text and reading of exception words (words that do not follow phonics rules, such as 'tough'; e.g., Bowey and Rutherford, 2007; Nation and Snowling, 1997; 1998). In reading connected text, semantic knowledge of mountains may speed up the recognition of the word ‘peak’ and being aware of morphology might help recognition of a morphologically complex word such as ‘unstoppable’ (Nation, 2017; Tamura, Castles, & Nation, 2017). Overall, these results are consistent with the “within language” findings as previously reported in SVR studies with Spanish-English bilinguals: associations between English spoken language and English reading comprehension (Gottardo & Muller, 2009; Lesaux et al., 2010; Proctor, Carlo, August, & Snow, 2005) and associations between Spanish language comprehension and Spanish reading comprehension (Nakamoto, Lindsey, & Manis, 2008; Proctor et al., 2010).

Spanish reading comprehension had a direct effect on English reading comprehension. To better understand this association, it is important to note that phonological awareness and bilingual word reading skills both had direct effects on Spanish reading comprehension but not English reading comprehension. Based on the SVR model, we would expect that word reading skills in English (less balanced bilingual word reading) would be significantly associated with English reading comprehension. However, the current model suggests that in this sample of balanced bilinguals, English language comprehension and Spanish reading comprehension (though a relatively smaller effect) are most associated with English reading comprehension outcomes. Proctor et al. (2010) also found a small but significant contribution of Spanish reading comprehension on English reading comprehension, in addition to English oral language skills and Spanish-English alphabetic knowledge, suggesting evidence for linguistic-interdependence at the reading comprehension level.

As with monolingual speakers, these skills change over the course of development such that word decoding skills play a key role in reading comprehension early on when the child is first learning to read, while later, the importance of oral language skills will gradually increase

(Lervag & Aukust, 2010; Hoover & Gough, 1990). Together, these patterns of data are in line with the developmental shift in language demands required for comprehending text in early and later elementary grades (Manis et al., 2004). Results converge with findings from Lesaux et al. (2010) showing that, for bilingual readers, English spoken language knowledge exerts a stronger influence than word reading in models of English reading comprehension. The present study extends previous work to suggest that Spanish reading comprehension also plays a key role in English reading outcomes, and likely relates to the broader metalinguistic proficiency that is enhanced by exposures to different expression of linguistic structures (Ben-Zeev, 1977; Bialystok, 2017), as well as, sociocultural contexts that support bilingual development.

Effects of SES and Spanish Language Use

We observed significant positive associations between familial SES, the number of hours a child spoke Spanish in a typical week, and outcomes of bilingual language and reading competencies. Familial SES was positively associated with phonological awareness and English and Spanish spoken language comprehension, and indirectly contributed to bilingual word reading skills and reading comprehension in both languages. Children's approximate number of hours speaking Spanish in the home positively related to Spanish spoken language proficiency and indirectly contributed to Spanish reading comprehension. While we didn't test the direct effects of the number of hours speaking English on bilingual literacy outcomes, we would expect this inverse association to also be true. It is known that distal effects of SES on child outcomes are mediated by the proximal effects of practices at home, such as the amount and richness of language stimulation (e.g. Duncan & Brooks-Gunn, 2000; Hoff, 2003) and encouragement of bilingual competence (Pearson, 2007; Oller & Eilers, 2002). For example, caregivers in higher monolingual and bilingual SES homes are more likely to facilitate the development of critical thinking skills by probing children questions and asking for explanations rather than giving directives (Hoff, 2006). Further, children from higher SES homes are more likely to use context-independent language at home that often corresponds with schooling language (Uccelli et al., 2015). Thus, noticing of academic language and concepts likely relates to the development metalinguistic skills that can be facilitated across languages (Durgunoglu, 2017). Bilingual children tend to produce oral narratives of equal complexity across their two languages (Fiestas & Pena, 2004), suggesting potential pathway in which children's exposure to and use of one language may contribute to broader comprehension skills in another (Durgunoglu, Peynircioglu, & Mir, 2002; Ordonez, Carlo, Snow, & McLaughlin, 2002).

Chapter III

Study 2: Language Comprehension in the Bilingual Brain

In Chapter 2, I examined how bilingual children's language experiences and proficiencies support the development of reading comprehension within and across the two languages. Results showed that in both Spanish and English, spoken language comprehension was one of the key contributors to reading comprehension. Core components of spoken language knowledge such as phonological awareness, breadth and depth of semantic knowledge, and grammatical competencies build the foundation to later reading abilities and school success (Cutting & Scarborough, 2006; Muter et al., 2004). Reading acquisition is further facilitated by building a functional neurocircuitry for integrating spoken-language processing networks with printed-language representations (Dehaene, 2009). Thus, critical to our understanding of bilingual influences on reading development is first having a foundational understanding of how spoken-language processing networks are specialized in the bilingual developing brain.

In this dissertation chapter, I explore the neural correlates of spoken language comprehension. Specifically, the present study investigates how early bilingual exposure and dual-language proficiencies influence children's functional organization for spoken language processing. The goal of this dissertation study was to: 1) examine the functional organization of the bilingual brain during tasks of auditory sentence processing in English; 2) evaluate the relationship between brain activity and bilingual language competencies in each of the child's languages; and 3) assess how the neural organization for sentence comprehension may mediate the relationship between children's bilingual language proficiencies and English reading comprehension.

Language comprehension is a complex and multi-faceted skill that requires one to compute several operations in parallel. For example, sentence processing not only requires the retrieval of lexical and sublexical information (e.g. phonological, morphological, syntactic units of language), but also requires the listener (or reader) to build sentence structure, form meaning, and draw upon pragmatic inferences, among other specific and general cognitive demands (Hagoort, 2005, 2013; Jackendoff, 2007). Integrating the many operations for the interpretation of a sentence involves several specialized brain areas within a larger neural network of temporal, parietal, and inferior frontal regions (Friederici, 2009; Hagoort, 2017; Hickock & Poeppel, 2016; Lau, Phillips, Poeppel, 2008). This dynamic process is naturally influenced by variations in learning experiences (Kuhl, 2010). Yet, little is known about the neural architecture of language comprehension in the developing brain and how is it shaped by bilingual language experiences as children become skilled in their language and cognitive abilities (Kroll et al., 2015).

Adult Models of Language Processing

Studies on language organization in adult the brain suggest a dual-route model of language processing: bilateral auditory cortices and the superior temporal gyrus (STG) support early stages of speech processing (e.g. phonological and spectrotemporal analysis), a temporal-lobe ventral stream supports speech comprehension (e.g. lexical access and combinatorial processes) and a left hemisphere dominant dorsal-stream supports sensory-motor integration involving the temporo-parietal junction and the inferior frontal lobe (Hickok & Poeppel, 2000, 2007, 2016). The anterior portion of the left superior temporal gyrus (left aSTG) has also been discussed as being involved in syntactic (Humphries et al., 2006, 2007) and compositional semantic operations (e.g. Brennan and Pylkkanen, 2012; Bemis and Pylkkanen, 2013).

Friederici (2012) has proposed a language comprehension model, which argues for specialized semantic and syntactic processing in the adult brain: the inferior frontal gyrus (IFG) opercular (BA 44) is specialized in syntactic processing (e.g. Zaccarella et al. 2017; Friederici 2018), whereas the left IFG triangular (BA45, BA47) and the left middle temporal gyrus (MTG) are specialized in semantic processing (e.g. Goucha & Friederici 2015; Hagoort & Indefrey 2014; Binder et al. 2009). Based on this model, the left posterior superior temporal gyrus (pSTG) in involved in integrating syntactic and lexical-semantic information (e.g. Bornkessel et al. 2005; Zaccarella et al. 2017). A meta-analysis of numerous neuroimaging studies reveals a clear dorsal/ventral gradient in both left inferior frontal cortex and left posterior temporal cortex, with dorsal foci for syntactic processing and ventral foci for semantic processing (see Hagoort & Indefrey, 2014).

Specialization of the Brain in Early Development

Theoretical neurocognitive perspectives posit that brain regions show transitions to focal patterns of activity with experience and maturation, supporting higher level cognitive functions (*interactive specialization hypothesis*, Johnson, 2011). Specialization for language in early development is often characterized by increasingly localized and left-lateralized activations that lead to a more coordinated network of regions involved (Price, 2012; Dehaene-Lambertz et al., 2006; Werker & Hensch, 2015). A number of studies have provided similar accounts for neural and cognitive changes associated developmental experiences, as recently summarized Hernandez and colleagues (2018). For example, the 'adaptive control hypothesis' suggests that the use of two languages engages a general cognitive control mechanism to a greater extent than the use of one language (Green & Abutalebi, 2013). Additionally, work by Petitto, Kovelman, and colleagues propose a ‘perceptual wedge hypothesis’, where exposure to two languages early in development would lead to a qualitative shift in the mechanisms of acquisition, or ‘additional flexibility’, in language processing (Kuo & Anderson, 2012; Petitto et al., 2012; Werker & Hensch, 2015). Together, literature suggests that in bilingual development, exposure to two languages early in life influences the structural and functional neural plasticity of language and related cognitive skills, thereby shaping the bilingual brain differently from those of monolinguals’ (Grosjean, 1989; Kroll et al., 2015; Li, Legault, & Litcofsky; 2014).

A few studies have examined whether adult-like language specialization during sentence processing occurs in the developing brain. Friederici and colleagues have proposed a neural specialization framework for the development of spoken language comprehension in children, specifically related to semantic and syntactic linguistic processes. They suggest that the developing brain shows neural specificity for syntax that gradually separates from neural specificity for semantic processes in the left inferior frontal cortex starting around age nine (Skeide, Brauer, & Friederici, 2014). However, the precise nature of this specialization is not well understood (Brauer & Friederici, 2007; Knoll et al., 2012).

Only a handful of studies have examined the neural specialization of language in the bilingual developing brain. These studies vary in the particular linguistic skill and the bilingual language group being assessed, where all three studies used experimental stimuli in both of the participants’ languages: morphological awareness in Chinese-English bilinguals (Ip et al., 2016), morphosyntax processes in Spanish-English bilinguals (Arredondo et al., 2018) and phonological processing and word reading in French-English and Spanish-English bilinguals (Jasinska et al., 2017). Collectively, the findings from these studies show evidence of neural specificity for a given linguistic process and indices of brain activity differ from their respective monolingual comparison groups. This is taken to suggest that systematic use of two languages might change the way in which bilinguals' attune to the salient features of the language being processed (e.g. differing word structures of Chinese and English), even if the speakers are highly proficient in both languages (see discussion by Kovelman & Marks, 2019). Recent work by Arredondo et al. (2018) examined children's brain responses during sentence processing of morphosyntax violations in a sample of Spanish-English bilingual children with similar dual-language profiles as the sample studied in this dissertation. The authors report activation in left inferior frontal region (IFG) when children listened to sentences with grammatical errors in both English and in Spanish. Bilingual children showed stronger and more restricted IFG activity as compared to their monolingual peers. The authors conclude that the specialized recruitment of the left IFG in young bilinguals is likely related to children's enriched bilingual experiences.

The present study uses functional Near-Infrared Spectroscopy (fNIRS) neuroimaging to measure children's functional organization for spoken language comprehension in Spanish-English bilingual children ages 7-12. I operationalize language comprehension using two English sentence processing experimental tasks that require children to make explicit semantic plausibility or explicit morphosyntax grammaticality judgments. The choice to use these particular sentence tasks were threefold: first, both tasks involve language processing demands as developmentally appropriate for assessing language acquisition and comprehension, drawing on the connections of vocabulary and general word knowledge, as well as, acquisition of inflectional morphology that is dependent on children's language-specific experiences (Peña, Bedore & Kester, 2015; Rice, Wexler & Hershberger, 1998); second, given that sentence processing and comprehension requires the computation of both semantic and syntactic features of language, we can compare the recruitment of specific brain regions as proposed by Friederici and colleagues (Friederici, 2012; Skeide, Brauer, & Friederici, 2014) across the two tasks, as well as, within task demands; third, by looking at general sentence processing and task specific demands, we can compare how bilingual language knowledge and reading comprehension relate to brain activity differentially across the two tasks. To examine these pathways, I use structural equation modeling to assess how children's brain activity during tasks of sentence processing are related to behavioral assessments of language proficiency in Spanish and English, and English reading comprehension.

Based on the reviewed literature on neural models of language processing, we expect to see recruitment of the left inferior frontal gyrus and posterior superior temporal gyrus during tasks of sentence processing; specifically, recruitment of the left IFG opercular during the syntax sentence processing task and the left IFG triangular during the semantics sentence processing task, key regions underlying semantic and syntactic processes in adults. Theoretical perspectives on brain specialization given early exposure to bilingual experiences (Johnson, 2011; Hernandez et al., 2018; Kroll et al., 2015) suggest that children's dual language and reading experiences may influence the functional neural architecture supporting language comprehension. I hypothesize that bilingual language experiences may have a cumulative impact on children's cortical specialization (stronger and more restricted activity) for language, such that, children with more balanced bilingual experiences and proficiency will show greater cortical specialization than less balanced (more English dominant) bilinguals.

Method

Participants

The present study includes data from 107 (Semantics Task) and 87 (Syntax Task) early-exposed Spanish-English speaking bilingual children. From the initial 132 bilingual children who participated in Study 1 (Chapter 2), only a subset of the participants completed the fNIRS neuroimaging tasks. Data from those who met the following neuroimaging inclusion criteria were analyzed: participants who were right-handed, had no known history of head injury or were being treated by psychotropic medications at the time of testing, and participants with overall task accuracy of 65% or higher for each experimental task. Additionally, a few participants were removed for poor fNIRS signal quality as described below (see Table 7).

Procedure

Experiment procedure, parent questionnaires, and child assessments were identical to those described in Chapter 2. In addition to the bilingual language and literacy assessments, children also completed two experimental neuroimaging tasks of language comprehension.

fNIRS Experimental Tasks

Stimuli. All sentence stimuli in the semantic and the syntactic task had the following structure: an optional carrier phrase ("Last week/Every day") + subject and verb phrase (e.g. "She baked) + optional number and object (e.g. "two cakes"). The sentences included one of the following four verb forms: 1) Third person present tense (-s); 2) Present progressive copula (be); 3) Auxiliary verb (do); and 4) Simple past tense (-ed). Across all conditions, half of the stimuli sentences include the temporal marker carrier phrase varying.

Stimuli were matched across conditions in each task in terms of the number of words and the frequency of "not" usage in the sentences. A female native speaker of American English recorded all sentence. Sound files were equalized for RMS amplitude and trimmed using Audacity software (Audacity Team, 2017).

Semantics Task. There were three conditions of the semantic sentence stimuli: strongly congruent (SCon), weakly congruent (WCon), and incongruent (InCon; see Appendix B for full list of sentences). Each experimental condition varied in the degree of semantic association between the verb and object pairing embedded within the sentence (adapted from a previous neuroimaging study on auditory sentence processing by Wang, Rice, & Booth., *in prep*). The SCon and WCon conditions were based on the association strength values between the verb and the object as defined in the University of South Florida Free Association Norms (Nelson et al. 1998; Nelson, McEvoy, & Schreiber, 2004). The strongly congruent condition had an association of 0.28-0.81 (M = .41, SD = .12) between the verb and the object in the sentence (e.g. sing-song). The weakly congruent condition had an association of 0.02-0.19 (M = 0.11, SD = 0.05) between the verb and the object in the sentence (e.g. catch-fish). In the incongruent condition, the verb and the object in the sentence had no semantic association (e.g. bounce-paper).

These verb-object pairs are embedded within a sentence context that naturally elicits a biased interpretation based on experiential knowledge (e.g. She is singing a song; He did not catch any fish; They are bouncing the paper). Participants who scored above 65% accuracy on the task, combined across all conditions, were included in the neuroimaging analyses (no participants were excluded based on this criterion for the semantics sentence task).

Syntax Task. Similar to the semantics task, there were three conditions of the syntax sentence stimuli: grammatically correct (CORR), -ing inflectional morpheme omission (ING), and -ed and -s inflectional morpheme omission (ED&S), based on the following parameters. In the ING condition, children heard short sentences where –ing verb endings are omitted (e.g.

Right now, he is walk_ his dog). In the ED&S condition, children heard short sentences where either the –ed or -s verb endings are omitted (e.g. Laura score_ a winning goal; Yesterday, they finish_ all of the homework.). Ten sentences in the ED&S condition are missing the –s ending (e.g. Nicholas bite_ into a pizza) and ten sentences are missing the –ed ending (e.g. Last week, they laugh_ with grandma). In the CORR condition, children heard sentences with grammatically correct verb endings (e.g. Carmen is tying her shoelaces; Yesterday, Daniel picked flowers). Of the 20 correct sentences, ten sentences include –ing endings, five sentences include –ed endings, and five sentences include verb –s endings. Participants who scored above 65% accuracy on the task, combined across all conditions, were included in the neuroimaging analyses (twelve participants were excluded based on this criterion).

In each sentence processing task, participants heard 60 sentences total, 20 per condition. Participants were seated in front of an external 23- inch Philips 230E Wide LCD screen connected to a Dell Optiplex 780 desktop computer. A cartoon alien appeared at the center of a computer screen while the auditory stimuli was presented aurally via EPrime software through two external speakers positioned equidistant to each side of the monitor. The task is an event-related design where the three conditions were pseudo-randomized so that there were no more than four of same conditions in a row. Each trial was 5000ms long: the duration of sentences were approximately 3000ms followed by a question mark that appeared for 2000ms at center of the screen indicating the response interval. Silent, rest periods with a fixation cross were randomly jittered for 0-6000ms throughout the task between trials, with jitter periods lasting approximately 25% of the total duration of the experimental task (randomized using OptSeq2; Dale, 1999). Each task was approximately six minutes long.

Prior to data collection, participants were trained on a “silly sentence game” and taught to use a button box to indicate whether the sentence was semantically plausible or grammatically correct (“Does the sentence makes sense?”). Participants used their right thumb to indicate whether the sentence is “correct” and their left thumb to indicate whether the sentence is “incorrect”, as quickly as possible. Task training included an initial practice round of 3-4 trails with feedback from the experimenter and a practice session on seven trials on the computer. Practice sentences were all distinct from the experimental stimuli. Feedback was given during the computer practice session and additional instructions were repeated if necessary.

fNIRS Data Acquisition & Processing

The study used a TechEN-CW6 system with 690 and 830 nm wavelengths. The fNIRS cap set-up included 12 emitters of near-infrared light sources and 24 detectors spaced ~2.7 cm apart, yielding 46 data “channels” (23 channels per hemisphere; see Figure 3A). Sources and detectors were mounted onto a custom-built head cap constructed from 2 mm silicone-rubber material, with attached grommets to hold them in place during data collection. The alignment of the sources and detectors were placed precisely in a grid-like shape yielding full coverage of the underlying regions of interest across multiple channels. The probes were applied consistently as possible for each participant using the international 10-10 transcranial system positioning (Jurcak, Tsuzuki, & Dan, 2007); nasion, inon, Fpz, and left and right pre-auricular points, head circumference were measured and F7, F8, T3, and T4 were anchored to a specific source or detector. Once all optodes were placed on the cap, digital photos of the participant’s head and cap alignment were taken from the left, right, and center midline angles.

Techen-CW6 software signal-to-noise ratio (SNR) minimum and maximum were set to the standard 80 dB and 120 dB power range, respectively. Before the start of each experimental task, data quality control check was completed by looking to find participant's cardiac signal across key channels of interest and making sure fNIRS signal in these channels fell between the minimum and maximum power parameters. If needed, trained experimenters adjusted positioning of the cap or participant's hair as necessary to detect cardiac signal. Data was collected at a sampling frequency of 50Hz.

Estimation of Brain Regions. We digitized the geometric structure of our cap design on a mannequin head using a Polhemus Patriot 6 Degree-of-Freedom (DOF) Digitizer. The coordinates provided by the digitizer were then processed in AtlasViewer GUI, a MATLAB-based software (Aasted et al., 2015), to transform digitized coordinates to Montreal Neurological Institute (MNI) stereotactic space and estimate the underlying Brodmann areas (BA) of interest covered by the probe-set layout (see Figure 3B).

Anatomical Localization using MRI. Additional measures were taken to ensure proper anatomical localization of each fNIRS channel. A subset of children (N = 10) who participated in the study and an additional eight children were invited for a structural MRI scan (Full MRI sample: M_{age} = 9.62, Range = 6.42 – 12.25, 4 females). All children met the required metal screening criteria to participate. Children were fitted with a replica cap with the same probe-set layout as described above that had in place vitamin-e capsules where each source and detector would be located (see Figure 3D & 4E). MRI data was collected on a 3-T General Electric Signa scanner (GE Health Systems, Milwuakee, WI) with a standard quadrature head coil while participants watched a short cartoon clip.

The MRI image was registered to a MNI 152 Nonlinear 6th Generation) template using Statistical Parametric Mapping (SPM) toolbox using a standard localization pipeline. MNI coordinates of each fNIRS optode indicated by vitamin E capsule were manually identified in 3d space using MRIcro (NITRC, 2018). Then, the midpoint of each fNIRS channel (here, between vitamin E capsule pairs) were then projected onto the cortical surface. The corresponding brain regions associated with the channel mid-point in MNI space were confirmed using the xJView toolbox (http://www.alivelearn.net/xjview/). Specifically, cortical region localization for each participant was simulated with a Monte-Carlo 1000 voxel points within a spherical model that centered at the mid-point of each data channel. The channel mid-point (and standard deviation) localized using the simulation was averaged across all MRI participants and then plotted on to a 3D image brain template (MNI 152) in order to visualize the brain regions maximally covered by the channels (see Figure 4). The channel coordinates were matched with the atlas database provided in xJView toolbox. MNI x, y, z coordinates corresponding to each channel as estimated from the child MRI vitamin-e cap images.

fNIRS Data Analysis

We used the NIRS Toolbox, a MATLAB-based analysis software (Abdelnour and Huppert, 2009; Barker et al., 2013), and a set of customized scripts based on Hu, Hong, Ge, & Jeong (2010) to analyze the fNIRS data. We used the general linear model (GLM) framework for data analyses of the sentence processing tasks (Friston et al., 2006).

At the subject-level, the following preprocessing steps were applied: trimming of raw data file to keep only 5 seconds of pre- and post- experimental task baseline data, resampling the data from 50Hz to 5Hz given that the fNIRS signal of interest lies in the range of 0-1 Hz, optical density change data conversion, and hemoglobin concentration change data conversion using the modified Beer-Lambert law. Each participant's hemoglobin concentration data was analyzed using a fixed-effects GLM, assuming the dual-gamma canonical hemodynamic response function peaking 6-seconds after trial onset (Friston et al., 2006; Hu, Hong, Ge, & Jeong, 2010). This yielded estimated HbO (oxygenated hemoglobin) and HbR (deoxygenated hemoglobin) beta values for each participant, each condition, and each channel.

Next, the subject-level data went through a quality control step to identify presence of excessive signal and motion artifacts on a channel-by-channel basis (Scholkmann, Spichtig, Muehlemann, & Wolf, 2010). We extracted the subject-level covariance matrix and calculated the median, interquartile range, and upper bound values across all participants, all channels, and all conditions (separately for HbO and HbR for each experimental task). Participants with 40% or more channels exceeding the covariance upper bound of the sample were removed from the group-level analyses (4 participants were removed from the Semantics and 5 participants were removed from the Syntax task; two participants were the same across the tasks). Poor signal quality was likely due to excessive body and head movements during data collection and/or poor contact between NIRS optodes and the scalp.

Group-level analyses were conducted using a linear mixed-effects model for each data channel. fNIRS time course data are known to serially correlate due to the slowness of the hemodynamic response, systemic physiology, and contain heavy-tailed noise variations due to motion-related artifacts that are often several folds larger in magnitude then other noise. We used an autoregressive filter combined with a weighted least square (WLS) estimation approach to eliminate the non-spherical noise structure caused by physiological and motion artifacts in the time series (Caballero-Gaudes & Reynolds, 2017; Friman, Borga, Lundberg, & Knutsson, 2004). The pre-whitening autoregressive filter cleans the temporal serial correlation in the data while the weighted least square estimation will adjust contribution weight of a heavy tailed noise time point during the model coefficient estimation process. The group-level linear mixed-effects model included task conditions (3 conditions for each experimental task) as fixed effects, participants a random effect variable, and hemoglobin beta values (HbO and HbR) as the predicting dependent variables. Estimated group-level beta values were extracted for each channel for each of the following contrasts: task > rest and specific conditional contrasts for each task (mid > high, low > high, ed&s > correct, ing > correct). Group-level results (unstandardized beta) for each contrast were plotted on to the MNI 152 brain template using the previously specified MNI coordinates for data visualization.

Results

Behavioral Performance

Participant's scores on language and literacy assessments for the two-neuroimaging task are reported in Table 8. Assessment scores from the neuroimaging subsamples did not significantly differ from the scores of the larger sample reported in Chapter 2.

Semantic Task. Percent accuracy and response time on the semantics task are reported in Table 8. Percent accuracies across all three experimental conditions significantly differed from chance ($p < .001$). A one-way ANOVA on accuracy was significant ($F(2,315) = 14.51$, $p < .001$) where accuracy on the semantic incongruent (InCon) condition was significantly greater than the strongly congruent (SCon, $p = .001$) and the weakly congruent (WCon, $p < .001$) conditions. Accuracy on the SCon condition did not differ from the WCon condition ($p = .29$). One-way ANOVA on response time was also significant ($F(2,135) = 3.46$, $p = 0.033$), where response times on the WCon condition was greater than the SCon ($p = .08$) and the Inc condition ($p = .06$), but did not reach statistical significance.

Syntax Task. Percent accuracy and response time on the syntax task are shown in Table 8. Percent accuracies across all three experimental conditions significantly differed from chance ($p < .001$). A one-way ANOVA on accuracy was significant, $F(2, 255) = 77.72$, $p < .001$, where accuracy on the ED & S condition was significantly lower than the Correct ($p < .001$) and ING ($p < .001$) conditions. Accuracy on the Correct condition did not differ from the ING condition ($p = .30$). One-way ANOVA on response times (ms) was also significant ($F(2,255) = 7.92$, $p < .001$), where response times for the ED & S condition was significantly slower from both the Correct ($p < .001$) and ING ($p = .03$) conditions. Response times for the Correct condition did not differ from the ING condition ($p = .59$).

fNIRS Results

Task v. Rest. Figure 5 shows children's overall hemodynamic brain response during the two sentence processing tasks (statistical significance at Benjamini-Hochberg FDR-corrected, $q < .05$). Both sentence processing tasks elicited significant activity (HbO) in the same three key regions of interest: left inferior frontal gyrus opercular (IFG pOper, BA 44), left primary auditory cortex (PAC), and left posterior superior temporal gyrus (pSTG). All statistical results are summarized in Table 9.

Conditional contrasts. Figure 6 shows children's specialized brain response to task specific conditional contrasts (statistical significance at $p < .05$). Two key regions within the IFG were significantly activated during the semantic task: the dorsolateral prefrontal cortex showed significant activity during processing of sentences with no semantic association and the ventral IFG triangular (pTri, BA 45) showed significant activity during processing of sentences with weak semantic congruency, both conditions in comparison to sentences with strong semantic congruency.

Brain response to sentences with specific morphosyntax grammatical violations show focal patterns of activity within the left IFG and PAC. We observed significant activity in the dorsal IFG pOper, dorsolateral prefrontal cortex, and primary auditory cortex during processing of sentences with -ing omissions in comparison to grammatically correct sentences. The channels covering the pOper and LAC were statistically significant at the FDR-corrected $q < .05$ threshold. Further, we observed significant activity in the dorsal IFG pOper during processing of sentences with -ed and -s omissions in comparison to grammatically correct sentences. Activity in these two channels covering BA 44 were statistically significant at the corrected $q < .05$.

Structural Modeling of Brain and Behavior Relationships

To evaluate how brain activity, bilingual language proficiencies, and English reading comprehension are related, we ran two structural models with channels showing significant brain activity during the sentence processing tasks and behavioral latent variables of language competencies. Latent variables of Spanish spoken language comprehension, English spoken language comprehension, and phonological awareness from Chapter 2 (EFA measurement model) were used in the current analyses. Subject-level beta values from the GLM for task > rest related brain activity for the three key regions of interest (IFG pOper, LAC, and pSTG) we entered into the model, separately for each experimental task. In addition, conditional contrasts showing more focal regions of activity for the WCon > SCon condition in the semantics task and

ED&S > Correct condition in the syntax task were entered into the model[1]. English reading comprehension was entered as the outcome variable.

Each structural model tested the following paths: the direct effects between behavioral latent variables of Spanish and English language competencies and phonological awareness on English reading comprehension; the direct effect between the three latent variables and individual brain regions identified as key in sentence processing; direct effects between brain activity and English reading comprehension; and the indirect effects between latent variables of bilingual language competencies and reading comprehension via brain activity. Correlations across latent variables and across individual brain regions were also specified in the model. Participant's age and scores on the WISC-IV-digit span (backward) were initially entered as covariates. Digit span did not significantly predict any observed variables in the model, thus, only age was included as a covariate in the final analyses.

Brain and behavioral relations during the semantics task (Figure 7). The model with key channels activated during the semantic task yielded good fit ((χ^2 (144) = 217.35, p < .001, CFI = .94, TLI = .93, RMSEA = .06, SRMR = .06). Statistical results are summarized in Table 10. We observed a significant positive relationship between latent variables of English language comprehension and English reading comprehension, and phonological awareness and English reading comprehension. Spanish language comprehension did not significantly predict English language comprehension in this model. Direct effects of bilingual language proficiencies on brain activity included the following: a positive relationship between English language comprehension and the left PAC and pSTG regions during task > rest brain activity, and a

[1]In an initial iteration of the SEM models, we did not include the conditional contrast specific channels for either task. Based on the evaluation of path statistics and overall model fit, there were no major differences between the two iterations of models tested. Thus, the models with condition specific channels are reported as final results.

positive relationship between Spanish language comprehension and brain activity in the IFG pTri in the WCon>SCon condition, the task specific conditional contrast. There were no significant relationships between brain regions involved in language comprehension during the semantic sentence processing task and English reading comprehension. There was no evidence of a meditation effect of brain activity between bilingual language proficiencies and English reading comprehension across all regions of interest involved in the semantic sentence processing task.

Brain and behavioral relation during the syntax task (Figure 8). The overall model with key channels activated during the syntax task yielded good fit ((χ^2 (144) = 246.29, $p < .001$, CFI = .93, TLI = .91, RMSEA = .07, SRMR = .07). Statistical results are summarized in Table 10. We observed significant positive relationship between latent variables of English language comprehension and phonological awareness, and English reading comprehension. Spanish language comprehension did not significantly predict English language comprehension. Direct effects of bilingual language proficiencies on brain activity included the following: a positive relationship between English language comprehension and the pSTG region, a positive relationship between Spanish language comprehension the IFG pOper, and a negative relationship between English language comprehension and the IFG pOper, all during task > rest brain activity. Behavioral variables of bilingual language proficiencies did not significantly predict brain activity in the IFG pOper during the ED&S > Correct condition, the task specific conditional contrast. There were no significant relationships between brain regions involved in language comprehension during the syntax task and English reading comprehension. There was no evidence of a meditation effect of brain activity between bilingual language proficiencies and English reading comprehension across all regions of interest involved in the syntax sentence processing task.

Discussion

The present study investigated how early bilingual exposure and dual-language proficiencies influences children's functional organization for spoken language processing. The goal of this dissertation study was to: 1) examine the functional organization of the bilingual brain during tasks of auditory sentence processing in English; 2) evaluate the relationship between brain activity and bilingual language competencies in each of the child's languages; and 3) assess how the neural organization for sentence comprehension may mediate the relationship between children's bilingual language proficiencies and English reading comprehension.

Spanish-English bilingual children (ages 7-12) completed two auditory sentence processing tasks that tapped into semantic and morphosyntactic demands while undergoing fNIRS neuroimaging. Theoretical perspectives on brain specialization given early exposure to bilingual experiences (Johnson, 2011; Hernandez et al., 2019; Kroll et al., 2015) suggest that dual language and reading experiences may influence the functional neural architecture supporting language comprehension. Yet, there is limited understanding of the neurobiology of language comprehension in young children (e.g. Brauer & Friederici, 2007; Knoll et al., 2012; Skeide et al., 2016), and even less is known about bilingual influences on the developing brain. We hypothesized that bilingual language experiences will have a cumulative impact on children's cortical specialization for language within the left inferior frontal and superior temporal gyrus during sentence processing, key regions underlying language comprehension in adults (Friederici, 2002; 2012).

Results revealed robust hemodynamic response in children's left IFG pOper, primary auditory cortex, and posterior STG while children were listening to sentences. We observed focal patterns of brain response to task related conditional contrasts; the ventral IFG triangular (pTri, BA 45) showed significant activity during sentence processing with specific semantic demands and dorsal IFG opercular (BA 44) showed significant activity during sentence processing with specific morphosyntactic demands. Bilingual spoken language competencies predicted brain activity within the pSTG and IFG, and directly predicted reading comprehension. We observed no relationships between children's brain activity during tasks of sentence processing and English reading comprehension. The present study is one of the first to investigate the neurocircuitry for sentence processing using fNIRS, among a relatively large sample of young bilinguals, and within the context of children's emerging literacy skills.

Neurocircuitry for Language Comprehension

Three key regions of interest showed strong activations when participants were listening to sentences in comparison to rest: the left inferior frontal gyrus opercular (IFG pOper, BA 44), left primary auditory cortex (PAC), and left posterior superior temporal gyrus (pSTG). Activity within these regions are in line with previous neurocognitive models of sentence processing in adults (Friederici, 2002; Binder et al., 2009; Hagoort & Indefrey, 2014) and the few studies on children (e.g. Knoll et al., 2012; Skeide, Brauer, & Friederici, 2014). The primary auditory cortex is involved in first-pass acoustic analysis where information from the speech signal is relayed onto higher-level processing within milliseconds after the onset of a spoken word (Marslen-Wilson 1987, 1990). Involvement of the temporal lobe, specifically pSTG and the middle temporal gyri (MTG), support phonological processing and making sound-to-meaning connections, and, is known for access to lexical representations (e.g. morphological units of language) and the integration of syntactic and semantic information during language processing (Binder et al., 2009; Friederici, 2012; Hickock & Poeppel, 2007).

The left IFG is generally involved in higher-order processing of sentences, specifically sentential semantics aspects in the IFG pTri and syntactic aspects in the IFG pOper (Friederici, 2012; Hagoort & Indefrey, 2014). Together, regions within the fronto-temporal network of auditory comprehension work in parallel to incrementally update the input representation and facilitate comprehension (Hagoort, 2005, 2013; Zacarella, Schell, Friderici, 2017). Although specific contributions of these areas to syntactic versus semantic analysis, broadly, is debated, involvement of the IFG, pSTG, and MTG on sentence processing are robust across an array of neuroimaging studies (Hagoort & Indefrey, 2014; Vigneau et al. 2006). In addition, contributions from other regions have also been implicated in sentence-level computations, such as the left anterior temporal lobe and the left temporoparietal junction (e.g. Bemis & Pylkkänen, 2013; Brennan & Pylkkänen, 2012; 2017; Friederici, 2012; Hickock & Poeppel, 2007).

Neural Specificity in Task Related Processing Demands

We observed focal patterns of brain response within the IFG and STG to task related conditional contrasts. The channel covering dorsolateral prefrontal cortex showed significant activity during processing of sentences with incongruent semantic associations (e.g. bounce-paper) and channel covering the ventral IFG triangular (pTri, BA 45) showed significant activity during processing of sentences with weak congruency in semantic association (e.g. break-glass), both conditions in comparison to sentences with strong congruency in semantic association (e.g. sing-song). These results are consistent with previous studies, mostly with adults, that show activity in the IFG pTri and the medial prefrontal cortex during tasks with higher semantic processing demands, such as in processing sentences with semantic violations (selection restriction or violation of world knowledge; e.g., Groen et al., 2010; Hagoort et al. 2004;

Kuperberg et al. 2000; Vandenberghe, Nobre, Price, 2002; Stringaris et al., 2007), semantic ambiguity (e.g. Rodd et al. 2012), and semantic complexity (e.g. Chen et al., 2008; Diaz & Hogstrom, 2011), where drawing meaning of the sentence required additional effort in comparison to other types of sentences. Children's behavioral data show that processing incongruent sentences took the longest response time (despite higher accuracy), suggesting that activity observed in the dorsolateral prefrontal cortex during this condition may be related to verbal working memory and maintaining information in active form in processing sentences that appear semantically unusual or strange (Nathaniel-James & Firth, 2002).

Channels covering dorsal IFG pOper and primary auditory cortex showed significant activity in processing of sentences with -ing omissions and the dorsal IFG pOper showed significant activity in processing of sentences with -ed and -s omissions, both conditions in comparison to grammatically correct sentences in the syntax task. These patterns of activations are consistent with previous neuroimaging studies, mostly with adults, comparing sentences with syntactic violations (e.g. Embick et al., 2000; Meyer, Friederici, von Cramon, 2000; Rüschemeyer et al., 2006) and syntactic ambiguities (e.g. Rodd et al. 2010), in contrast with correct sentences. Activity in the left IFG are consistent with recent findings on sentences processing with Spanish-English bilingual children who were exposed to both languages early in development (Arredondo et al., 2018). They observed greater activation in left IFG when children listened to sentences with errors on later acquired (-ed) than earlier acquired (-ing) morphemes in English.

Activity observed in the left PAC during ING > Correct condition may reflect the fact that omission of -ing morphemes within the sentence are perceptually easier to detect in comparison to omissions of -ed and -s units, thus involving the let PAC in early stages of phonological and spectrotemporal analysis. Children had the lowest behavioral accuracy and slowest response times in judging sentences with -ed and -s omissions, which may be reflected in the stronger activations observed within the IFG pOper given the difficulty of acquiring this particular grammatical feature in child language acquisition. This interpretation is supported by the general behavioral results of task accuracy and response time. Children had relatively high accuracy in judging sentences with grammatically correct verb endings and sentences where –ing verb endings were omitted, supporting the developmental trajectory of acquiring morphosyntax grammar rules and tense marking, where -ing and -ed/-s omissions are considered early and later acquired morphemic features, respectively (Peña, Bedore & Kester, 2015; Rice, Wexler & Hershberger, 1998). This pattern is also seen in the response times differences across conditions, where the later acquired grammatical rules (e.g. past-tense and present-tense 3rd person singular omissions) show longer response times in comparison to correct sentences or sentences with earlier acquired (e.g. present participle) grammatical rules.

Bilingual Brain to Behavior Relationships

Bilingual language proficiencies had a direct influence on children's brain activity during tasks of sentence processing. Children with more balanced dual-language experiences and proficiencies showed greater recruitment of left inferior frontal regions and children with greater English, than Spanish, proficiency showed greater recruitment of the left temporal regions during sentence processing. These results speak to the growing theoretical frameworks linking early-life experiences with the brain bases of language and cognition (Hernandez et al., 2018; Kovelman & Marks, 2019).

Neurocognitive perspectives suggest that structural and functional brain development arises as a result of complex interactions between neurobiology and individual experiences

(Johnson, 2011). In the case of language processing, cortical regions develop their functional specificity given linguistic experiences and neural maturational processes (Kuhl, 2010; Kroll et al., 2015; Werker & Hensch, 2015). The specificity of language, as characterized by increasingly focal and left-lateralized activation patterns, naturally presents two related interpretations on how quantifiable changes in brain activity are related to developmental experiences. One viewpoint suggests that individuals with greater language abilities may show less neural activity in comparisons to those with lower language abilities (Knoll et al., 2012; Raizada et al., 2008), suggesting more efficient use of neural resources (Prat, Keller & Just, 2007). This idea of requiring less processing power under certain linguistic contexts is also seen in the classic 'N400 effect', where semantic-priming paradigms elicit a response of smaller event-related potential (ERP) amplitude for conditions in which the contexts is "semantically supportive." Modulation of the N400 effect under varying contexts and within neuroanatomical frameworks has been influential in understanding how language is encoded in the brain (Lau, Phillips, & Poeppel, 2008).

On the other hand, enriched language experiences (as is provided by early dual-language experiences) may also result in greater measurable brain activity as broader language knowledge draws upon richer linguistic representations and competes for and shares resources (Hernandez, 2013; Li, Legault, & Litcofsky, 2014; MacSwan, 2017). To this end, Li and colleagues (2014) present bilingualism as "non-linear dynamical system" in which language experiences influence the brain differently than observed in monolinguals, even when the two groups are equally comparable across behavioral measures of language competency. The latter account supports the current findings of this dissertation study, where, in a sample of young bilinguals with balanced dual-language proficiencies, greater Spanish proficiency positively related to greater activations in the left IFG across both sentence processing tasks. These results are in line with the recent 'Integrated Multilingual Model' that suggests bilinguals have both shared and discrete competencies in each of their languages, while also recognizing that bilinguals' two linguistic systems interact to support brain functionality for language (MacSwan, 2017).

Brain Activity in Relation to Reading Comprehension

We did not observe any direct or indirect relationships between brain activity as related to sentence processing and reading comprehension outcomes. Language and reading comprehension are both complex and multi-faceted skills that requires one to compute several operations in parallel, such as composing sentence structure and forming meaning while inhibiting irrelevant information (Hagoort, 2017). Thus, it is no surprise that this complex ability is reflected in brain activity across several regions within a larger processing network (Hickock & Poeppel, 2017). The lack of an association between brain activity during English auditory sentence comprehension tasks and reading comprehension suggests that the current method of modeling may not have captured the many operations involved in these dynamic processes. A natural next step and future direction is to look at functional connectivity patterns within and across key regions and in relation to children's bilingual language and reading comprehension outcomes.

Chapter IV

General Discussion

This dissertation study assessed the behavioral and neural processes underlying emergent literacy skills in early-exposed Spanish-English bilingual children (ages 7-12) and investigated how the functional organization of the bilingual developing brain is shaped by bilingual languages experiences and proficiencies. The design and method of the dissertation included functional Near-Infrared Spectroscopy (fNIRS) neuroimaging during two auditory language comprehension tasks, as well as, an extensive battery of behavioral language and cognitive assessments in both languages. Through two related studies, this dissertation addressed the overarching hypothesis that bilingual children's language and literacy skills interact, where knowledge across the child's two language may be independent and interdependent across varying linguistic contexts and processing domains (Cummins, 1979; MacSwan, 2017; Proctor et al., 2010). A neurocognitive model of brain development parallels this very notion and proposes that structural and functional brain development arises as a result of complex interactions between neurobiology and individual experiences (Hernandez, 2018; Johnson, 2011). Collectively, this framework posits that early-life bilingual experiences influence the concomitant neural architecture underlying language and cognition (e.g. Li, Legault, & Litcofsky, 2014).

In Chapter 2, I examined the core components of literacy (phonological awareness, word reading skills, semantic and grammar knowledge) and how they relate within and across the child's two languages to support reading comprehension. Three main findings emerged from this study. First, bilingual children’s language and literacy skills were best represented by latent variables as shared (phonological awareness) and unique (semantic and grammar knowledge) competencies across languages. Second, reading in one language supported reading in another at the word- and passage- level. Bilingual spoken language proficiencies and phonological awareness predicted word reading skills, which directly predicted Spanish but not English reading comprehension. Spanish reading comprehension predicted English reading comprehension. Third, SES and the approximate number of hours a child speaks Spanish in a typical week, made significant contributions to bilingual language and reading outcomes. SES was positively associated with phonological awareness and Spanish and English spoken language proficiencies. Spanish use was positively associated with Spanish language proficiency.

Overall, the results from this study support the *continuum* model of language interdependency (Proctor et al., 2010). The findings from this study highlight that Spanish language and literacy skills directly contributed to children’s development of English literacy skills, including at the passage comprehension level. This relationship is likely driven by an interaction among bilingual children’s English language and reading practices, as well as, Spanish language use on a regular basis (Bohman et al., 2010), which directly contributed to children’s overall Spanish spoken language and reading comprehension. Parental questionnaire data shows that the majority of children in this study are growing up in an English dominant community with English as the primary language of instruction in school. These findings make a critical contribution to understanding bilingual literacy development and suggest educational and social practices raise awareness to the fact that children’s different home language should be viewed as a resource to be encouraged and used, particularly in early development (Durgunoglu, 2017).

In Chapter 3, I examined how early bilingual exposure and dual-language proficiencies influence children's functional organization for spoken language processing. Participants listened to two auditory sentence processing tasks tapping into semantic and morphosyntactic knowledge during fNIRS neuroimaging. Four main findings emerged from this study. First, I observed significant hemodynamic response in children's left inferior frontal gyrus pOper (BA 44), primary auditory cortex, and posterior superior temporal gyrus while children were listening to sentences (both tasks) compared to rest. Second, I observed focal patterns of brain response to task related conditional contrasts; the ventral IFG triangular (pTri, BA 45) showed significant activity during sentence processing with specific semantic demands and dorsal IFG opercular (BA 44) showed significant activity during sentence processing with specific morphosyntactic demands. Third, bilingual spoken language competencies directly related to brain activity within the pSTG and IFG. Fourth, we observed no relationships between children's brain activity during tasks of sentence processing and English reading comprehension.

Results from this study are in line with previous neural models of language comprehension, reflecting brain activity within key left IFG and pSTG regions for overall sentence processing and focal patterns of activity within the left IFG for task specific conditions (Hickock & Poeppel, 2015; Friederici, 2012; Skeide, Brauer, & Friederici, 2014). The data further support the hypothesis that enriched language experiences, as provided by early bilingual experiences, influence the brain functionality for processing language (Hernandez, 2018; Johnson, 2011; MacSwan, 2017). Language and reading comprehension are both dynamic skills that requires one to compute several operations in parallel and involves the coordinated functionality of several language processing regions. The systematic understanding of this complex, yet everyday computation, is primarily based on adult and monolingual models of brain development. This dissertation study is one of the few to examine how bilingual experiences influence this neurodevelopmental process, thereby informing the neurobiology of language literature to account for bilingual and cross-linguistic models of development.

Unique Strengths

This dissertation presents unique methodological strengths worth highlighting. A relatively large number of families participated in the research study. All participants were early-exposed Spanish-English bilingual children that vary in their dual-language experiences and proficiencies (Pena, Bedore, Kester, 2015). Thus, we were able to take a closer examination at understanding how variations *within* Spanish-English bilingual experiences shape language, literacy, and brain development. One major contribution of this method, theoretically and given its social and educational implications, is that findings need not be interpreted to reflect traditional binary group (monolinguals, bilinguals) comparisons where monolingual development is considered the "norm" (Surrain & Luk, 2017).

Further, the present study used language assessments specifically designed to capture developmentally appropriate language skills within Spanish-English bilingual children growing up in the U.S., in both languages (Peña et al., 2014, 2018). These assessments were designed specifically in response to the need for valid, reliable instruments for assessment of speech and language ability, along a continuum, in Spanish-English bilingual children. As mentioned before, some parts of the assessment allow for child responses to the items in either of the child's languages. The assessment will continue to be developed with the inclusion of the data from this sample of Spanish-English bilingual children from Michigan, adding to the variability of unique bilingual skills from this region of the country as compared to Texas, where the assessment is being developed. An additional methodological strength worth noting is that we use subject specific MR images to co-register and localize the positions of the fNIRS optodes (at least with a subset of participants). Studies that have registered fNIRS optodes on MR images is scarce, although significant progress has been made over the past few years (e.g., Emberson, Richards, & Aslin, 2015).

Limitations

The present research has some limitations that should be addressed. For the purpose of this dissertation study, both exploratory and confirmatory factor analyses in Study 1 were computed on the same sample of participants. Future analyses should test the measurement model established here with a separate sample of participants (Klein, 2010). In both Study 1 and Study 2 modeling, we did not test bi-directional relations between language and literacy variables of interest, direct paths between indicators (e.g. English semantic knowledge) within a latent variable and other key variables of interest (e.g. word reading), or mediating/moderating paths between SES and Spanish use and language and literacy outcomes. Research suggests that SES may be a significant moderator between bilingual language development and reading comprehension (Melby-Lervag & Lervag, 2014) and this is worth testing in future analyses.

In the fNIRS analyses, only left hemisphere fNIRS channels showed brain activity are reported in Study 2. Moving forward, it is important that we also examine right hemisphere homologues and as well as other bilateral regions (e.g. MTG & ATL; Hagoort & Indefrey, 2014). To this end, fNIRS analyses was computed (but not interpreted) for both oxygenated (HbO) and deoxygenated hemoglobin concentration (HbR), while only HbO are reported here. In the next step, the same analyses will be completed on HbR values.

Future Directions

Two foreseeable future directions are in line to be explored. In the process of conducting this research study, we have identified a sub-set of children who scored below age and grade level norms for reading comprehension in both English and in Spanish. Specific reading comprehension deficit (S-RCD) affect 10% of the population, where children struggle with reading comprehension despite adequate word level reading and intelligence (Landi & Ryherd, 2017). A traditional and logical approach to treating reading deficits in the U.S. is to foster children's English literacy skills. In bilinguals, this often comes at the expense of developing children's heritage language skills. Thus, as a next step, we will explore the neural profiles of bilingual children with a potential risk for reading deficits and aim to identify their cross-linguistic variability and their impact on bilingual language and literacy outcomes.

The current neuroimaging analyses take a region of interest approach to understanding brain activity and relating it to the behavioral variables of language and literacy in bilingual children. Currently, this method is informative within the field of bilingual development as it builds on previous monolingual models and provides foundational understanding of the specializations of the individual regions within a larger network. A probable future direction is to analyze patterns of interactions among brain regions to gain a network perspective of the developing brain and appropriately model trajectories of development longitudinally.

Broader Implications

The overarching prediction of this dissertation was that children with a more balanced bilingual exposure and proficiency will have better English reading proficiency. Specific implications of this overarching framework are as follows. First, children who are receiving formal education in English during the regular school day will experience additional benefits from learning to read in Spanish during their afterschool hours. Second, I found that children's phonological awareness skills in Spanish and English are shared across the two languages and that those with greater phonological awareness were better at word-reading in both languages (i.e. more balanced readers at the word-level). The implication of this finding suggests that word reading skills, such as knowledge of alphabet and phonological awareness, gained in the child's heritage language may directly transfer to benefit their word reading skills in English. Third, I found that children with more balanced spoken and reading proficiency in their two languages show heightened activation in left IFG region traditionally associated with heightened sensitivity to language and the ability to learn new language rules.

To conclude, this dissertation study highlights the value of the heritage language in bilingual development, especially where English is the language of the larger community. The findings of this dissertation showcase the unique linguistic strengths bilingual children bring to U.S. classrooms and shed light on how supporting the development of English language skills in young bilinguals need not devalue children's heritage language knowledge. This interdisciplinary approach has the potential to yield exciting new insights into the brain and behavior of the developing child and carries theoretical implications for understanding acquisition in typical development and in language and reading disorders, across different populations of learners.

Tables

Table 1 Descriptive statistics of child and parent/family background variables.

	N	*M (SD)*	Range
Child Variables			
Age (years)	132	8.75 (1.41)	6,8 - 11,8 (y, m)
Age of First word in Spanish	132	1.02 (0.40)	4 - 24 m
Age of First word in English	132	2.39 (1.30)	1 - 60 m
Age at which child started reading in Spanish[a]	132	5.28 (1.29)	1 - 7
Age at which child started reading in English[a]	132	5.14 (1.07)	3 - 7
Hours speaking English[b]	132	135.87 (19.5)	95 - 195
Hours speaking Spanish[b]	132	57.33 (17.3)	11 - 94
% of English Input & Output[b]	132	70.40 (8.52)	52.60 - 94.09
% of Spanish Input & Output[b]	132	29.60 (8.52)	6.0 - 47.40
Children receiving Spanish instruction in school	13	10%	
% of Children attending ENL[c]	35	27%	
Parent & Family Variables			
Parent 1 Education[d]	127	2.83 (1.13)	1 - 4
Parent 2 Education[d]	117	2.85 (0.99)	1 - 4
1. Primary & Secondary School	41	17%	
2. GED & Associate’s Degree	37	15%	
3. Bachelor’s Degree	86	35%	
4. Master’s & Doctoral Degree	80	33%	
Household Income	125	2.46 (0.75)	1 - 4
1. < $12,000	14	11%	
2. $12,000 - $50,000	44	35%	
3. $50,000 - $100,000	62	50%	
4. > $100,000	5	4%	
Subjective Social Status – Community Level[f]	126	7.80 (2.05)	2 - 11
Subjective Social Status – National Level[f]	126	6.74 (2.16)	1 - 11
Children qualified for Free/Reduced Lunch	39	30%	

[a] Options for responses on age at which child started reading in Spanish or English are the following: (1) 3 years or earlier; (2) 4 years; (3) 5 years; (4) 6 years; (5) 7 years or later

[b] Number of hours speaking each language in a typical week and percentage of English and Spanish language use determined using the Bilingual Input Output Survey (Peña et al., 2014)

[c] En Nuestra Lengua; Saturday heritage language school based in Ann Arbor

[d] Breakdown of parental education Ns and percentages include the count of both parents’ (when applicable) responses to each level and percentages were calculated from a total of 244 parent responses (p1 = 127, p2 = 117)

[e] Breakdown of household income shows number of responses to each level and percentages were calculated from total 125 responses received

[f] Parent responses from the McArthur Subjective Socioeconomic Status questionnaire along two dimensions – at the community level and at the national level.

Table 2 Descriptive statistics of assessments of language, literacy, and cognition. Standard scores are reported for the Woodcock assessments while raw scores are reported for BESA-ME language assessments (percent correct) and WISC-R Digit Span measuring verbal working memory.

		M (SD)		
	N	**English**	**Spanish**	***t, p***
Woodcock Assessments[a]				
Sound Awareness	109	107 (19)	102 (19)	3.29, .001
Word ID	127	110 (13)	103 (29)	3.78, .000
Passage Comprehension	121	98 (12)	84 (21)	9.89, .000
BESA-ME[b] (raw scores)				
Semantic Knowledge	120	76 (15)	64 (21)	6.96, .000
Morphosyntax Knowledge Total	117	89 (11)	66 (23)	11.35, .000
Cloze Items	118	86 (16)	64 (27)	9.45, .000
Sentence Repetition	117	91 (12)	66 (25)	10.13, .000
WISC-R Digit Span[c] (raw scores)				
Forward	114	8.23 (.18)	-	
Backward	114	6.17 (.23)	-	

Note.
[a] English: Woodcock-Johnson III Normative Update (Tests of Achievement, Woodcock, McGrew & Mather, 2001) and Spanish: Batería III Woodcock-Muñoz Normative Update (Pruebas de Aprovechamiento, Woodcock et al., 2004; 2007)
[b] Bilingual English Spanish Assessment – Middle Elementary (Peña et al., 2018). Percentage correct from raw scores are reported for each BESA-ME assessment as a standard score is not available for this experimental version of the task. Percentage correct were calculated from possible raw scores for each subtest in each language.
[c] Forward & Backward subtests of the WICS-V Memory for Digit Span (Wechsler, 2014a); showing raw scores out of total 18 trial

Table 3 Correlations among study variables.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Demographics	1. Hours speaking English (child)	-																	
	2. Hours speaking Spanish (child)	**-.52**	-																
	3. Parent 1 Education	**.25**	-.24	-															
	4. Parent 2 Education	.12	-.10	**.71**	-														
	5. Household Income	.13	-.07	**.62**	**.77**	-													
	6. Subj. Social Status - Community	.02	.04	.10	**.38**	**.33**	-												
	7. Subj. Social Status - National	.12	-.16	**.54**	**.61**	**.61**	**.55**	-											
	8. Digit Span (backward)	.09	**-.30**	.23	**.29**	**.27**	.12	.21	-										
BESA-ME	9. English Semantics	**.31**	-.19	**.44**	**.32**	**.26**	.17	**.31**	.24	-									
	10. English Morphosyntax	**.34**	**-.35**	.23	**.25**	.16	**.28**	**.42**	.17	**.63**	-								
	11. Spanish Semantics	-.17	.24	**.29**	**.41**	**.26**	-.02	.14	.22	**.25**	.07	-							
	12. Spanish Morphosyntax	-.15	**.37**	.16	**.33**	**.26**	.02	.11	.10	.12	-.01	**.67**	-						
Woodcock Johnson/Munoz	13. English Sound Awareness	**.27**	-.08	**.32**	**.30**	.11	.13	.16	.18	**.60**	**.50**	.16	.05	-					
	14. English Word ID	.13	-.06	**.33**	**.26**	.24	.15	.20	**.30**	**.66**	**.41**	**.35**	.24	**.59**	-				
	15. English Passage Comprehension	**.26**	-.11	**.33**	**.34**	.23	.13	.19	.24	**.73**	**.56**	**.40**	.22	**.67**	**.78**	-			
	16. Spanish Sound Awareness	.01	.09	**.35**	**.42**	.23	.08	.07	**.35**	**.47**	**.30**	**.52**	**.48**	**.63**	**.66**	**.65**	-		
	17. Spanish Word ID	-.05	.16	**.35**	**.32**	.19	-.03	.06	.14	**.42**	.18	**.56**	**.50**	**.42**	**.71**	**.51**	**.72**	-	
	18. Spanish Passage Comprehension	-.14	.24	.19	**.30**	.15	-.01	.02	.20	**.42**	.14	**.69**	**.66**	**.36**	**.68**	**.59**	**.73**	**.83**	-

Note. Significant two-tailed partial correlations (controlling for age and gender) are in boldface. Correlations greater than .42 are at the $p < .001$ level; correlations equal to and in between .33 and .42 are at the $p < .01$ level; and correlations equal to and under .32 are at the $p < .05$ level.

Table 4 Fit Statistics for measurement models and structural mode

Model	χ^2	*df*	CFI	TLI	RMSEA	SRMR
Measurement models						
Language skills						
Model A: 2 factor	131.26***	64	.94	.91	.089	.043
Model B: 3 factor°	80.25**	52	.97	.95	.031	.031
Model C: 4 factor	57.59*	41	.98	.96	.024	.024
Socioeconomic status						
Model D: 1 factor	52.48^	5	.85	.67	.269	.069
Model E: 1 factor°	1.17	2	1.0	1.0	.000	.010
Structural model						
Model F: full model	325.43***	209	.94	.93	.065	.058

Note. *** $p < .001$ ** $p < .01$ * $p < .05$ ^model did not converge °final measurement models

Table 5 Study 1 factor loadings for observed variables on latent variables in measurement model

	Model A		**Model B**		Model C		Model D		**Model E**	
Observed Variable	Factor Structure	Loading (SE)	Factor Structure	Loading (SE)	Factor Structure	Loading (SE)	Factor Structure	Loading (SE)	Factor Structure	Loading (SE)
Language skills										
Eng. BESAME Semantics	1	0.70 (.07)	1	0.52 (.14)	1	0.41 (.16)				
Eng. BESAME Syntax 1	1	0.59 (.08)	1	0.75 (.08)	1	0.56 (.18)				
Eng. BESAME Syntax 2	1	0.65 (.09)	1	0.51 (.15)	1	0.52 (.14)				
Spn. BESAME Semantics	2	0.67 (.07)	2	0.53 (.08)	2	0.63 (.11)				
Spn. BESAME Syntax 1	2	0.95 (.02)	2	0.97 (.05)	2	0.95 (.06)				
Spn. BESAME Syntax 2	2	0.85 (.05)	2	0.70 (.07)	2	0.90 (.08)				
Eng. WJ SA Deletion	1	0.72 (.07)	3	0.60 (.12)	3	0.79 (.21)				
Eng. WJ SA Substitution	1	0.82 (.04)	3	0.57 (.12)	3	0.66 (.20				
Eng. WJ SA Reversal	1	0.67 (.07)	3	0.47 (.14)	3	0.46 (.24)				
Eng. WJ SA Rhyming	1	0.81 (.07)	3	0.56 (.16)	4	0.64 (.17)				
Spn. WM SA Deletion	1	0.64 (.07)	3	0.93 (.12)	3	0.83 (.16)				
Spn. WM SA Substitution	1	0.74 (.06)	3	0.83 (.06)	3	0.91 (11)				
Spn. WM SA Reversal	1	0.79 (.06)	3	0.85 (.09)	3	0.72 (13)				
Spn. WJ SA Rhyming	1	0.55 (.08)	3	0.74 (.13)	4	0.57 (.18)				
Socioeconomic status										
Parent 1 Education							1	.78 (.04)	1	.80 (.04)
Parent 2 Education							1	.89 (.03)	1	.90 (.03)
Household Income							1	.74 (.05)	1	.76 (.04)
Subjective Status – Community							1	.53 (.07)	-	-
Subjective Status – National							1	.81 (.04)	1	.76 (.05)

Note. Factor loadings for observed variables on latent variables from EFA in establishing a measurement model. The only observed variables removed during EFA was the Subject Status – Community measure. Model B and Model E were the final measurement models tested in the full SEM. SA = Sound Awareness.

Table 6 Standardized indirect path effects

		β	s.e.	*p*
Word Reading	SES	-.41	.10	.000
	Spanish Use	-.11	.07	.111
English Reading Comprehension	SES	.20	.07	.003
	Spanish Use	-.04	.04	.293
	English LC via Word Reading	.02	.03	.650
	Phonological Awareness via Word Reading	-.03	.07	.655
Spanish Reading Comprehension	SES	.12	.03	.001
	Spanish Use	.11	.03	.001
	Spanish LC via Word Reading	.09	.03	.012
	Phonological Awareness via Word Reading	.24	.08	.002

Table 7 Participant inclusion and exclusion details

	fNIRS Experimental Tasks	
	Semantics	Syntax
Behavioral inclusion (Chapter II)	132	132
Medications	6	6
Concussions	2	2
Left handed	4	4
Imaging inclusion	122	122
No NIRS data	11	18
Task accuracy <65%	0	12
Noisy channels >40%	4	5
FINAL (Chapter III)	107	87

Table 8 Descriptive statistics of participants included in Chapter 3 (Study 2)

	Semantics (n = 107)		Syntax (n = 87)	
Age (years)	8.75 (1.4)		9.0 (1.3)	
Gender	57 females		59 females	
English:Spanish Input & Output %	70:30 %		71:29 %	
	English	**Spanish**	**English**	**Spanish**
Woodcock Assessments (standard scores)				
Sound Awareness	107 (19)	103 (20)	110 (18)	105 (18)
Word ID	111 (13)	104 (28)	112 (12)	108 (26)
Passage Comprehension	99 (12)	85 (21)	100 (11)	87 (19)
BESA-ME (raw scores)				
Semantic Knowledge	76 (15)	64 (21)	80 (14)	67 (21)
Morphosyntax Knowledge	89 (11)	67 (22)	92 (8)	69 (22)
WISC-R Digit Span (raw scores)				
Forward	8.3 (2.0)		8.6 (1.9)	
Backward	6.3 (2.6)		6.5 (2.6)	
	Accuracy	**RT (ms)**	**Accuracy**	**RT (ms)**
Experimental Task				
Overall	89 (8)	3137 (245)		
Strong Congruency	88 (11)	3101 (377)		
Weak Congruency	86 (12)	3095 (365)		
Incongruent	93 (8)	3215 (376)		
Overall			86 (8)	3182 (429)
Correct			92 (9)	3062 (509)
ING Omission			95 (8)	3152 (437)
ED & S Omission			73 (17)	3333 (413)

Table 9 Statistical results for brain activity in key regions of interest.

	Region (left)	Channel	Brodmann Area	MNI coordinates (x y z)	β	t	p	q
Semantics Task v Rest	Inferior Frontal Gyrus opercular	4	44	-57 20 14	2.65	3.32	.001	.008
	Primary Auditory Cortex	7	41	-63 -21 -5	3.01	3.18	.002	.010
	posterior Superior Temporal Gyrus	9	22	-62 -40 19	3.53	3.18	.002	.010
WCon > SCon	Inferior Frontal Gyrus triangular	1	45	-53 37 -11	0.48	1.98	.048	.625
InCon > SCon	Dorsolateral Prefrontal Cortex	2	46	-52 38 12	0.48	2.12	.034	.625
Syntax Task v Rest	Inferior Frontal Gyrus opercular	4	44	-57 20 14	3.22	3.73	.000	.003
	Primary Auditory Cortex	7	41	-63 -21 -5	5.01	4.73	.000	.000
	posterior Superior Temporal Gyrus	9	22	-62 -40 19	6.06	5.05	.000	.000
	Visual Association Cortex	15	19	-44 -93 -2	3.56	2.64	.009	.045
ING > Correct	Dorsolateral Prefrontal Cortex	2	46	-52 38 12	0.63	2.39	.017	.105
	Inferior Frontal Gyrus opercular	4	44	-57 20 14	0.97	3.68	.000	.013
	Primary Auditory Cortex	7	41	-63 -21 -5	1.03	2.42	.016	.105
	Supramarginal Gyrus	8	40	-62 -19 18				
ED & S > Correct	Inferior Frontal Gyrus opercular	3	44	-57 17 -9	1.04	3.12	.002	.031
	Inferior Frontal Gyrus opercular	4	44	-57 20 14	0.78	3.05	.003	.036

Table 10 Sentence modeling results. Standardized beta values, standard error, and p

		Semantics Model			Syntax Model		
Outcome variable	**Predictor**	β	se	*p*	β	se	*p*
Inferior Frontal Gyrus (IFG pOper)	English LC	.18	.16	.276	-.43	.17	.013
	Spanish LC	-.11	.16	.499	.31	.14	.027
	Age	0.16	.13	.199	-.13	.13	.340
Primary Auditory Cortex (PAC)	English LC	.52	.14	.000	-.26	.18	.166
	Spanish LC	0.19	.15	.189	.14	.15	.360
	Age	-.34	.12	.004	-.13	.14	.328
Posterior STG (pSTG)	English LC	.35	.15	.018	.40	.18	.027
	Spanish LC	-0.08	.14	.57	-.03	.14	.863
	Age	-.29	.12	.015	-.49	.12	.000
WCon > SCon	English LC	-.04	.25	.782	-	-	-
	Spanish LC	.281	.14	.045	-	-	-
	Age	-.11	.12	.395	-	-	-
ED&S > Correct	English LC	-	-	-	-.32	.14	.091
	Spanish LC	-	-	-	-.01	.15	.982
	Age	-	-	-	.17	.14	.232
English Reading Comprehension	PA	.44	.12	.000	.36	.14	.009
	English LC	.48	.13	.000	.57	.18	.001
	Spanish LC	-.08	.07	.220	-.06	.14	.36
	IFG pOper	.04	.05	.374	.02	.06	.765
	PAC	-.09	.05	.095	.04	.08	.579
	pSTG	-.01	.05	.825	-.04	.08	.620
	WCon > SCon	.01	.05	.775	-	-	-
	ED&S > Correct	-	-	-	.06	.07	.348
	Age	.18	.06	.004	.16	.08	.044
Phonological Awareness (PA)	Age	.51	.07	.000	.51	.07	.000
Eng. Language Comprehension (LC)	Age	.57	.07	.000	.60	.07	.000
Span. Language Comprehension	Age	.49	.07	.000	.47	.08	.000

Table 11 Correlations among latent variables and between individual channels activated during sentence processing tasks as tested in Figure 7 and Figure 8 structural models.

Semantics Task	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1. Phonological Awareness							
2. English LC	.78***						
3. Spanish LC	.53***	.41***					
4. IFG pOper							
5. PAC				.26**			
6. pSTG				.22*	.27**		
7. WCon > SCon				-.24*	.03	-.04	

Syntax Task	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1. Phonological Awareness							
2. English LC	.81***						
3. Spanish LC	.52***	.41***					
4. IFG pOper							
5. PAC				.28**			
6. pSTG				.05	.47***		
7. ED&S > Correct				-.01	-.39***	.13	

Figures

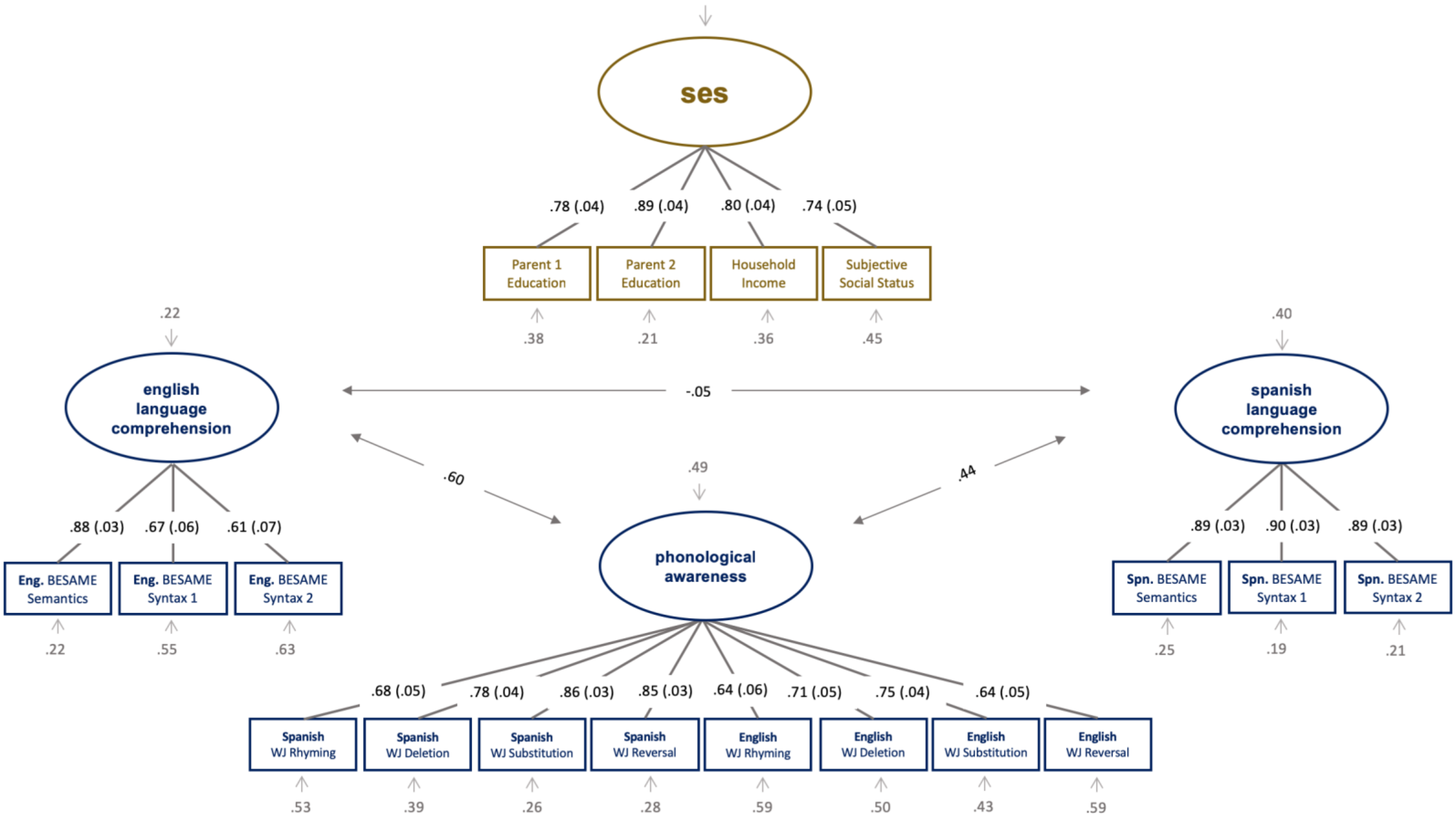


Figure 1 Factor loadings for each latent construct for the final measurement models. All factor loadings from the observed variables to the latent constructs and correlations between latent constructs shown are significant p < .01, except for the correlation between English and Spanish oral language latent constructs (r = - .05). Arrows pointing to each indicator show residual variance.

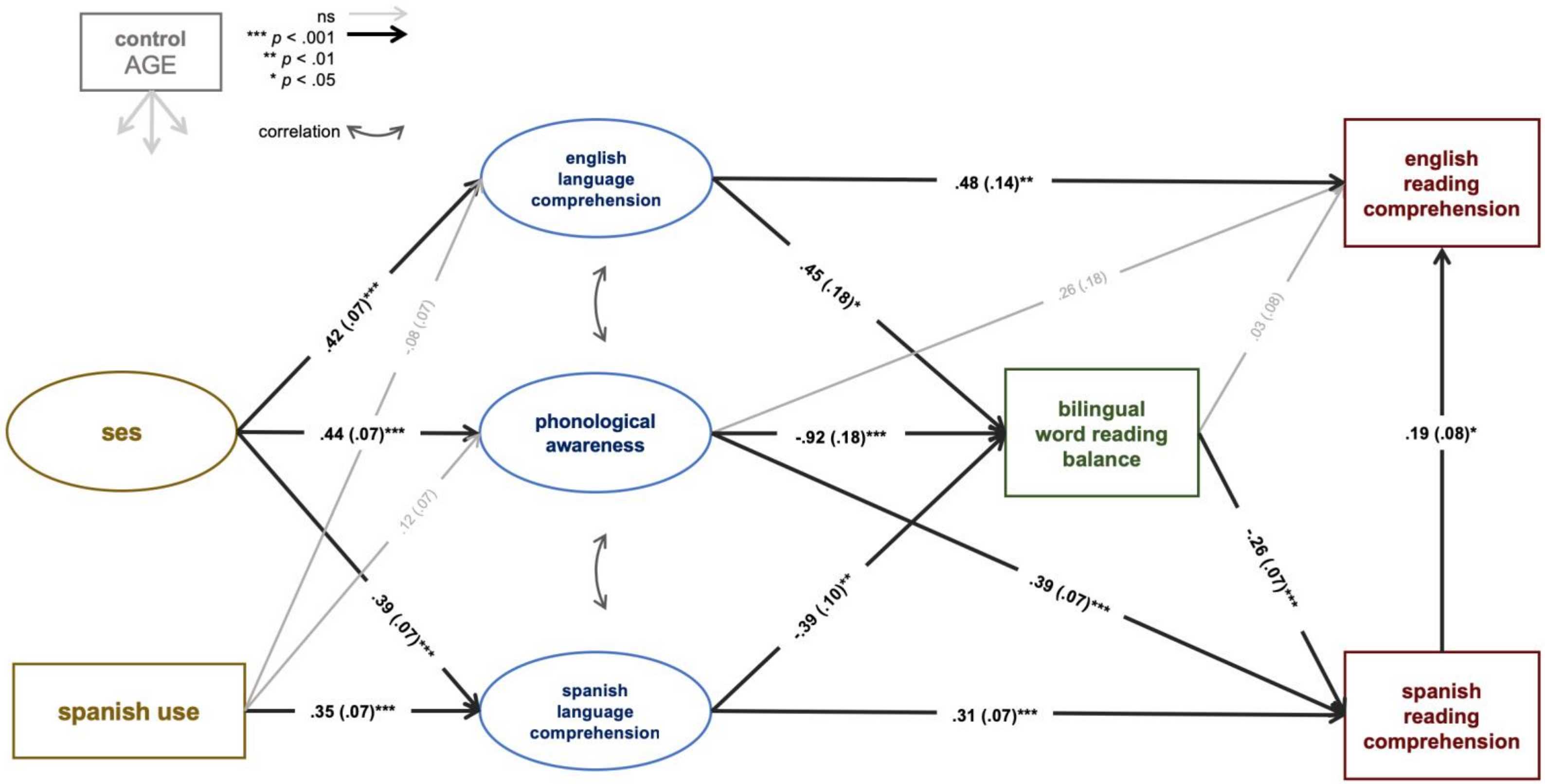


Figure 2 Structural model with standardized beta-coefficients (standard error; Model F). Solid black lines indicate significant paths and grey lines indicate non-significant paths. Curved, double-headed arrows represent correlations.

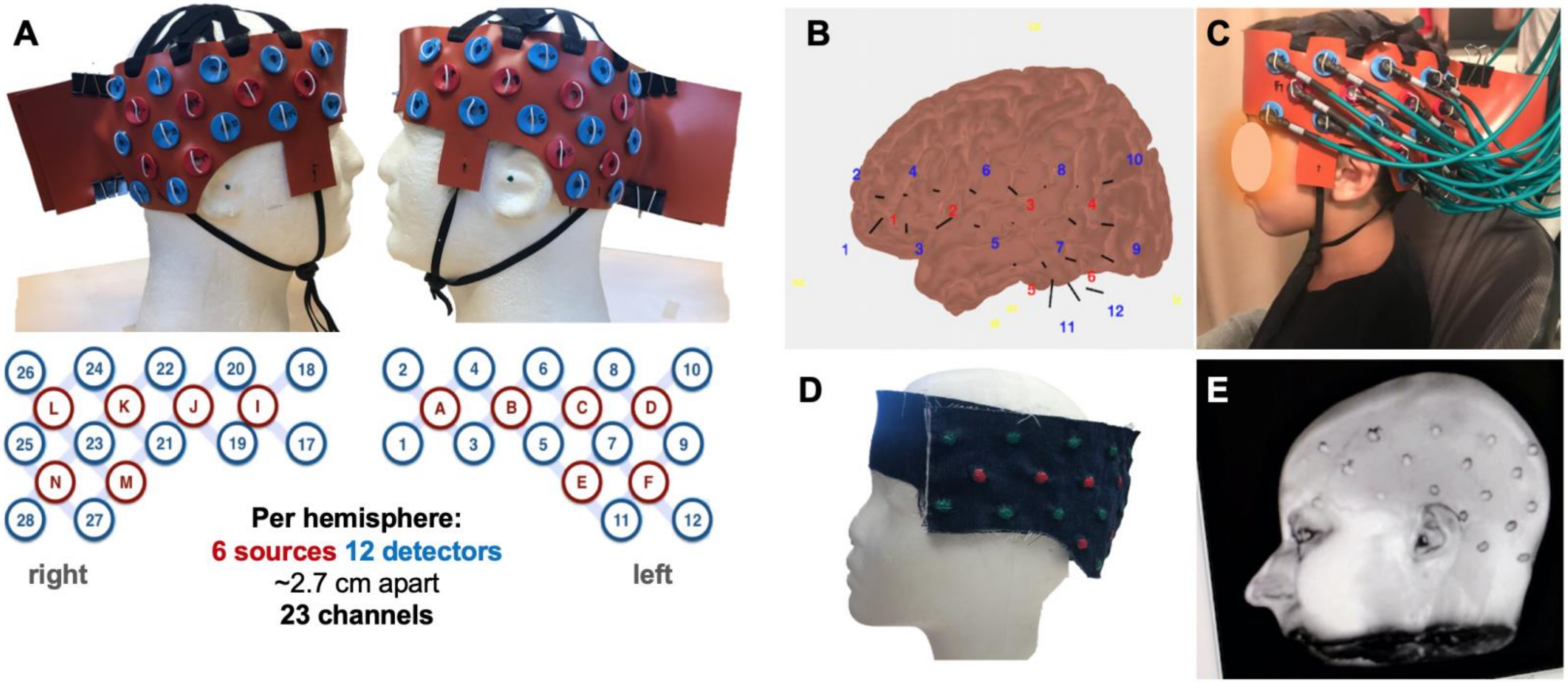


Figure 3 fNIRS localization efforts. fNIRS probe-set layout (A) where sensors are mounted onto a custom-built head cap constructed from silicone-rubber material, (B) schematic showing estimated brain regions covered by the set probe design as digitized using AtlasViewer GUI (Aasted et al., 2015)., (C) participant wearing fNIRS experimental cap during data acquisition, (D) MRI version of the cap with vitamin-e capsules, and (E) visualization of vitamin-e capsules on skull.

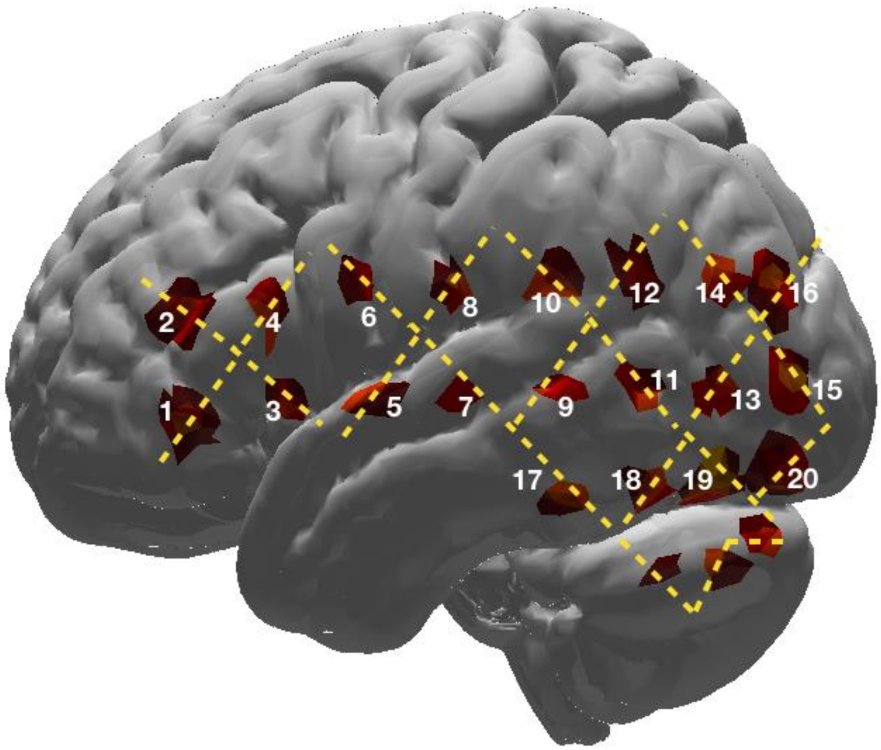


Figure 4 Estimated channel localization. Channel mid-point (and standard deviation) in red as localized from a subset of 18 participants using the cap in Figure 3D. Channel estimations are plotted on the MNI 152 template.

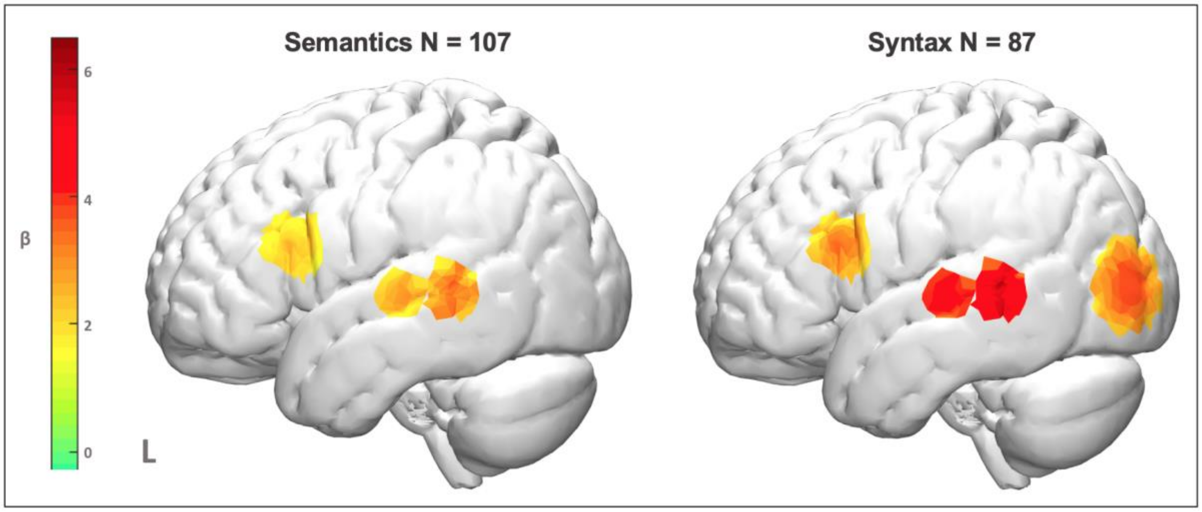


Figure 5 Task v rest brain activity during sentence processing. Children's brain responses during the two sentence processing tasks (task > rest, statistical significance at Benjamini-Hochberg FDR-corrected, $q < .05$). Color bar reflects beta-values from group-level GLM mapped onto the 3D brain template.

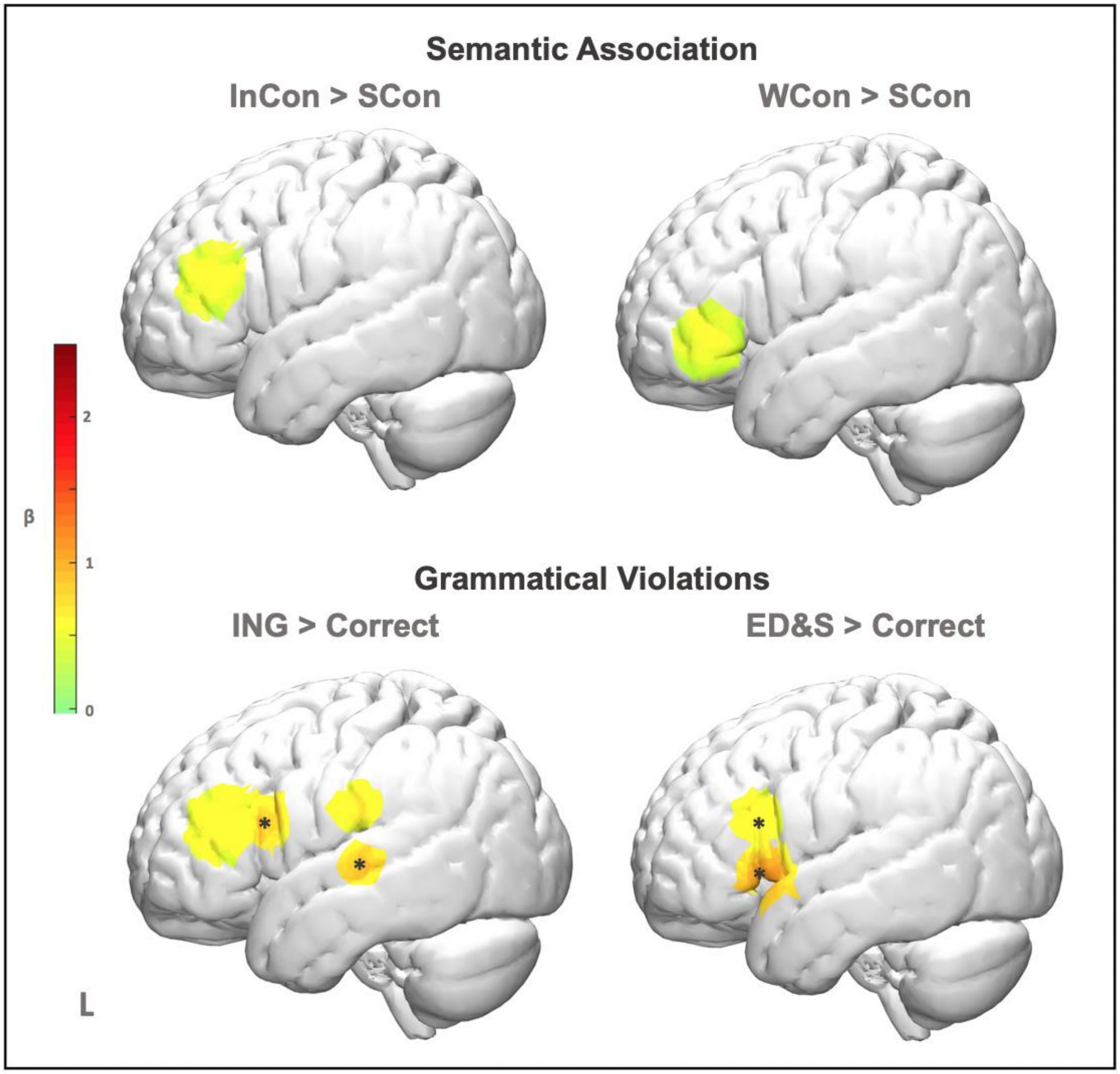


Figure 6 Brain activity for conditional contrasts. Children's brain responses for task specific conditional contrasts (statistical significance at $p < .05$; Asterix indicate channels significant at FDR corrected $q < .05$). Color bar reflects beta-values from group-level GLM mapped onto the 3D brain template

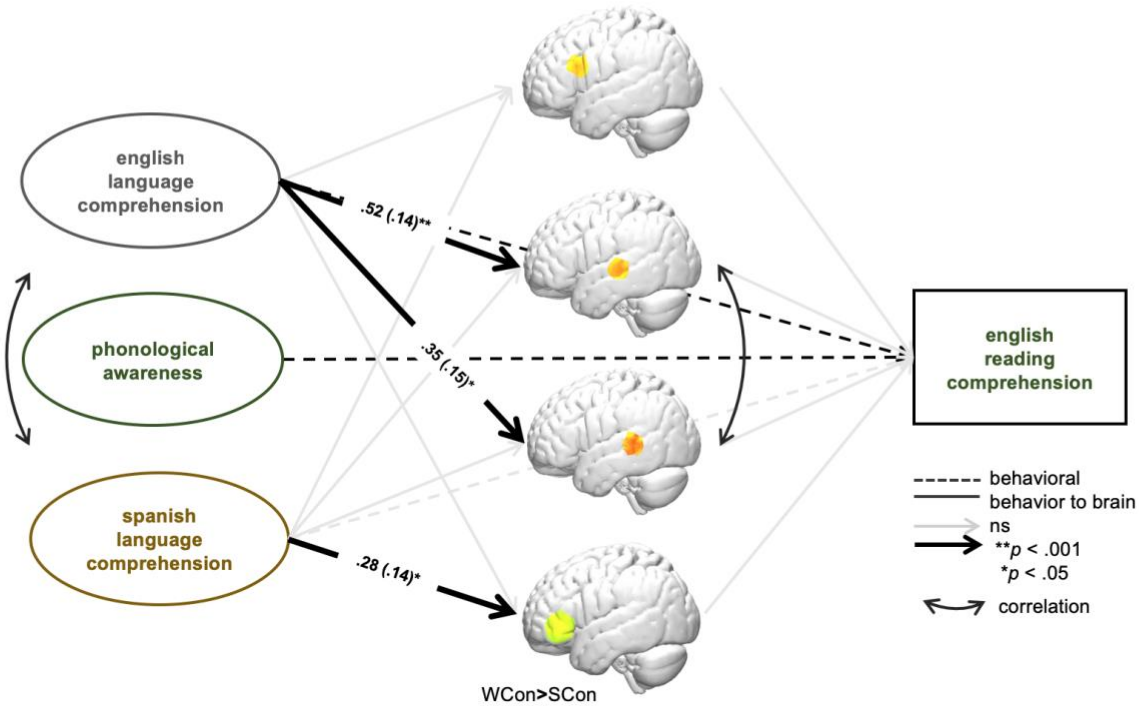


Figure 7 Semantics Task Structural Model. Structural model testing paths between left hemisphere regions involved in sentence processing during the semantics task (IFG pOper, PAC, pSTG, for task > rest, and IFG pTri for WCon>SCon condition), children's bilingual language abilities, and English reading comprehension. Double headed arrows indicate correlations among latent variables and between individual channels (see Table 11). Dashed lines represent paths between behavioral latent variables and reading comprehension (see Table 11). Solid lines represent paths between behavioral measures and brain activity (significant standardized beta-values (standard error) are noted). Age was included as a covariate.

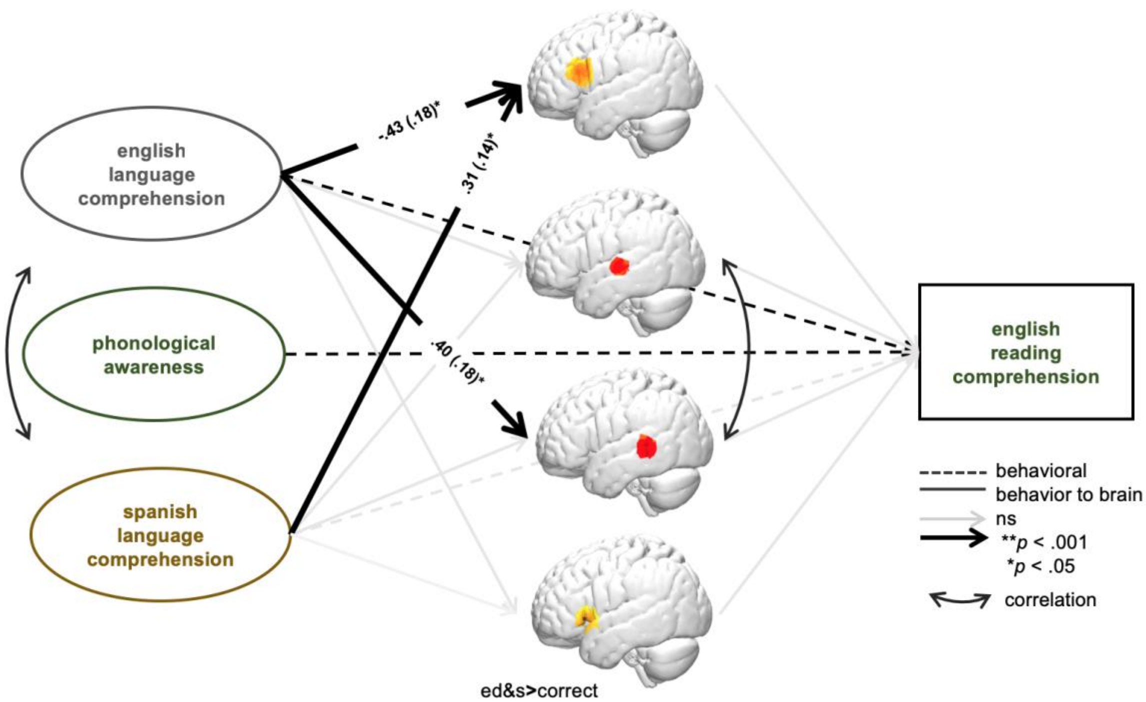


Figure 8 Syntax Task Structural Model. Structural model testing paths between left hemisphere regions involved in sentence processing during the syntax task (IFG pOper, PAC, pSTG, for task > rest, and IFG pOper for the ed&s > correct condition), children's bilingual language proficiencies, and English reading comprehension. Double headed arrows indicate correlations among latent variables and between individual channels (see Table 11). Dashed lines represent paths between behavioral latent variables and reading comprehension (see Table 11). Solid lines represent paths between behavioral measures and brain activity (significant standardized beta-values (standard error) are noted). Age was included as a covariate

Appendices

Appendix A
Parent Questionnaires

PARTICIPANT PRE-SCREENING QUESTIONNAIRE

BASIC INFORMATION

1. What is your name?

2. And just to confirm, your child's name is (*child's name*)?

(Write child's name) __________________________________

3. What is your relationship to (*child's name)*?

4. What grade is *(child's name)* in?

5. What gender is (*child's name*)?

6. What is his/her date of birth?

7. Does (*child's name)* have any siblings?

7a. *If yes*, what is the date of birth of (*child's name)*'s sibling(s)?

8. To the best of your knowledge, what hand (right or left) does your child use when writing?

9. When holding a spoon?

10. When holding a toothbrush?

> **10a.** *If sibling is 7-9 years old*, what hand (right or left) does *he/she use when writing*?
>
> **10b.** *When holding a spoon?*
>
> **10c.** *When holding a toothbrush?*

LANGUAGE USE

11. What language does (*child's name)* speak at home – English, Spanish, or both? Any other?

12. At what age was his/her first word in English?

13. At what age was his/her first word in Spanish?

14. What language do you speak to (*child's name)* at home (English/Spanish/both)?

14a. *If they have a spouse - what language does your spouse speak to (child's name)?*

15. Did your child attend daycare?

15a. *If yes, how old were they when they were enrolled in daycare?*

15b. *What language did he/she use (English/Spanish/both)?*

16. Does your child attend school?

16a. *If yes, what language does he/she use in school (English/Spanish/both)?*

DELAYS & IMPAIRMENTS

17. To the best of your knowledge, was your child on time with walking/talking/experience any difficulties with anything?

18. To the best of your knowledge, did or does your child experience any delays in language and/or reading development?

19. To the best of your knowledge, did or does your child experience any delays in social development (ex. Autism)?

20. To the best of your knowledge, did or does your child experience any cognitive or attentional difficulties (ex. ADHD, ADD)?

21. To the best of your knowledge, did or does your child experience any physical or neurological difficulties? (ex. Cerebral palsy, seizures)

22. To the best of your knowledge, does your child experience any hearing difficulties?

23. Has your child ever experienced a head injury such as a concussion?

23a. *If yes, at what age did this happen?*

24. Is your child currently taking any medications?

24a. *If yes, could you please specify what the meds are for?*

BACKGROUND QUESTIONNAIRE

Thank you again for your interest in our study on bilingual children's language abilities!

The following questionnaire will take you about 1-hour to complete. We ask a lot of questions in order to get a full understanding of your child's development up to today's date. We appreciate any feedback and additional comments you may have as you're filling it out and afterwards. If you have any questions, please don't hesitate to ask any of the research assistants. Please feel free to mark and make notes on the side, especially if any of the suggested responses do not fit your answer. You may skip any questions you do not wish to answer, and this information will be completely confidential and only used in conjunction with this study.

We appreciate your participation, as your help will help us understand more about bilingual children's development. Thank you for your time!

CHILD INFORMATION

1. Please fill out the following information:

   Child's First Name ____

   Child's Last Name ____

   Parent's/Guardian's Name ______________________________________

   Child's Date of Birth (MM/DD/YY) _______________________________

2. Child's Gender (please circle)   Male   Female

3. Was your child carried to full-term or born prematurely? __________________

4. How did you find out about this study?

5. Child's current grade or highest grade completed: _____________________

6. Has your child been held back one (or more) year(s) in school?   YES   NO

   If yes, in what grade and for how many years? ____________

7. Has your child obtained special services in school up to now (e.g. special education, speech therapy, occupational therapy, social work, etc)?

____

____

8. Which of the following does your child enjoy doing for fun? (Check all that apply)

	In Spanish	**In English**	**Neither**
Listen to music	□	□	□
Watch TV/cartoons	□	□	□
Read	□	□	□
books/magazines	□	□	□
Watch movies	□	□	□
Play games		□	□
Talk with friends			

NEUROLOGICAL IMPAIRMENTS & MEDICINE USE

9. Please place a check mark (√) in the box next to any of the following conditions for which your child has a history: (check all that apply)

□ birth related injuries

□ developmental delay / developmental disorder

□ speech/language impairment

□ head injury with loss of consciousness (e.g. concussion)

-at what age? _____

□ seizure disorder / epilepsy

□ reading impairment *(If your child has reading impairments, please tell us more below)

□ hearing impairment or some difficulty hearing

□ substance use / abuse

□ other neurological condition (please specify):

____

*If your child struggles with reading, please tell us more about it.

	Never	Rarely	Sometimes	Frequently	Always
1. Has difficulty with spelling	□	□	□	□	□
2. Has/had difficulty learning names	□	□	□	□	□
3. Has/had difficulty learning phonics (sounding out words)	□	□	□	□	□
4. Reads slowly	□	□	□	□	□
5. Reads below grade level	□	□	□	□	□

10. Please place a check mark (√) in the box next to any of the following diagnoses your child has previously received: (check all that apply)

□ Attention Deficit/Hyperactivity Disorder (ADHD)

□ Autism / Asperger's / Pervasive Developmental Disorder

□ Depression

□ Anxiety

□ Obsessive-Compulsive Disorder

□ Conduct Disorder / Oppositional Defiant Disorder

□ other mental health condition (please specify): ____________________

11. Is your child currently prescribed with medication? (circle) YES NO

If yes, please name the medications and for what they are prescribed (next page):

Medication Condition

______________________ ______________________

______________________ ______________________

PARENTAL BACKGROUND

12. Please specify how you would describe **yourself** (check as many as apply):

□ White
□ Hispanic, Latino, or Spanish origin
□ Black or African American
□ Asian

□ American Indian or Alaska Native
□ Middle Eastern or North African
□ Native Hawaiian or Other Pacific Islander
□ Some other race, ethnicity, or origin (please specify) ________________________

13. Where were **you** born?

□ In the United States or another English-speaking country (e.g. Canada, Australia)

□ Outside the United States (Please specify) ________________________________

14. If you were NOT born in the U.S. (e.g., in Mexico), at what age did **you** come to the U.S. or another English-speaking country (e.g. Canada)?

□ Ages 0-10
□ Ages 11-18
□ After the age of 18

15. Please select the languages **you** speak at home (check as many as apply):

□ English
□ Spanish
□ Other (Please specify) ____

16. Please indicate **your** level of education:

□ Primary School
□ Some Secondary School
□ High School Diploma or Equivalent (GED)
□ Some College
□ Associate's Degree
□ Bachelor's Degree
□ Master's Degree
□ Ph.D. (Doctorate Degree) or Professional Degree (MD, JD, DDS, etc.)
□ Other (please specify): ____________________

Questions 17 through 21 are about the child's ***other*** *parent or primary caregiver. If this is not applicable to you, please skip this page and jump to question 22.*

17. Please specify how you would describe **the other parent** (check as many as apply):

□ White
□ Hispanic, Latino, or Spanish origin
□ Black or African American
□ Asian
□ American Indian or Alaska Native
□ Middle Eastern or North African
□ Native Hawaiian or Other Pacific Islander
□ Some other race, ethnicity, or origin (please specify) ________________________

18. Where was **the other parent** born?

□ In the United States or another English-speaking country (e.g. Canada, Australia)

□ Outside the United States (Please specify) ________________________________

19. If the other parent were NOT born in the U.S. (e.g., in Mexico), at what age did **the other parent** come to the U.S. or another English-speaking country (e.g. Canada)?

□ Ages 0-10
□ Ages 11-18
□ After the age of 18

20. Please select the languages **the other parent** speaks at home (check as many as apply):

□ English
□ Spanish
□ Other (Please specify) ____

21. Please indicate **the other parent's** level of education:
□ Primary School
□ Some Secondary School
□ High School Diploma or Equivalent (GED)
□ Some College
□ Associate's Degree
□ Bachelor's Degree
□ Master's Degree
□ Ph.D. (Doctorate Degree) or Professional Degree (MD, JD, DDS, etc.)
□ Other (please specify): ____________________

CHILD'S READING BACKGROUND

22. In a typical week, how much do you read **English** books to your child on a **weekday**?

□ less than 15 minutes
□ 15 minutes – 30 minutes
□ 30 minutes – 1 hour
□ 1 hour – 1.5 hours
□ 1.5 hours – 2 hours
□ more than 2 hours

23. In a typical week, how much do you read **English** books to your child on a **weekend**?

□ less than 15 minutes
□ 15 minutes – 30 minutes
□ 30 minutes – 1 hour
□ 1 hour – 1.5 hours
□ 1.5 hours – 2 hours
□ more than 2 hours

24. In a typical week, how much do you read **Spanish** books to your child on a **weekday**?

□ less than 15 minutes
□ 15 minutes – 30 minutes
□ 30 minutes – 1 hour
□ 1 hour – 1.5 hours
□ 1.5 hours – 2 hours
□ more than 2 hours

25. In a typical week, how much do you read **Spanish** books to your child on a **weekend**?
□ less than 15 minutes
□ 15 minutes – 30 minutes
□ 30 minutes – 1 hour
□ 1 hour – 1.5 hours
□ 1.5 hours – 2 hours
□ more than 2 hours

26. At what age did you begin reading **English** books to your child?

□ 0-3
□ 3-5
□ 5-7
□ after the age of 7

27. At what age did you begin reading **Spanish** books to your child?

□ 0-3
□ 3-5
□ 5-7
□ after the age of 7

28. To the best of your knowledge, how much does **your child** read at home in **English** on a **weekday?**

□ less than 15 minutes
□ 15 minutes – 30 minutes
□ 30 minutes – 1 hour
□ 1 hour – 1.5 hours
□ 1.5 hours – 2 hours
□ more than 2 hours

29. To the best of your knowledge, how much does **your child** read at home in **English** on a **weekend?**

□ less than 15 minutes
□ 15 minutes – 30 minutes
□ 30 minutes – 1 hour
□ 1 hour – 1.5 hours
□ 1.5 hours – 2 hours
□ more than 2 hours

30. To the best of your knowledge, how much does **your child** read at home in **Spanish** on a **weekday?**

□ less than 15 minutes
□ 15 minutes – 30 minutes
□ 30 minutes – 1 hour
□ 1 hour – 1.5 hours
□ 1.5 hours – 2 hours
□ more than 2 hours

31. To the best of your knowledge, how much does **your child** read at home in **Spanish** on a **weekend?**

□ less than 15 minutes
□ 15 minutes – 30 minutes
□ 30 minutes – 1 hour
□ 1 hour – 1.5 hours

□ 1.5 hours – 2 hours
□ more than 2 hours

32. To the best of your knowledge, at what age did your child **say** his/her **first** word in **English?**

□ 1 year or earlier
□ 2 years
□ 3 years
□ 4 years
□ 5 years
□ 6 years
□ 7 years or later

33. To the best of your knowledge, at what age did your child **say** his/her **first** word in **Spanish?**

□ 3 years or earlier
□ 4 years
□ 5 years
□ 6 years
□ 7 years or later

34. To the best of your knowledge, at what age did your child begin to **read** by themselves (silently or out loud) in **English?**

□ 3 years or earlier
□ 4 years
□ 5 years
□ 6 years
□ 7 years or later

35. At what age was your child when he/she began attending an English-speaking school?

□ Pre-school
□ Kindergarten
□ 1st grade
□ 2nd grade
□ 3rd grade or later

36. Please provide us with the name of your child's elementary school:

____

37. Does your child partake in any form of after-school tutoring programs that provide extra help with reading in English? If yes, how many hours per week?

□ less than 1 hour
□ 1-2 hours
□ 2-3 hours
□ 3-4 hours
□ 4-5 hours
□ 5 hours or more

38. To the best of your knowledge, at what age did your child begin to **read** by themselves (silently or out loud) in **Spanish?**

□ 1 year or earlier
□ 2 years
□ 3 years
□ 4 years
□ 5 years
□ 6 years
□ 7 years or later

39. Is your child currently learning how to read in Spanish?
(Please read all answers through first then check all that apply)

□ No, my child is not learning how to read in Spanish.

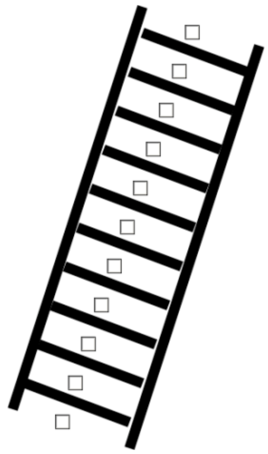
□ At home
□ At school (How many hours per week? _____)
□ In an after-school program (e.g. at church, parent groups) (How many hours per week? _____)
□ El Nuestra Langua
□ Other: ________________ (How many hours per week? _____)

40. We would like to know a little bit more about your child's background involving Spanish. Please provide us with information on your child's Spanish-learning experiences (e.g. regular visits to Spanish-speaking countries, experience living in a Spanish-speaking country, etc)

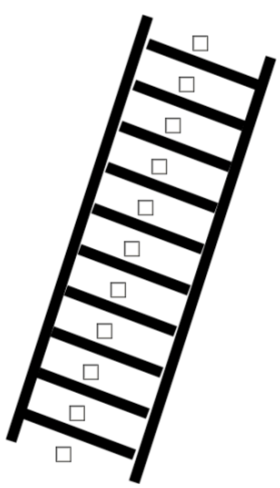
____

DEMOGRAPHIC INFORMATION

41. COMMUNITY SCALE: Think of this scale as representing where people stand in their communities. People define community in different ways; please define it in whatever way is most meaningful to you. At the top of the scale are the people who have the highest standing in their community. At the bottom are the people who have the lowest standing in their community. Where would you place yourself on this scale? Please slide the bar to the number where you think you stand at this time in your life, relative to other people in your community.



42. NATIONAL SCALE: Think of this scale as representing where people stand in the United States. At the top of the scale are the people who are best off- those who have the most money, the most education, and the most respected jobs. At the bottom of the scale are the people who are worst off- who have the least money, least education, and least respected jobs or no job. The higher you are on this scale, the closer you are to the people at the very top; the lower you are, the close you are to the people at the very bottom. Where would you place yourself on this scale? Please slide the bar to the number where you think you stand at this time in your life, relative to other people in the United States.



43. Which of the following best describes **your** current main daily activities and/or responsibilities?

□ Working full time
□ Working part time
□ Unemployed or laid off
□ Looking for work
□ Keeping house/raise children full-time
□ Retired

44. Which of the following best describes the **other** parent current main daily activities and/or responsibilities?

□ Working full time
□ Working part time
□ Unemployed or laid off
□ Looking for work
□ Keeping house/raise children full-time
□ Retired

45. Which of these categories best describes your total combined household (family) income for the past 12 months?*

□ Less than $5,000
□ $5,000 through $11,999
□ $12,000 through $15,999
□ $16,000 through $49,999
□ $50,000 through $74,999
□ $75,000 through $99,999
□ $100,000 and greater
□ Don't know
□ No response

*This should include income (before taxes) from all sources, wages, rent from properties, social security, disability and/or veteran's benefits, unemployment benefits, workman's compensation, help from relatives (including child payments and alimony), and so on.

46. Please provide us with any additional information that will help us to better understand your child's development with languages.

PARENTL ACADEMIC SOCIALIZATION

Instructions**:** Please mark the answer that most applies to you for each statement.
Please note: This questionnaire refers to your child who is participating in this study.

	Never (1)	Seldom (2)	Sometimes (3)	Usually (4)	Always (5)
I put pressure on my child to do well in school.	☐	☐	☐	☐	☐
I force my child to get involved with school activities, even if he or she doesn't want to.	☐	☐	☐	☐	☐
I worry that my child can't do as well in school as I expect him/her to.	☐	☐	☐	☐	☐
I am understanding when my child doesn't do well in school.	☐	☐	☐	☐	☐
I am more concerned that my child does his or her best in school than that he/she get a particular grade.	☐	☐	☐	☐	☐
It is as important to me for my child to be happy as it is for my child to do well in school.	☐	☐	☐	☐	☐
I have very high standards for my child's school performance.	☐	☐	☐	☐	☐
I give my child extra problems the teacher hasn't yet.	☐	☐	☐	☐	☐
I tell my child that he/she could do better in school if he/she worked harder.	☐	☐	☐	☐	☐
I tell my child that he/she can get smarter as long as he/she tries hard.	☐	☐	☐	☐	☐
I tell my child that if he/she doesn't do well on a test, it's probably because he/she didn't study hard enough or long enough.	☐	☐	☐	☐	☐
I tell my child that he/she can get good grades in school as long as he/she always tries hard.	☐	☐	☐	☐	☐
I make my child feel ashamed if he/she does badly in school.	☐	☐	☐	☐	☐
I punish my child when he/she doesn't do well in school.	☐	☐	☐	☐	☐

PARENT ETHNIC SOCIALIZATION

Instructions: The next set of questions is about things that parents sometimes do to help their child understand their ethnic background. For the next few statements, please indicate how important you think each statement is.

How important is it for you….

	Not at all important (1)	Not very important (2)	Somewhat important (3)	Very important (4)
… that your child speaks English proficiently?	☐	☐	☐	☐
… that your child reads and writes in English proficiently?	☐	☐	☐	☐
… that your child speaks Spanish proficiently?	☐	☐	☐	☐
… that your child reads and writes in Spanish proficiently?	☐	☐	☐	☐
… that your child understands the history and traditions of your family's ethnicity?	☐	☐	☐	☐
… that your child experiences things that reflect your family's ethnicity, such as eating food, listening to music, and/or watching movies?	☐	☐	☐	☐
… that your child understands the history and traditions of American (U.S.) culture?	☐	☐	☐	☐
… that your child experiences things that reflect American (U.S.) culture, such as eating food, listening to music, and/or watching movies?	☐	☐	☐	☐

Appendix B
Experimental Task Stimuli

SEMANTICS PLAUSIBILITY JUDGMENT TASK STIMULI

Training	Experimental
2 incongruent (InCon)	20 InCon
2 weak congruent (WCon)	20 WCon
3 strong congruent (SCon)	20 SCon
Trial Info	
5 second trials	
3 sec stim + 2 sec ?	
25% Jitters	
Total Duration: 400 sec	

Semantic Training		
sentence	**condition**	**verb-object association**
everydayshedrivesthebluecar	SCon	0.48
lastweektheyclimbedatallladder	WCon	0.047
heiskickingtheball	SCon	0.29
everydayshesingsthreelowoners	InCon	0
heiswalkingtwodoors	InCon	0
lastweektheyplayedtwogames	WCon	0.074
everydaytheyreadthreebooks	SCon	0.389

Semantic Experimental Run		
sentence	**condition**	**verb-object association**
lastweekheclimbedtwomountains	SCon	0.291
hedidnotflushthetoilet	SCon	0.418
sheisboilingthreeeggs	SCon	0.374
everydayshedrivesthebluecar	SCon	0.48
herjobwastostaplethepapers	SCon	0.283
heiskickingtheball	SCon	0.29
lastweekshebakedtwocakes	SCon	0.402
everydaytheycountlotsofnumbers	SCon	0.451
everyweekheridesthebrownhorse	SCon	0.372
lastweektheyframedthreepictures	SCon	0.811
Itistimetomowthelawn	SCon	0.449
theylearnedhowtolauncharocket	SCon	0.311
heisaskingmanyquestions	SCon	0.422
lastweektheyscrambledthreeeggs	SCon	0.372
theydonottowthecar	SCon	0.322
sheissingingasong	SCon	0.456
everydaytheyreadthreebooks	SCon	0.389
everydayshescramblestwoeggs	SCon	0.372
onthecourttheybouncedtwoballs	SCon	0.564
heisscratchingtheitchonhisknee	SCon	0.359
hewasaskednottobreaktheglasses	WCon	0.1
lastweektheyclimbedatallladder	WCon	0.047
hedoesnotkissherhand	WCon	0.135
theyarebuildingonehouse	WCon	0.156
sheishangingthreepictures	WCon	0.094
theyarehuntingthreedeer	WCon	0.152
lastweekhehitahomerun	WCon	0.022
theysmellgrandmasperfumes	WCon	0.036
lastweekhesuckedthreelollipops	WCon	0.111
everydayshedrawstwosketches	WCon	0.108
lastweekshebakedtwopotatoes	WCon	0.179
shelikestotastenewfoods	WCon	0.157
heisfoldingthepapers	WCon	0.192
lastweektheyplayedtwogames	WCon	0.074
everydaytheydrinkbottledwaters	WCon	0.152
theydidnotcatchanyfish	WCon	0.162
heissettingthestages	WCon	0.114
everydayhelicksonesucker	WCon	0.02
hethinksdifferentthoughts	WCon	0.089
everydaysheridesherbicycle	WCon	0.055
shewritesfivecans	InCon	0
lastweektheyscaredhislegs	InCon	0

lastweekhehuggedthreeshows	InCon	0
theythankacandy	InCon	0
lastweektheychoppedtwophones	InCon	0
theyswimthreedogs	InCon	0
everydayshedrinksaswing	InCon	0
everydayhecooksonehouse	InCon	0
everydayshesingsthreelowoners	InCon	0
everydaytheyflushthetrees	InCon	0
heiswalkingtwodoors	InCon	0
theyaretyingthecomputers	InCon	0
theyarebouncingonepaper	InCon	0
everydaytheywalkthreebuttons	InCon	0
sheplantsthreekeys	InCon	0
heisplantingthreeshoes	InCon	0
hewearstwosongs	InCon	0
sheisrunningtwocakes	InCon	0
lastweektheyclimbedonephoto	InCon	0
lastweekshecalledoneshirt	InCon	0

MORPHOSYNTAX GRAMMATICALITY JUDGEMENT TASK STIMULI

Training	**Experimental**
3 correct 2 -ing 2 ed & s	20 correct 20 -ing 20 ed & s (10 of each)
Trial Info	
5 second trials 3 sec stim + 2 sec ? 25% Jitters	
Total Duration: 400 sec	

Syntax Training	
sentence	**condition**
outsideheiswalkinghisdog_corr	correct
hecolorondrawingbooks_s	ed&s
rightnowmariaiswalkdogs_ing	ing
everydaydanieljumpsonthebed_corr	corect
theteacherfinishreadingabook_ed	ed&s
heisclimbupthehill_ing	ing
nicolasdroppedhisfavoritebook_corr	correct

Syntax Experimental Run	
sentence	**condition**
carmenistyinghershoelaces_corr	correct
everydaylauraplayswithherbrother_corr	correct
hecolorswithhismarkers_corr	correct
everydayhewearshisfavoritehat_corr	correct
hewritesessaysfortheclass_corr	correct
everydayshereadsthenewspaper_corr	correct
nicolasdroppedhisfavoritebook_corr	correct
lastweeksimondancedtomusic_corr	correct
martinislaughingwithhismom_corr	correct
lastweekdanielpickedlowoners_corr	correct
shebouncedonthebed_corr	correct
inclassheislearningmath_corr	correct
lastweeklaurahuggedadog_corr	correct
shevisitsherfamilyinchina_corr	correct
theyopeneduptheirpresents_corr	correct
sheischeeringfortheteam_corr	correct
simoniscleaningthekitchen_corr	correct
shefeelshappyinthemuseum_corr	correct
thebakerismixinghisdough_corr	correct
danielislisteningtoasong_corr	correct
lastweektheylaughwithgrandma_ed	ed&s
everydayhehidehishomework_s	ed&s
shediscovergumonherchair_ed	ed&s
everydayshewearherfavoriteshoes_s	ed&s
lastweeksophiaplaysoccer_ed	ed&s
laurascorethewinninggoal_s	ed&s
diegoaddrockstohiscollection_ed	ed&s
everydaymariawrapeightpresents_s	ed&s
lastweektheycleanthekitchen_ed	ed&s
mariarunoutsidewithherdog_s	ed&s
hewatchamovieathome_ed	ed&s
everydaydanieljumparound_s	ed&s
lastweektheywaitforthebus_ed	ed&s
nicolasbiteintoapizza_s	ed&s
theyfinishanewpuzzle_ed	ed&s
nicolasknockonthedoor_s	ed&s
lastweeksimonlearnalotofwords_ed	ed&s
everydaylauraplayherpiano_s	ed&s
lastweekdanielpickapples_ed	ed&s
mariawantafurrypet_s	ed&s
rightnowsheiswashdishes_ing	ing
simoniscleanhiscar_ing	ing
nowlauraisbrushherteeth_ing	ing

danieliswatchamovie_ing	ing
sheisteachherstudents_ing	ing
rightnowheisnapoutside_ing	ing
martinislaughatthecartoon_ing	ing
nowtheyareplaywithtoys_ing	ing
lauraisshopfordresses_ing	ing
rightnowtheyarecountjellybeans_ing	ing
theyarecutthepaper_ing	ing
nowsheisswimwithfriends_ing	ing
theartistismixthepaint_ing	ing
rightnowtheyarestudymath_ing	ing
theyarewishforrecess_ing	ing
childrenareskipintheplayground_ing	ing
rightnowsheispetbunnies_ing	ing
theyarewarmupthesoup_ing	ing
nowtheboysarepickberries_ing	ing
thestudentsaresearchformarkers_ing	ing

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