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Language Experience and Socioeconomic Status (SES): Implications for Language,
Cognitive, and Brain Development in Bilingual Children

A dissertation submitted in partial satisfaction of the requirements for the degree Doctor
of Philosophy

in

Cognitive Science

by

Marybel Robledo Gonzalez

Committee in charge:

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Professor Judy Reilly
Professor Bradley Voytek

2017

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The Dissertation of Marybel Robledo Gonzalez is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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University of California, San Diego

2017

DEDICATION

I dedicate this dissertation to my loving husband Jose, our daughter Clara, and our soon to be born baby, whom without their love, patience, and support, this work would not have been possible. To my husband, for not letting me give up on my dream and reminding me that I needed to finish, if not for me, for our children. To my daughter Clara, for inspiring me every day to learn more. I also dedicate this dissertation to my parents, siblings, and grandmother Yaya. While my parents did not complete an education past high school and my grandmother never learned to read, they highly valued education and always encouraged me and supported me in achieving my goal of obtaining a Ph.D. To my mother, for always believing in me and relentlessly asking me when I would finish. To my grandmother Yaya, for always believing that I was strong, independent, and capable of anything. To my father, for instilling in me a strong work ethic and for reminding me that while choosing to get an education would be a difficult path, the alternative would not be much easier. To my older sister, for opening the doors to higher education.

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LIST OF ABBREVIATIONS

SES: Socio-economic status
MINT: Multilingual naming test
VF: Verbal fluency
DCCS: Dimensional-Card Sort
BLE-Q: Bilingual Language Experience Questionnaire
MRI: Magnetic Resonance Imaging
DTI: Diffusion Tensor Imaging
FA: fractional anisotropy
MD: mean diffusivity
SLF: superior longitudinal fasciculus
IFOF: inferior fronto-occipital fasciculus
aCg: anterior cingulum
ACC: anterior cingulate cortex

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ABSTRACT OF THE DISSERTATION

Language Experience and Socioeconomic Status (SES): Implications for Language,
Cognitive, and Brain Development in Bilingual Children

by

Marybel Robledo Gonzalez

Doctor of Philosophy in Cognitive Science

University of California, San Diego, 2017

Professor Terry Jernigan, Chair

The acquisition of a second language often occurs during early childhood, a period of dynamic change in cognitive, language, and brain development. This thesis

examined the contribution of two important factors in bilingualism, language experience and SES, in association with individual differences in language skills, executive function, and white matter maturation in bilingual children. Language skills in both English and Spanish were measured, including vocabulary, verbal fluency, and spoken narrative skills. Executive function measures for response inhibition, inhibitory control, and cognitive flexibility were also examined. While bilinguals had lower receptive English vocabulary than the monolingual children, within the bilingual group, language experience was a contributing factor to language outcomes in both languages. When both SES and language experience were entered as predictors of the language measures, SES was only significant for English expressive vocabulary scores in bilinguals. Bilingual children underperformed on executive function tasks compared to the monolingual children, although, SES accounted for group differences in cognitive flexibility (though not inhibitory control) performance. The group comparisons revealed an interaction effect of language group by SES for response inhibition, such that among the bilingual children, there was a negative association between SES and performance, but not for the monolingual children. Within the bilingual group, language experience and SES both were contributing factors to individual differences in executive function performance, while differing patterns of associations for executive function measures emerged. In addition, white matter maturation was compared in bilingual children to monolingual children in three white matter fiber tracts, the inferior fronto-occipital fasciculus (IFOF), the superior longitudinal fasciculus (SLF), and the anterior cingulum. Monolingual children showed more mature values of white matter characteristics in the SLF compared to the bilingual group, independent of SES. *Post-hoc* analysis revealed group differences

in white matter maturation in the separate segments of the IFOF, such that monolinguals had more mature values on white matter measures in the anterior and middle IFOF, while bilinguals had more mature values in the posterior IFOF. Within the bilingual group, language experience was related to more mature white matter characteristics in the anterior cingulum, a brain region thought to support language control in bilinguals.

General Introduction

It is estimated that at least half of the world's population speaks two or more languages and can be considered bilingual or even multilingual (Grosjean, 2010). In the United States (U.S.), it was estimated that 21% of children spoke another language other than English at home, with the majority speaking Spanish in the home (Ryan, 2013). A U.S. census analysis projected that the number of people who spoke another language other than English in the home would likely continue to increase (Ortman, 2011). Although these projections may give way to uncertainty in the present U.S. political climate, there has been an increase in the popularity of dual-language and bilingual education programs at the elementary school level.

Although bilingualism can be defined by various factors, such as proficiency and age of exposure, this dissertation will adopt François Grosjean's definition of bilingualism, the daily use of two or more languages. Bilinguals who acquire their second language during early childhood, not only develop language skills in both languages, but do so against the backdrop of developmental changes in cognitive skills as well as brain structure (Casey, Tottenham, Liston, & Durston, 2005; Jernigan, Baaré, Stiles, & Madsen, 2011). This makes childhood a particularly interesting period to examine the effects of bilingualism on such development. Further, bilingual children in the U.S. are very diverse and can vary across many dimensions such as culture, socio-economic status (SES), and language experience. Given the propensity for bilingual children to emerge from among diverse backgrounds, further studies are needed to understand how individual differences in language and environmental characteristics in

bilingual children relate to cognitive development and brain development. Following is a review of the literature that has examined language development, cognitive skills, and brain development in bilingual children.

Language Skills

While language development in monolingual children has been studied extensively, studies on language development in children who are acquiring two or more languages are only just emerging (Hammer et al., 2014). Various studies have compared bilingual children and monolingual children on vocabulary skills (Bialystok, Luk, Peets, & Yang, 2010; D. Oller & Eilers, 2002). Other studies on bilingual children have examined individual differences in broader language skills, such as spoken narrative skills (Miller et al., 2006; Raúl Rojas & Iglesias, 2013; Ucceli & Paez, 2007). Recent studies have examined the effect of environmental factors, such as language experience and SES, on language skills in bilingual children (Bohman, Bedore, Peña, Mendez-Perez, & Gillam, 2010; Duursma, Romero-Contreras, Szuber, Proctor, & Snow, 2007; Golberg & Paradis, 2008; D. Oller & Eilers, 2002; Raul Rojas et al., 2016).

Vocabulary. Bilingual children have lower vocabularies than monolingual children across the developmental age range (Bialystok et al., 2010; D. Oller & Eilers, 2002). Nonetheless, there exists individual variability among bilinguals in vocabulary skills between languages, such that bilinguals can have similar vocabulary levels in both languages or can be dominant in the vocabulary of one language versus the other. For instance, bilinguals can be dominant in one language in school-related vocabulary but dominant in the other language for home-related vocabulary (Grosjean, 2010). Recent studies have found language experience in the environment can account for individual

differences in language skills in bilinguals (Bohman et al., 2010; Golberg & Paradis, 2008; Raul Rojas et al., 2016). Also, it is known that monolingual children from a low SES demographic have lower vocabulary skills compared to higher SES children (Hart & Risley, 1995; Hoff, 2003; Pan, Rowe, Singer, & Snow, 2005). However, the effect of SES and language experience on vocabulary skills in bilinguals needs further investigation. While it is expected that language skills in bilinguals should increase with age alike monolinguals, it is unclear what factors contribute to development of language skills when a child is learning two languages.

Verbal fluency. Verbal fluency performance assess skill in retrieval of words given a specific criterion, such as words starting with a phonological sound or letter, or words belonging to a semantic category. Performance on the VF tasks may be associated with lexical knowledge (Prigatano et al., 2007; Prigatano & Gray, 2008) as well as other cognitive control processes (Kavé et al., 2008, Hurks et al., 2006; Koren et al., 2005). Performance on verbal fluency tasks has been examined extensively across various populations in children, including children born pre-term or with low birth weight, Down Syndrome, attention deficit hyperactivity disorder, brain traumatic injury, and specific language impairment (Aarnoudse-Moens et al., 2009; Nash & Snowling, 2008; Pineda et al., 2008; Prigatano & Gray, 2008; Henry et al., 2012). It is known performance on the verbal fluency increases with age, a developmental trend reported in several languages (Korkman et al., 2001; Sauzeon et al., 2004; Kavé, 2006). Recent findings report that SES may be positively associated with the development of performance on the verbal fluency in typically developing children (Ardila et al. 2005, Hurks et al., 2005; Kavé et al., 2013). In bilinguals, verbal fluency in adults has been studied to some extent, while

studies on verbal fluency in English-Spanish bilingual children has not been examined. Bilingual adults score lower on verbal fluency tasks, in particular in the semantic or category condition, compared to monolinguals (Gollan, Montoya, & Werner, 2002; Rosselli et al., 2000). Although, given that studies have also reported an association between vocabulary and better verbal fluency performance in bilingual adults, this is not surprising (Bialystok, et al., 2008; Luo, et al., 2010). However, studies have found that adult bilinguals who are highly proficient in vocabulary, outperform monolinguals on letter fluency production (Bialystok, et al., 2008; Luo, et al., 2010). Interestingly, letter fluency is thought to elicit more cognitive effort in the retrieval of words from the lexicon, since the retrieval criteria is not typical of natural speech. On the other hand, more natural search strategies, such as semantic association, are used in category fluency.

Spoken narrative skills. Spoken narratives can provide a quasi-naturalistic sample of child language usage, which can then be analyzed at the lexical level, at the morphosyntax level, and at the sentence structure level. While spoken narratives have been studied extensively in monolingual children and even in many languages (Bamberg, 1987; Berman, 1995; Berman & Slobin, 1994; Reilly, 1992), they have to a much lesser extent been studied in English-Spanish bilingual children in the U.S. (Raúl Rojas & Iglesias, 2013; Ucceli & Paez, 2007). The majority of studies that have examined spoken narrative skills in children have focused on outcome measures of productivity, such as the total number of words and total number of different words in the narrative (Miller et al., 2006; Muñoz, Gillam, Peña, & Gulley-Faehnle, 2003; Pearson, 2002; Raúl Rojas & Iglesias, 2013; Ucceli & Paez, 2007). Rojas and Iglesias (2013) conducted a large study on English-Spanish bilingual children and found differences in the developmental

trajectories of spoken narratives between languages, although narrative skills in both languages increased with age. Interestingly, Rojas and Iglesias (2013) reported that it is possible that the differences in developmental trajectories could have been attributable to other individual differences not measured in the bilingual sample. For instance, language skills in the minority language may diminish with age as the child undergoes a primary education in the societal dominant language, while maintenance of the minority language is dependent on the level of experience at home and in school (Gathercole & Thomas, 2009; Gutiérrez-Clellen & Kreiter, 2003). Findings from one large study examining English-Spanish bilinguals from kindergarten to third grade, suggest a relationship between productive measures of narrative performance in both languages with English reading scores (Miller et al., 2006). Thus, studying more in depth measures of linguistic narrative skills in bilinguals, such as morphological errors and complexity of sentence usage, is important to be able to examine language skills that are richer and more naturalistic than other language measures studied, in particular across both languages. In addition, the relationship between spoken narratives to other measures of language proficiency, such as vocabulary, and environmental factors, such as SES and language experience, needs further investigation.

Language experience and SES. One important environmental factor that influences language development in bilinguals is language experience in the home and in the school (Bedore et al., 2012; Duursma et al., 2007; Pearson, 2007). Findings from one study that examined vocabulary proficiency in English-Spanish bilinguals in 5th graders, reported that while English vocabulary was not predicted by English usage in the home, Spanish vocabulary was associated with the amount of Spanish usage in the home

(Duursma et al., 2007). A large study in English-Spanish pre-kindergarten and kindergarten bilinguals examined environmental factors in relation to semantic vocabulary development and morphosyntax development, and found higher Spanish performance was related to lower SES (Bohman et al., 2010). Bohman et al. (2010) also concluded that vocabulary performance most strongly related to language usage, while morphosyntax performance related to both language usage and input in the environment.

Although, bilingualism and low SES often co-occur among children in the U.S., the effect of low SES on language development in bilinguals has not been well studied (D. Oller & Eilers, 2002). It is known that monolingual children from low SES backgrounds have poorer language skills compared to higher SES children, a relationship that has been linked to the amount and quality of language input in the environment (Arriaga, Fenson, Cronan, & Pethick, 1998; Hart & Risley, 1995; Locke, Ginsborg & Peers, 2002; Qi, Kaiser, Milan, & Hancock, 2006). In the case of bilinguals, they demonstrate lower vocabulary and verbal fluency performance compared to monolinguals. Other recent studies in bilinguals suggest that SES may be associated with performance in the language of instruction in school, similar to monolinguals, while the minority language is most influenced by language usage of the minority language in the home (Duursma et al., 2007; Golberg & Paradis, 2008; Raul Rojas et al., 2016). Overall, findings suggest that the influence of language experience on language skills in bilinguals is likely to interact with other environmental factors such as SES, however, the relationship is not very clear (Bohman et al., 2010; Chondrogianni & Marinis, 2011; Engel de Abreu, Cruz-Santos, Tourinho, Martin, & Bialystok, 2012; Golberg & Paradis, 2008; LI et al., 2014; D. Oller & Eilers, 2002; Raul Rojas et al., 2016).

Summary. Future research is needed to understand the relationship of individual differences across various language skills, such as vocabulary, spoken narrative skills, and verbal fluency, both within a language and between languages. This is particularly important to understand how factors, such as language experience and SES, account for the disparate outcomes in language skills, such as vocabulary, in bilinguals compared to monolinguals, and to be able to describe how these factors relate to other dimensions of language skills in bilinguals.

Executive Function

In the most recent decade, there has been a surge in the number of studies examining executive function skills in bilinguals compared to monolinguals (Kroll & Bialystok, 2013). Much of the interest in studying bilinguals is motivated by the hypothesis that bilinguals must resolve competition between simultaneous activation of two languages and recruit mechanisms of executive function to select a target language (Green, 1998). In turn, such recruitment of cognitive processes in managing the competing activation of two languages, may contribute to differences in executive function skills between bilinguals and monolinguals. Studies have reported advantages in performance for bilinguals on executive function tasks that involve inhibition of interfering information, task-switching or cognitive flexibility, working memory, and conflict resolution. However, the effect of bilingualism on executive function lacks consistent replication across executive function measures and results may be confounded by several factors in the distribution of the sample population (Paap, Johnson, & Sawi, 2015; Valian, 2015).

Various recent studies reporting on large sample sizes have failed to replicate the finding that bilinguals outperform monolinguals in executive function tasks (Antón et al., 2014; Duñabeitia et al., 2014). Paap et al., 2015 concludes that the effects of bilingualism on executive function may only be observable in limited circumstances, if at all. A central element true of most studies on executive function in bilinguals, is that it is unclear whether a certain set of characteristics of the bilingual sample examined contributed to such an observable or not observable effect of bilingualism on executive function performance. One potential source of ambiguity in the findings is that the majority of studies examining executive function in bilinguals use a group-based approach, comparing a bilingual group to a monolingual group (Kroll & Bialystok, 2013; Luk & Bialystok, 2013). In using the categorical approach, bilinguals are usually only measured along one dimension, such as language proficiency using vocabulary or self-report. Although most studies examine middle class SES children, it is difficult to match the bilingual and monolingual groups across all possible factors that may have an effect on the development bilingualism and executive function. Paap et al. (2015) discusses a number of possible confounding factors in examining the effect of bilingualism on executive function, such as, socio-economic status, immigrant status, and cultural differences, and in any given study, controlling for all of these factors is difficult. In addition, Valian (2015) points out that bilingualism may have an impact on executive function performance just as any other experience-dependent activity such as exercise, in which the time-scales and intensity of bilingualism practice would need to be considered. It is possible that given any combination of participants in a bilingual and monolingual group, there may be other differences, within the bilingual group or monolingual group,

that may be contributing to better executive function skills in either group (Valian, 2015). Further, the lack of consistency in replication across executive function measures suggests that studies that report significant findings in bilinguals outperforming monolinguals, are in fact reporting differences in performance in the mechanisms of the specific task, rather than an advantage of a component of executive function (Paap et al., 2015).

Individual differences in bilingual language experience. Although bilinguals are diverse in language experience even within the same language populations, the relationship between individual differences in language experience to executive function performance has only been recently examined. In most of the studies that compare bilingual performance to monolingual performance, bilinguals are described by a measure of proficiency, such as vocabulary, verbal fluency, or self-rated proficiency. However, findings suggest that the bilingual experience is composed of various factors, such as proficiency of language, usage of language, or the amount of experience of language in the environment (Kaushanskaya & Prior, 2015; Sheng, Lu, & Gollan, 2014) and that these factors may interact with the effect of bilingualism on executive function (Bialystok & Barac, 2012; Thomas-Sunesson, Hakuta, & Bialystok, 2016). Relevant to academic outcomes, is the effect of language experience in the environment that bilingual children are immersed in. Bialystok and Barac (2012) found that the length of time children were enrolled in a dual immersion program predicted executive function performance. Still, it remains unclear how the specific language experience environment, i.e. the degree of language usage and practice of either language in the home and in the school, may relate to executive function skills in bilingual children.

Language switching in adults. Psycholinguistics often use the term language switching to imply a voluntary adaptive response to the language constraints of the environment, e.g. switching between languages to communicate with monolingual speakers of either language (Bullock & Toribio, 2009). The term language switching can be differentiated from code-switching in that it is used in bilingual studies that examine the mechanisms underlying language switching, such as language control and switching costs, and while language switching is specifically elicited during a task, code-switching refers to internal spontaneous switches in language (Bullock & Toribio, 2009). Grossjean (2010) points out that bilinguals may switch between languages to socially adapt communication, such as preference of expression of emotions, or concepts in which one language is more culturally sensitive to, or to highlight a word or concept. Recent findings suggest that the degree of language switching experience in bilinguals as opposed to language proficiency may account for better performance in executive function tasks (Hartanto & Yang, 2016; Prior & Gollan, 2011; Verreyt, Woumans, Vandelandotte, Szmalec, & Duyck, 2016). Specifically, these findings suggest an association between voluntary language switching behavior in balanced bilinguals and better executive function performance (Prior & Gollan, 2011; Verreyt, Woumans, Vandelandotte, Szmalec, & Duyck, 2016). The evidence from these studies suggests that since bilinguals recruit inhibitory control and switching skills to select a target language (Green, 1998), bilinguals who purposefully switch more frequently between languages may show an advantage in non-linguistic inhibitory and task-switching performance than bilinguals who rarely switch.

In contrast, two adult studies have found no association between the frequency of language switching and executive function performance in bilinguals (Paap et al., 2017; Yim & Bialystok, 2012). Yim and Bialystok (2012) examined code-switching behavior in a laboratory setting at the intra- and inter-sentential level and found no association between the frequency of code-switching and non-verbal executive function performance. Although the study implemented a task to elicit naturalistic code-switching, participants were not asked about the frequency of code-switching or language switching in their natural environment, hence the study's measure of code-switching may not have been representative of the extent to which the bilinguals practiced language switching in their environment. Paap et al. (2017) asked bilinguals to report on their frequency of language switching between contexts, e.g. at home versus school or different speakers, and found no association to performance on a non-linguistic switching-task. However, Paap et al. (2017) did not consider language balance among their bilinguals, as Verreyt et al. (2016) did, and only classified bilinguals based on frequency of language switching.

Language mixing in adults and children.

Language mixing for the purposes of this dissertation refers to the mixing of languages in speech within the same context. Although language mixing may include language patterns like code-switching, code-switching is thought to follow grammatical constraints and purposeful. On the other hand, the term language mixing will be adapted to liberally encompass language switching and mixing behaviors that are inadvertent or a result of failure to switch languages, and hence may reflect language control abilities. For instance, Festman et al. (2010) and Festman & Münte (2012) found that adult bilinguals with higher rates of inadvertent switches or failures to switch to the correct

language demonstrated poorer performance on executive function tasks, compared to bilinguals with lower rates of inadvertent switches or failures to switch. Thus, these findings suggest a relationship between higher rates of inadvertent switches or failures to switch to the correct language, i.e. poorer language control abilities, and performance on executive function tasks that may recruit similar inhibitory control mechanisms.

While bilingual children also demonstrate various patterns of language mixing when speaking, language mixing in bilingual children can be influenced by many factors (Bullock & Toribio, 2009). Bilingual children may mix languages at the lexical level, i.e. insert a word from the other language, to fill gaps in semantic or vocabulary knowledge (Bernardini & Schlyter, 2004; Paradis, Nicoladis, & Genesee, 2000). In turn, mixing languages to fill gaps in knowledge has been linked to language dominance such that children mix more often in their less dominant language (Genesee, Nicoladis, & Paradis, 1995). However, Cantone (2007) proposed this may not be a universal rule and that children can mix languages frequently in both or either language, regardless of dominance. As bilingual children acquire proficiency in the grammatical structure of both languages, language mixing behavior seems to be constrained by rules and closer to adult like patterns of code-switching (Müller & Cantone, 2009). Another possible contributing factor is that bilingual children are sensitive to the language mixing patterns of their interlocutor and have been shown to adapt their language behavior to the language patterns of their interlocutor (Genesee, Nicoladis, & Paradis, 1995; Min, 2011). For example, child language mixing has been associated with parental discourse preferences, such that language mixing occurred at a higher rate with a parent who accepted mixing of languages in discourse (Min, 2011).

While language skills develop throughout childhood, language characteristics among bilingual children can vary tremendously between languages, such as proficiency and balance between languages, as well as patterns of language usage. This makes language mixing a particularly interesting language characteristic to study in bilingual children. It is possible that like adults, language mixing behavior in children can also be the result of a failure to switch to the other language, i.e. poor language control. Adult studies suggest that it is plausible that language control of both languages is achieved through mechanisms of executive function, such as inhibitory control (Festman & Münte, 2012; Festman, Rodriguez-Fornells, & Münte, 2010; Luk, Green, Abutalebi, & Grady, 2011). While both language and executive function skills develop during childhood, it is unknown how differences in executive function skill performance relate to differences in language mixing behavior, or language control, in bilingual children.

Effects of SES on executive function. Findings from studies examining cognitive skills in children from low SES backgrounds suggest that low SES children are at risk for underperforming in executive function tasks (Ardila, Rosselli, Matute, & Guajardo, 2005; Farah et al., 2006; Noble, McCandliss, & Farah, 2007; Noble, Norman, & Farah, 2005; Sarsour et al., 2011). In the case of low SES bilingual children, low SES is a factor that may have negative effects on executive function skills, while the effects of bilingualism are difficult to observe independent of SES. Only a few studies have examined the relationship of low SES and bilingualism to executive function (Calvo & Bialystok, 2014; Carlson & Meltzoff, 2008; Engel de Abreu et al., 2012; Riggs, Shin, Unger, Spruijt-Metz, & Pentz, 2014; White & Greenfield, 2016). Carlson and Meltzoff (2008) compared low SES bilingual children to middle class monolingual children, and

found that the bilingual group outperformed the monolingual group on a task involving management of conflicting information, only after statistically controlling for differences in vocabulary scores between the groups. A recent study by Calvo and Bialystok (2014) reported an effect of SES and bilingualism on accuracy in tasks of conflict resolution and working memory, such that higher SES and bilingualism were associated with better executive function scores. The study also reported that while bilingual working class children outperformed monolingual working class children on executive function scores, working class bilingual children performed comparable to middle class monolingual children. These findings thus far suggest that bilingualism may in some cases offset the negative effects of low SES on executive function.

Executive function summary. Findings from studies examining the effects of bilingualism and SES on executive function suggest that bilingualism may have a positive effect on executive function development while low SES may have a negative effect on executive function development. In addition, studies also suggest that in examining the effects of bilingualism on executive function, other contributing factors that may mediate the effects of bilingualism on executive function performance may emerge from language experience in the environment. Beyond examining the group differences between monolinguals and bilinguals, it is important to first understand how environmental factors, such as SES and language experience, relate to individual differences in executive function in bilinguals. Understanding the relationship between environmental factors and executive function in bilinguals would be informative in identifying supportive factors that contribute to positive outcomes in language and cognitive development in low SES bilinguals.

Understanding Effects on Brain Structure

Maturation of white matter fiber tracts has been studied well in children (Jernigan et al., 2011; Lebel, Walker, Leemans, Phillips, & Beaulieu, 2008). While it is known that many fiber tracts exhibit protracted maturation during childhood, only recent studies have examined the effect of environmental factors on developmental trajectories.

Differences in SES have been associated with structural differences in both white matter and grey matter in brain regions related to executive function and language, specifically the white matter tracts: the inferior longitudinal fasciculus (ILF), the superior longitudinal fasciculus (SLF), and the cingulum (Noble, Korgaonkar, Grieve, & Brickman, 2013; Ursache & Noble, 2016), and frontal and temporal grey matter structures (Noble et al., 2015; Piccolo, Merz, He, Sowell, & Noble, 2016). Recent evidence from a study examining brain development in large cohort of low-SES children found that low-SES children had overall decreased surface area compared to higher-SES children (Noble et al., 2015).

Effects of bilingualism on brain structure. Further, it is thought that the continual recruitment of executive function skills to maintain language control is a bilingual experience that may be associated with differences between bilinguals and monolinguals in the reorganization of brain networks as well as brain structure (Mechelli et al., 2004; Mohades et al., 2012; *for a review see* (García-Pentón et al., 2016; Mechelli et al., 2004; Mohades et al., 2012). Although in the recent decade, there has been increasing interest in examining the effects of bilingualism on brain structure, very few studies have examined the effects of bilingualism on brain structure in children (Mohades et al., 2012, 2015). It is unclear at what timescale the associated effects of bilingualism

on the brain unfold and whether such associations are dependent on long-term temporal scales that come with experience throughout the lifespan. Thus, early childhood may be a very informative developmental phase to study the dynamics of acquisition of a second language and subsequent emergence of bilingualism.

Bilingualism has been associated with differences in characteristics of white matter microstructure in regions important for language in both children and adults, primarily the superior longitudinal fasciculus (SLF), the inferior fronto-occipital fasciculus (IFOF), and anterior cingulate cortex (ACC) (García-Pentón et al., 2016; Luk, Bialystok, Craik, & Grady, 2011; Mohades et al., 2012; Pliatsikas, Moschopoulou, & Saddy, 2015). While one study in children suggests that age of acquisition contributes to differences in white matter maturation (Mohades et al., 2012), it is unknown how more specific individual differences in bilingual language experience contributes to white matter maturation in bilinguals during childhood.

While we have now begun to map out the developmental patterns of maturation of the brain during childhood, recent findings suggest some environmental factors during childhood can influence the development of the brain and behavior, with some factors contributing negatively, such as low socio-economic status (SES) (Noble et al., 2015; Noble, Houston, Kan, & Sowell, 2012; Piccolo et al., 2016; Ursache & Noble, 2016) and other factors contributing positively, such as bilingualism (Bialystok & Barac, 2012; García-Pentón et al., 2016). Low socio-economic status often co-occurs with bilingualism, however, the relative contributions of both SES and bilingualism to the development of language and cognitive skills and especially brain development are rarely examined together (Calvo & Bialystok, 2014; Thomas-Sunesson et al., 2016). This

dissertation investigates the effects of bilingualism and SES on white matter microstructure. Findings have the potential to elucidate the role of bilingualism in development during childhood and whether bilingualism may act as a compensatory mechanism within a low SES environment, when children are more at risk for altered developmental trajectories in executive function and brain maturation (Ursache & Noble, 2016).

Present Study

The present dissertation is a comprehensive study of the effect of language experience and SES on language skills, executive function skills, and brain development in bilingual children. In this dissertation three general questions are discussed: (1) What is the role of language experience in the environment in the development of language skills and to what degree can this account for differences in language performance in bilinguals compared to monolinguals? (2) How do the bilingual children in this sample differ from monolingual children on executive function skills, and what are the contributions of language experience and SES to the development of executive function in bilingual? (3) What are the associations between language experience and SES and white maturation in bilinguals? Chapter 1 examines the effect of bilingual language experience and SES on language outcomes in both languages. Chapter 2 examines executive function performance in bilingual children compared to monolingual children. Chapter 3, investigates individual differences in bilingual language experience in children in relation to executive function performance. Chapter 4 examines differences in white matter microstructure between monolingual and bilingual children, as well as the associations between bilingual language experience and white matter maturation.

Chapter 1: Characterizing Language Skills in Bilingual Children

Bilingual children and adults have lower language skills, such as vocabulary and verbal fluency, when compared to monolinguals. Often, bilingual children are tested in the language dominant in society, which is often their second language, and not in the minority language. One important question to discuss in the context of bilingual children who are developing language skills, is what factors account for the disparate trajectories in language skills in bilingual children compared to monolingual children? Recent findings suggest that environmental factors such as language experience in the home and at school, and SES, relate to language skills in bilinguals. Findings from the limited studies on language experience and SES in bilinguals present a complex relationship, suggesting that in bilinguals, Spanish language skills are sensitive to language environment and possible SES as well, while English skills are most sensitive to and not language environment (Bohman et al., 2010; Duursma et al., 2007; Golberg & Paradis, 2008; Raúl Rojas & Iglesias, 2013). This chapter examines the degree to which language experience in the environment relates to vocabulary and verbal fluency outcomes in bilingual children, and the effect of SES on language outcomes. First, to examine disparate outcomes in language skills in bilingual children relative to monolingual children, receptive vocabulary skills were compared between groups. Second, within the bilingual group, I examined individual differences in English and Spanish vocabulary and verbal fluency in relation to language experience and SES. I hypothesized that within the bilingual group, higher English language experience would associate with better performance in English language measures and worse performance in Spanish language

measures, while SES would also contribute to English skills. Third, to address whether language experience and SES relate to richer, more naturalistic language skills in bilinguals, the role of language experience and SES was examined in relation to narrative performance in both English and Spanish. Similarly, I hypothesized that language experience and SES would positively associate with spoken narrative skills, such that higher English experience and higher SES would predict better English and worse Spanish spoken narrative performance.

Methods

Participants

Sixty-nine typically developing English-Spanish bilingual children ages 5 – 13 years of age participated in at least one visit as part of the Pediatric Longitudinal Imaging, Neurocognition, and Genetics (PLING) study at the University of California, San Diego (UCSD). The study was conducted with approval from the UCSD human research protection program and institutional review board. A screening questionnaire for participation was conducted over the phone prior to study participation. Participants were inducted into the study if they were typically developing and had no diagnosis of a major developmental, psychiatric, or neurological disorder, or brain injury. Participants were considered bilingual and included in testing of English-Spanish bilingual assessments if parent reported during screening that Spanish was spoken in the home and the child had knowledge of both English and Spanish. Written informed consent was obtained from all parents and written informed assent was obtained for children age seven years and older. Demographic information including age, sex, parent education, annual household income, race, and ethnicity, were collected using a study-specific

demographic questionnaire. The following subjects were excluded from the bilingual cohort: nine participants refused to complete any of the Spanish language assessments and reported not knowing Spanish; one participant reported significantly higher SES relative to the cohort. All bilingual participants identified as Hispanic or Latino.

Fifty-Eight English monolingual PLING participants who completed the English receptive vocabulary task were matched on age and sex to the bilingual group. Due to the distribution of the demographics, it was only possible to match half of the group on household income. Demographic information for the language groups for the between group analysis is presented in Table 1.1.

Table 1.1

Demographic Information and English TPVT Mean and Standard Deviations by Language Groups.

	Language Group	
	English-Spanish Bilinguals	English Monolinguals
N (Female)	58 (26)	58 (30)
Mean Age (<i>SD</i>)	8.52 (<i>1.87</i>)	8.77 (<i>2.10</i>)
Range	4.94 – 13.75 years	5.05 – 13.01 years
Annual Household Income ^a		
Mean (<i>SD</i>)	3.98 (<i>1.42</i>) ^c	6.90 (<i>2.68</i>)
Range	1 – 7	1– 12
Parent Education ^b		
Mean (<i>SD</i>)	3.96 (<i>1.53</i>) ^c	6.13 (<i>1.17</i>)
Range	1 – 7	1 – 7
TPVT Receptive Vocabulary		
Mean (<i>SD</i>)	993.48 (<i>218.81</i>)	1190.76 (<i>234.61</i>)
Range	571 – 1541	713 – 1835

^aHousehold income: 1 (less than \$5,000); 2 (\$5 - 9,999); 3 (\$10 - 19,999); 4 (\$20 -29,999); 5 (\$30 - 39,999); 6 (\$40 - 49,999); 7 (\$50 - 99,999); 8 (\$100 - 199,999); 9 (\$200 - 249,999); 10 (\$250 - 299,999); 11 (\$300,000 or more).

^bParent education: 1 (Less than 7 years); 2 (7 - 9 years); 3 (10 -11 years); 4 (High School Diploma); 5 (1 – 3 years of college); 6 (Bachelor's Degree); 7 (Professional Degree e.g., Masters, Doctorate, MD, JD).

^cN = 50; seven bilingual participants did not report household income or parent education.

Materials and Procedure

Receptive vocabulary in bilinguals and monolinguals. English receptive vocabulary was assessed in both the monolingual and bilingual group using the Toolbox Picture Vocabulary Test (TPVT), a subtest of the NIH Toolbox Cognition Battery (Bauer & Zelazo, 2014). Participants were presented with an auditory recording of a word, and were asked to select the image that most closely matches the meaning of the word from an array of four images. The TPVT is a computerized adaptive test so that the presentation of the following word is dependent on previous performance. A computed score for TPVT is calculated and it ranges from 200 to 2000. Further details on scoring can be found in the manual (“National Institutes of Health Toolbox Cognition Battery (NIH Toolbox CB),” 2013).

Language experience and language skills in bilinguals. To examine individual differences within the bilingual group, additional language skills were assessed in the bilingual cohort in both English and Spanish. A language experience questionnaire assessed language experience and practice in the school and in the home.

Bilingual language experience. The Bilingual Language Experience Questionnaire (BLE-Q) was a study-specific parent questionnaire designed to assess bilingual language experience and practice in the home and in the school (Appendix A). The questionnaire was adapted from previous language questionnaires used to assess language experience (Gollan, Starr, & Ferreira, 2015; Gutiérrez–Clellen & Kreiter, 2003; LI et al., 2014; Marian, Blumenfeld, & Kaushanskaya, 2007). The total number of responses for English, Spanish, and both English-Spanish were counted. Responses for both English-Spanish were divided in half and added to the English and Spanish response counts. The proportion of BLE-Q English language experience was the total count for

English (i.e. ‘Primarily English’ + $0.5 \times$ ‘Both’) over the total number of responses (i.e., ‘Primarily English’ + ‘Primarily Spanish’ + ‘Both’). The proportion of BLE-Q Spanish language experience was the total count for Spanish (i.e., ‘Primarily Spanish’ + $0.5 \times$ ‘Both’) or the total number of responses. Similarly, proportions for home language experience and school language experience were calculated based on the respective home or school environment questions.

Vocabulary measure. Both receptive and expressive vocabulary were examined in the bilingual cohort. Spanish receptive vocabulary was administered using the Spanish version of the TPVT, normed on a Spanish speaking population in the U.S. The Multilingual Naming Test (MINT) (Gollan, Weissberger, Runnqvist, Montoya, & Cera, 2012) was used to assess expressive vocabulary in both English and Spanish. The MINT was specifically designed to assess picture naming in bilingual populations and has been used to assess vocabulary in bilingual children (Sheng et al., 2014). The MINT consists of sixty-eight picture items. Participants were administered the MINT in English and Spanish, first in the language the child reported dominance in. In each administration, participants were asked to name each picture item in the language of administration. Vocabulary scores for the MINT in each language were calculated as the total of correct responses.

Verbal fluency (VF) tasks. Sound fluency and category fluency were administered in both English and in Spanish. The VF tasks in English were administered in a separate session from the VF tasks in Spanish. For the category fluency task, children were asked to name as many words as possible in the category of food given one minute. Food was a semantic category in which English-Spanish bilingual children were

likely to have knowledge of items in both languages. For the sound fluency VF task, participants were asked to name as many words starting with the sound /s/ given one minute, excluding proper nouns (e.g. names of people or places). A total score for correct responses was tallied for both category and sound fluency tasks in English and Spanish. Code-switches were excluded from the correct count. For sound fluency, words starting with the similar phonetic sounds, /sh/, /z/, and /θ/, were counted as correct. For category fluency, commonly used words that borrowed from the other language, e.g. burrito and carne asada fries, were counted as correct in either language. Participants tend to score higher on category fluency compared to sound/letter fluency tests. A measure of average VF was calculated for each language using a non-parametric approach by first ranking category and sound fluency within each language, and then averaging the ranked scores for English and for Spanish separately.

Spoken narrative measures. The picture book, “Frog, where are you?” (Mayer, 1969) was used to elicit spoken narratives for both English and Spanish separately. The child was first shown the pictures in the book and asked to silently examine each page carefully. Children were then asked to tell a story from the beginning going page by page. Spoken narratives were recorded using a digital voice recorder. Separate native Spanish-English bilingual research assistants, one transcriber for Spanish and one for English, transcribed all samples. Transcripts were then reviewed for accuracy by the lead researcher. A coding scheme to analyze morphosyntactic errors and complex syntax structure was adapted from (Reilly, Losh, Bellugi, & Wulfeck, 2004). All transcripts were coded in English and Spanish by the lead researcher, a native English-Spanish bilingual, using the CHAT rules from the Child Language Data Exchange System

(CHILDES) (MacWhinney, 2000). For reliability, 20% of transcripts for English and Spanish were coded by a reliability coder. Transcripts were marked for retraces, with and without change (e.g. “the dog <kept barking> was barking at the bees”), phonological fragments and sounds (e.g. “ um, uh, oh”), and all dialectal pronunciations of word variant forms were coded to their standard form (e.g. “dat” for “that”). Retraces and phonological fragments were excluded from word counts.

Propositions. A proposition was defined as a verb and its arguments. All propositions were coded and tallied. The number propositions served as a measure of story length.

Morphosyntactic errors. Instances of morphological errors were coded, including omissions, substitutions, or overgeneralizations of prepositions, pronouns, verb auxiliaries, determiners, noun plurals, verb tense, and number verb agreement, as well as word order errors. Imprecise word choices, such as imprecise semantic labels for nouns or verbs were not counted as errors. For Spanish, all errors in gender determiners and articles were counted. For each narrative, the morphosyntax error rate was the proportion of the total number of morphological errors over the total number of propositions. Separate morphosyntax error rates were calculated for Spanish and English narratives.

Complex Syntax Structure. Five types of complex sentences were coded: coordinate sentences (e.g., and, or, but), verb complements (e.g., try+verb, think+verb, and infinitival compliments), adverbial clauses (e.g., when, because, while), relative clauses (e.g. who, whom), and passive sentences. All complex sentences were counted and the frequency measure, complex syntax rate, was derived as a proportion of the number complex sentences over the total number of propositions for each child narrative.

As in Reilly et al. (2004), dividing by the number of propositions controls for variability in story length. The complex syntax rate is a frequency measure that controls for story length.

Socio-economic status (SES). Parents reported parental education for both guardians on a scale of 1 – 7. The parent education scale was then reversed so that higher numbers represented more educational years¹. Parents reported household income on an ascending scale from 1 to 11 by income brackets². Parent education and household education were missing for seven bilingual participants. For all subjects across the monolingual and bilingual group with available TPVT and SES data, a measure of average SES was computed for N = 109 by first ranking scores for household income and highest parent education, and then taking the average of the two ranked scores. Similarly, for just the bilingual group, a separate measure of average SES was computed for N = 53 by first ranking scores for household income and highest parent education, and then taking the average of the two ranked scores. The study specific measure of SES accounted for both parent education and household income.

Analysis Plan

All analyses were done using JMP Pro 13 (64 bit). All language measures were examined for effects of age, sex, and SES. The correlations between language skills in the bilinguals were examined to describe the linguistic diversity among the bilinguals (Appendix B).

¹Parent education: 1 (Less than 7 years); 2 (7 - 9 years); 3 (10 -11 years); 4 (High School Diploma); 5 (1 – 3 years of college); 6 (Bachelor’s Degree); 7 (Professional Degree e.g., Masters, Doctorate, MD, JD).

² Household income: 1 (less than \$5,000); 2 (\$5 - 9,999); 3 (\$10 - 19,999); 4 (\$20 -29,999); 5 (\$30 - 39,999); 6 (\$40 - 49,999); 7 (\$50 - 99,999); 8 (\$100 - 199,999); 9 (\$200 - 249,999); 10 (\$250 - 299,999); 11 (\$300,000 or more).

Bilingual and monolingual receptive vocabulary. A linear regression model tested group differences in TPVT receptive vocabulary scores by entering a categorical variable of language group as a predictor of TPVT receptive vocabulary, controlling for age.

Individual differences in bilingual language skills. Due to the constraints of time, not all bilingual participants completed all bilingual language tasks. Table 1.2 shows the demographics for the participants that completed each language task and BLE-Q for the bilingual group. Separate linear regressions tested the associations between language experience and language outcomes in both languages by first entering the BLE-Q English language experience measure as a predictor of each of the language outcome measures, controlling for age. The mediating effect of SES was then examined using hierarchical linear regressions by comparing a model in which BLE-Q English and age were entered as predictors, to a model in which SES was entered as an additional predictor to the model. Note, five participants were missing SES information of the N = 55 participants who completed the BLE-Q. The change in R^2 was examined for significance. The linear and hierarchical regressions were constructed using SPSS IBM SPSS Statistics (v24).

Table 1.2

<i>Demographic Information for Bilingual Cohort by Language Task.</i>				
	MINT Receptive Vocabulary English/Spanish	TPVT Expressive Vocabulary English/Spanish	Spoken Narratives English/Spanish	Verbal Fluency English/Spanish
N (Female)	55 (27)	50 (23)	44 (21)	37 (16)
Mean Age (SD)	8.60 (1.86)	8.63 (1.86)	8.84 (1.70)	8.63 (1.91)

Table 1.3

Descriptive Statistics for BLE-Q Language Experience and SES for Bilinguals.

	BLE-Q English Experience ^a	Household Income ^b	Parent Education ^b
Mean	.74	4.00	3.80
(SD)	(.19)	(1.43)	(1.47)

^aN = 55; ^bN = 51

Results

Table 1.3 shows the descriptive statistics for the BLE-Q English experience measure and SES. Table 1.4 shows the descriptive statistics for performance on all primary outcome language measures in the bilinguals.

Table 1.4

Descriptive Statistics of Primary Outcome Language Measures.

	TPVT Receptive Vocabulary	MINT Expressive Vocabulary	Complex Syntax Rate	Morphosyntax Error Rate	Average ranked VF
English	997.84	45.56	.44	.17	19
Mean (SD)	(209.65)	(9.7)	(.12)	(.15)	(8.92)
Spanish	957.74	27.12	.39	.24	16.66
Mean (SD)	(159.31)	(12.28)	(.12)	(.16)	(8.87)

Age, sex, and SES effects in the bilinguals for all language measures were estimated in linear regression models and are presented in Table 1.5. There was a significant effect of age on all vocabulary measures and verbal fluency in English and Spanish, and for the English morphosyntax error rate, such that performance increased with age for all measures. There was a significant positive effect of SES on the BLE-Q

English language experience measure and MINT English expressive vocabulary, such that higher SES bilinguals had higher BLE-Q English experience and higher English expressive vocabulary. There was a negative effect of SES on MINT Spanish expressive vocabulary, and Spanish verbal fluency, such that higher SES bilinguals had lower Spanish expressive vocabulary and lower verbal fluency. There were no significant effects of sex on any of the measures. In monolingual group, there was an SES effect on TPVT English receptive vocabulary, such that higher SES predicted higher receptive vocabulary scores ($t = 3.69, p < 0.001$).

Receptive Vocabulary Between Bilinguals and Monolinguals

The results of the hierarchical model testing for the associations of language group and SES with TPVT receptive vocabulary scores are presented in Table 1.6. There was a significant effect of language group on TPVT receptive vocabulary, such that English monolinguals outperformed English-Spanish bilinguals (model 1). When adding SES as an additional predictor (model 2), there was a significant change in R^2 , such that model 2, which included SES as an additional predictor, accounted for more of the variance in TPVT receptive vocabulary scores than age and language group alone. SES appeared, at least in part, to mediate the effect of language group on receptive vocabulary, such that the group differences were no longer significant.

Table 1.6

Hierarchical Linear Regression Model Testing Associations Between Language Group, SES, and English TPVT Receptive Vocabulary in Bilinguals and Monolinguals.

	R^2	df	ΔR^2	Age		Language Group		SES	
				β	p	β	p	β	p
model 1	.62	106		.68	< 0.001**	.35	< 0.001**	--	--
model 2	.67	105	0.05*	.65	< 0.001**	.12	0.125	4.10	< 0.001**

** $p < 0.001$

Bilingual Vocabulary

First linear regressions tested the association between BLE-Q English experience and vocabulary in bilinguals. As hypothesized, higher BLE-Q English experience significantly predicted higher English TPVT receptive vocabulary ($R^2 = .57$, $df = 50$; age: $\beta = 0.61$, $t = 6.34$, $p < 0.001$; BLE-Q English: $\beta = 0.33$, $t = 3.43$, $p = 0.001$) and MINT expressive vocabulary ($R^2 = .64$, $df = 52$; age: $\beta = 0.36$, $t = 4.25$, $p < 0.001$; BLE-Q English: $\beta = 0.64$, $t = 7.58$, $p < 0.001$). Higher BLE-Q English experience predicted lower Spanish vocabulary for both TPVT receptive ($R^2 = .43$, $df = 48$; age: $\beta = 0.65$, $t = 5.67$, $p < 0.001$; BLE-Q English: $\beta = -0.26$, $t = -2.23$, $p = 0.03$) and MINT expressive vocabulary ($R^2 = .40$, $df = 52$; age: $\beta = 0.42$, $t = 3.75$, $p < 0.001$; BLE-Q English: $\beta = -0.54$, $t = -4.76$, $p < 0.001$). Then, hierarchical linear regressions were used to test the mediating effect of SES to the association of BLE-Q English and vocabulary, shown in Table 1.7. Note, the hierarchical models present data for 48 participants who had SES and TPVT data available, and for 50 participants who had MINT and SES data available. Model 1 included BLE-Q English experience alone as predictor of vocabulary, controlling for age, while model 2 added SES as an additional predictor of vocabulary to model 1. The change in R^2 between model 1 and model 2 was compared. BLE-Q English was a significant predictor of English and Spanish TPVT receptive vocabulary, and English and Spanish MINT expressive vocabulary, independent of age and SES. Adding SES as an additional predictor did not significantly account for more of the variance for English and Spanish TPVT receptive vocabulary scores, and for Spanish MINT expressive vocabulary. Only for English MINT expressive vocabulary, did both

SES and BLE-Q English experience account for significantly more of the variance in English vocabulary scores, than BLE-Q English experience alone.

Table 1.7

Hierarchical Linear Regressions Testing for SES Effects on the Associations Between BLE-Q English Experience and Vocabulary in Bilinguals.

						BLE-Q English			
						Experience		SES	
						β	p	β	p

Note: data for 48 participants for TPVT and 50 participants for MINT is presented due missing SES.

* $p < 0.05$, ** $p < 0.01$

Bilingual Language Experience, SES, and Verbal Fluency

A similar linear regression analysis tested the hypothesis that BLE-Q English experience would positively predict English verbal fluency and negatively predict Spanish verbal fluency. Neither the effect of, BLE-Q English on English verbal fluency ($R^2 = .30$, $df = 34$; age: $\beta = 0.48$, $t = 3.32$, $p = 0.002$; BLE-Q English: $\beta = 0.24$, $t = 1.67$, $p = 0.104$), nor the effect of Spanish verbal fluency ($R^2 = .45$, $df = 34$; age: $\beta = 0.64$, $t = 5.04$, $p < 0.001$; BLE-Q English: $\beta = -0.26$, $t = -2.02$, $p = 0.05$) reached significance, although trends were observed in the hypothesized direction. Hierarchical linear

regressions tested for effects of SES by comparing the change in R^2 between model 1 between model 2, shown in Table 1.8. Note, due to missing SES data, the hierarchical models present data on 34 participants who also had verbal fluency data. There was no significant change in R^2 between model 2 and model 1, in either Spanish or English. Neither BLE-Q English nor SES reached significance as predictors of verbal fluency in either language, although BLE-Q English trended positively with English verbal fluency, and trended negatively with Spanish verbal fluency. *Post-hoc*, linear regressions were conducted to examine the association of BLE-Q English and SES to category fluency and sound fluency separately. *Post-hoc*, analysis revealed BLE-Q English was negatively associated with Spanish category fluency ($p = 0.012$), independent of age and SES, while there was no association between Spanish sound fluency and BLE-Q English experience, but a negative trend with SES. There were no associations for English category fluency and sound fluency with either BLE-Q English or SES.

Table 1.8

Hierarchical Linear Regressions Testing for SES Effects on the Associations Between BLE-Q English Experience and Verbal Fluency in Bilinguals.

	R^2	df	ΔR^2	β	Age p	BLE-Q English Experience		SES	
						β	p	β	p
English Verbal Fluency									
model 1	.24	31	--	0.38	< 0.024*	0.28	0.088	--	--
model 2	.24	30	0.001	0.39	< 0.036*	0.27	0.141	0.03	0.882
Spanish Verbal Fluency									
model 1	.39	40	--	0.61	< 0.001**	-0.28	0.056	--	--
model 2	.40	39	0.01	0.58	0.001**	-0.25	0.123	-0.07	0.656

Note: data for only 34 participants is presented due missing SES information.

* $p < 0.05$, ** $p < 0.01$

Bilingual Language Experience, SES, and Spoken Narrative Skills

To test the hypothesis that BLE-Q English experience would predict more naturalistic measures of language skills in bilinguals, linear regressions tested the associations between BLE-Q English experience and the spoken narrative measures, morphosyntax error rate and complex syntax rate, controlling for age. Contrary to my hypothesis, BLE-Q English experience was not a significant predictor of the English complex syntax rate ($R^2 = .07$, $df = 41$; age: $\beta = 0.21$, $t = 1.39$, $p = 0.17$; BLE-Q English: $\beta = -0.20$, $t = -1.32$, $p = 0.19$). BLE-Q English was a significant predictor of the English morphosyntax error rate ($R^2 = .44$, $df = 41$; age: $\beta = -0.30$, $t = -2.54$, $p = 0.015$; BLE-Q English: $\beta = -0.56$, $t = -4.65$, $p < 0.001$), such that higher BLE-Q English was associated with lower rates of morphological errors in English. BLE-Q English was a significant predictor of the Spanish complex syntax rate ($R^2 = .17$, $df = 41$; age: $\beta = 0.25$, $t = 1.74$, $p = 0.09$; BLE-Q English: $\beta = -0.36$, $t = -2.52$, $p = 0.016$) and there was a moderate association to the Spanish morphosyntax error rate, ($R^2 = .12$, $df = 41$; age: $\beta = 0.09$, $t = 0.59$, $p = 0.560$; BLE-Q English: $\beta = 0.31$, $t = 2.05$, $p = 0.047$), such that higher BLE-Q English was associated with worse performance on Spanish spoken narrative measures. Then hierarchical linear regressions tested the mediating effects of SES. The results are shown in Table 1.9. Note due to missing SES information, only data on 39 participants is presented. There were no significant effects of SES for any of the spoken narrative measures in English nor Spanish.

Table 1.9

Hierarchical Linear Regressions Testing for SES Effects on Associations Between BLE-Q English Experience and Spoken Narrative Skills in Bilinguals.

				Age		BLE-Q English Experience		SES		
				R^2	df	ΔR^2	β	p	β	p
English Complex Syntax Rate										
model 1		.03 <i>ns</i>	36	--	0.06	0.723	-0.16	0.344	--	--
model 2		.04 <i>ns</i>	35	0.01	0.03	0.847	-0.11	0.571	-0.123	0.513
Spanish Complex Syntax Rate										
model 1		.14 <i>ns</i>	36	--	0.19	0.238	-0.36	0.028	--	--
model 2		.16 <i>ns</i>	35	0.02	0.16	0.344	-0.29	0.103	-0.16	0.376
English Morphosyntax Error Rate										
model 1		.43	36	--	-0.26	0.047*	-0.56	<0.001**	--	--
model 2		.44	35	0.007	-0.28	0.040*	-0.52	0.001**	-0.09	0.529
Spanish Morphosyntax Error Rate										
model 1		.12 <i>ns</i>	36	--	0.15	0.337	0.29	0.081	--	--
model 2		.14 <i>ns</i>	35	0.007	0.12	0.467	0.36	0.052	-0.16	0.366

Note: data for only 39 participants is presented due missing SES information.

* $p < 0.05$, ** $p < 0.01$

Exploratory Analysis

Correlations between language measures. The correlations between language measures, while controlling for age, were conducted to fully characterize the relationship between language skills within and between languages. The correlation matrix is shown in Appendix D. Spanish MINT expressive vocabulary correlated with all Spanish language measures, such that higher Spanish expressive vocabulary was correlated with

higher receptive vocabulary, higher rates of complex syntax, lower rates of morphological errors, and higher verbal fluency. English MINT expressive vocabulary scores negatively correlated with the rate of English morphosyntax errors, such that higher vocabulary correlated with lower rates of morphological errors. English verbal fluency correlated with all English language measures, such that higher verbal fluency was related to higher expressive and receptive vocabulary, higher rates of complex syntax, and lower rates of morphological errors. Spanish verbal fluency correlated positively with the Spanish rate of complex syntax and expressive vocabulary. The morphosyntax error rate correlated with receptive and expressive vocabulary, respectively for English and Spanish. Between languages, there was a positive correlation for rate of complex syntax, such that higher scores in one language were correlated with higher scores in the other language. There was a negative correlation for MINT expressive vocabulary, such that higher English vocabulary correlated with lower Spanish vocabulary.

Home and school Spanish experience. To explore the possibility that language outcome measures correlated differently to home language experience than to school language experience, follow-up partial-correlations were conducted between BLE-Q school English experience, BLE-Q home English experience, and the language outcome measures, controlling for age. After controlling for age, home and school English were correlated to English vocabulary (home English: $r = .66, p < 0.001$; school English: $r = .54, p < 0.001$), Spanish vocabulary (home Spanish: $r = -.59, p < 0.001$; school Spanish: $r = -.52, p < 0.001$) and English morphosyntax error rate (home English: $r = -.55, p < 0.001$; school English: $r = -.49, p < 0.001$). For the Spanish morphological error rate,

there was a positive trend for both home English ($r = .29, p = 0.061$) and school English experience ($r = .23, p = 0.133$). The Spanish rate of complex syntax correlated somewhat more strongly with school Spanish experience ($r = .38, p = 0.03$) than with home Spanish experience ($r = .28, p = .127$). Spanish verbal fluency was positively related to school Spanish experience ($r = .40, p = 0.015$) and trended with home Spanish experience ($r = .29, p = 0.092$), while English verbal fluency was positively related to only home English experience ($r = .36, p = 0.029$).

Discussion

Similar to other studies that have examined vocabulary differences between monolingual and bilingual children (Bialystok et al., 2010; D. Oller & Eilers, 2002), monolinguals had higher English receptive vocabulary scores compared to bilinguals, independent of age. However, SES appeared to mediate, at least in part, the effect of language group on English receptive vocabulary, such that the group difference in receptive vocabulary between bilinguals and monolinguals was no longer significant.

Bilingual Language Experience

The English-Spanish bilingual children in this study were diverse in the linguistic environment that they experienced in the home and in their school education. Bilinguals with higher English experience had higher English vocabularies, and lower English morphological errors. However, bilingual children with higher English experience also had lower Spanish vocabularies, higher rates of Spanish morphological errors, and lower rates of Spanish complex syntax. However, various previous studies have not found an association between English language skills and English experience in the environment, with one study suggesting that English proficiency was not dependent on home English

use (Duursma et al., 2007; Golberg & Paradis, 2008). A very recent study suggests that English language proficiency is predicted by both SES and by the language environment in the home, specifically maternal English fluency and the child's productive use of English in the home (Paradis & Jia, 2017). The present study confirmed an association between language experience and English language skills, as well as Spanish language skills. However, while English language experience significantly predicted performance on almost all language outcomes in English and Spanish, it did not significantly predict English complex syntax, and Spanish and English verbal fluency. One limitation of the present study is that certain language measures had fewer available data, such as verbal fluency, where trends between language experience and verbal fluency were observed. These findings would need replication in future studies with larger bilingual samples.

SES

In the bilingual sample of the present study, there was a strong effect of SES on English language experience and vocabulary, such that higher SES bilinguals were more English dominant in their language experience and had higher English vocabularies. Lower SES bilinguals had higher Spanish language experience, higher Spanish vocabularies, and higher Spanish verbal fluency. Bohman et al. (2016) reports a similar effect where higher SES bilinguals performed worse on Spanish outcome measures than lower SES bilinguals. The study attributes such association to the possibility that lower SES participants in their sample were more likely to be children of first generation immigrants and in turn more likely to be dominant in the native language of their parents.

Interestingly, although there were effects of SES for a few of the language outcome measures, SES did not appear to mediate any of the associations between

language experience and language outcome measures. For English expressive vocabulary, the model with both SES and English language experience accounted for significantly more of the variance in English expressive vocabulary scores, than English language experience alone. This is consistent with previous studies that find English language skills are sensitive to SES while Spanish language skills are not (Golberg & Paradis, 2008; D. Oller & Eilers, 2002). Rojas, et al. (2016) conducted a large study on 1363 kindergarten children from Spanish speaking households, and found that both the language environment and maternal education predicted measures of narrative productivity in English, while only the language environment predicted Spanish narrative productivity. Although the present study examined different narrative measures of productivity, English language experience predicted the Spanish rate of morphological errors and the rate of complex syntax, and the English rate of morphological errors. Contrary to Rojas, et al. (2016), SES was not associated with English measures of narrative productivity. However, a possible limitation of the present study and other studies, is that SES and language experience seem to be highly correlated in the population of U.S. bilingual children, such that high SES bilinguals tend to be more English dominant in language experience, while low SES bilinguals are more Spanish dominant. This could be because lower SES families in our sample were first generation families who have not yet assimilated, and prefer the heritage language, Spanish, at home. Also, Spanish education for second language English learners is most often offered in the primary school years in lower SES neighborhoods, where there might be a larger representation of Spanish speakers in general.

Summary

While there is evidence for the importance of language experience for language skills in younger bilingual children (Bohman et al., 2010; Raul Rojas et al., 2016), this study extends these findings to a wider age group. The results of this study confirm an important relationship between the linguistic environment of a bilingual child and strengths and weaknesses in language skills across both languages, independent of age and SES. The present findings support the idea that the linguistic environment of a bilingual child can account for many of the observed differences in language skills compared to monolinguals, in particular in the case of vocabulary and verbal fluency skills. One important future direction is to further examine individual differences in school language experience and home language experience in relation to the acquisition of language skills over time.

Chapter 1, in part, will be prepared for submission of publication of the material. Co-authors: Terry L. Jernigan, Tamar H. Gollan, and Judy Reilly. The dissertation author was the primary investigator and author of this material.

Chapter 2: Executive Function Skills in Bilingual and Monolingual Children

While there is some evidence to suggest bilingual children outperform monolingual children on executive function tasks, the findings are inconsistent (Paap et al., 2015). A few studies on bilinguals including low SES samples raise questions about the role of SES in moderating the relationship between bilingualism and language and cognitive control skills (Calvo & Bialystok, 2014; Carlson & Meltzoff, 2008; Engel de Abreu et al., 2012; Riggs et al., 2014; White, 2014). Importantly, there is a strong association between bilingualism in children in the U.S. and low SES demographics. It is known that skills in cognitive control are critical for outcomes in academic skills and SES might mediate language and cognitive control performance (Noble, et al., 2007). This chapter examines executive function skills in low to middle SES bilingual children compared to monolingual children from low to high SES backgrounds. Given that the bilingual group was lower in SES compared to the monolingual group, I hypothesized that the bilingual children would outperform the monolingual children, when controlling for SES. Alternatively, the effects of SES on executive function may offset any observable effect of bilingualism on executive function.

Methods

Participants

A total of fifty bilingual children from the cohort described in chapter 1 completed all three executive function tasks. From the PLING monolingual sample described in chapter 1, forty-nine English monolingual children had complete data for all three executive function tasks. All participants in this sample reported household income

and parent education. Demographic information for all three groups is reported in Table 2.1.

Table 2.1

Demographics by Language Group.

	Language Group	
	English-Spanish Bilinguals	English Monolinguals
N (Female)	50 (22)	49 (26)
Mean Age (<i>SD</i>)	8.47 (1.76)	8.57 (2.10)
Range	4.94 – 13.75 years	5.05 – 12.83 years
Annual Household Income ^a		
Mean (<i>SD</i>)	3.98 (1.42)	6.82 (2.86)
Range	1 – 7	1 – 11
Parent Education ^b		
Mean (<i>SD</i>)	3.88 (1.52)	6.04 (1.22)
Range	1 – 7	1 – 7

^aHousehold income: 1 (less than \$5,000); 2 (\$5 - 9,999); 3 (\$10 - 19,999); 4 (\$20 -29,999); 5 (\$30 - 39,999); 6 (\$40 - 49,999); 7 (\$50 - 99,999); 8 (\$100 - 199,999); 9 (\$200 - 249,999); 10 (\$250 - 299,999); 11 (\$300,000 or more).

^bParent education: 1 (Less than 7 years); 2 (7 - 9 years); 3 (10 -11 years); 4 (High School Diploma); 5 (1 – 3 years of college); 6 (Bachelor's Degree); 7 (Professional Degree e.g., Masters, Doctorate, MD, JD).

Materials and Procedure

Socio-economic status (SES). Household hold income was reported on a scale from 1 – 11³. Parent education for both guardians was reported on a scale of 1 – 7. The parent education scale was then reversed so that higher numbers represented more educational years. Highest parent education was used as a measure of parent education⁴.

³Household income: 1 (less than \$5,000); 2 (\$5 - 9,999); 3 (\$10 - 19,999); 4 (\$20 -29,999); 5 (\$30 - 39,999); 6 (\$40 - 49,999); 7 (\$50 - 99,999); 8 (\$100 - 199,999); 9 (\$200 - 249,999); 10 (\$250 - 299,999); 11 (\$300,000 or more).

⁴Parent education: 1 (Less than 7 years); 2 (7 - 9 years); 3 (10 -11 years); 4 (High School Diploma); 5 (1 – 3 years of college); 6 (Bachelor's Degree); 7 (Professional Degree e.g., Masters, Doctorate, MD, JD).

A measure of average SES was computed by first ranking scores for household income and highest parent education, and then taking the average of the two ranked scores. The study specific measure of SES then accounts for both parent education and household income.

Executive function tasks. As part of the PLING battery, participants completed the NIH Toolbox Cognition Battery (Bauer & Zelazo, 2014) and the Cambridge Neuropsychological Test Automated Battery (CANTAB) (Cambridge Cognition Ltd., Cambridge, UK). The NIH Toolbox Cognition Battery and CANTAB were administered in separate sessions on a computer in a quiet room with an experimenter present to help keep the child on task.

Flanker Inhibitory Control and Attention Test. Inhibition and attention in response to conflicting information was measured using the Flanker Inhibitory Control and Attention Test from the NIH Toolbox Cognition Battery. Participants were required to attend to a center stimulus while inhibiting attention to flankers on either side. For age 7 years and younger, the flankers were fish while for age eight years and older, the flankers were arrows. On congruent trials, the center stimulus pointed in the same direction as the flankers. In the incongruent trials, the center stimulus pointed in the opposite direction of the flankers. Participants were instructed to indicate the direction of the center stimulus. For participants age 7 years and younger, 20 trials were administered in the fish block. Those scoring $\geq 90\%$ in accuracy on the fish block trials advanced to the 20-trial arrow block. Participants age eight and older, automatically receive 20 accuracy points and start at the arrow block-trials. The maximum accuracy points

possible were 40 points out of 40 trials. Accuracy scores were converted on a 0 to 5-point scale by multiplying the total number of correct trials, or accuracy points, by 0.125. A reaction time vector measure was computed from the median reaction time values based on correct incongruent trials with reaction times greater than or equal to 100 ms and reaction times that were no larger than three standard deviations from the participant's mean. Reaction time scores were converted to reaction time vector scores on a 0 to 5-point scale using a Toolbox defined log transformation formula that accounts for minimum and maximum reaction time scores based on validation data. Lower reaction time scores resulted in higher reaction time vector scores. A computed score for the Flanker task was calculated using a two-vector method that combined both accuracy and reaction time performance for participants who scored greater than 80% on accuracy, and only accuracy for participants scoring less than or equal to 80% in accuracy. Computed scores ranged from 0 to 10. The Flanker computed score is a combined index of overall accuracy in responding to congruent and incongruent trials, and response time to incongruent trials. Further details on scoring can be found in the manual ("National Institutes of Health Toolbox Cognition Battery (NIH Toolbox CB)," 2013). Weintraub et al., (2013) report a test-retest reliability intraclass correlation coefficient of .95 for the Flanker task for ages three to fifteen years.

Dimensional Change Card Sort Task (DCCS). Cognitive flexibility was measured using the DCCS subtest from the Toolbox Cognition Battery. During the DCCS, two target pictures were presented simultaneously that differ across two dimensions (e.g., shape and color). Participants were instructed to match a series of paired test pictures, for example yellow balls and blue trucks, to the target pictures.

Participants were first asked to match according to one dimension, e.g., color, and then after a given number of trials according to another dimension, e.g., shape. There are also switch-trials in which the sorting dimension is switched from trial to trial. There was a total of 40 possible trials. Participants age seven and younger conducted a pre-switch and post-switch block that consisted of ten trials. Participants age eight and older skipped the two initial blocks and automatically received ten points to their accuracy score. All participants then advanced to the 30 mixed-trial block. Accuracy scores were scaled on a range from 0 to 5 by multiplying the total number of correct responses by 0.125. A reaction time vector score was calculated using the median reaction time score for the non-dominant dimension (the less frequently cued sorting dimension). Median reaction time values were computed from correct trials with a reaction time trials greater or equal to 100 ms and reaction times no larger than three standard deviations from the participant's mean. Reaction time scores were scaled similarly to the Flanker on a scale from 0 to 5, and converted so that higher reaction time vector scores measured faster performance. A similar two-vector method and accuracy criteria was used to calculate DCCS computed scores on a 0 to 10-point scale. Higher computed scores for the DCCS reflect better performance on cognitive flexibility. Further details on scoring can be found in the manual National Institutes of Health Toolbox Cognition Battery (NIH Toolbox CB; 2013). (Weintraub et al., 2013) report a test-retest reliability intraclass correlation coefficient of 0.92 for the DCCS task for ages three to fifteen years of age.

Stop-Signal Task. To assess response inhibition, participants completed the stop-signal task, a subtest from the CANTAB battery. The stop-signal task consists of go and stop trials. During go trials, the participant is instructed to press the left-side button when

they see an arrow pointing left, and the right-side button when they see an arrow pointing right. During stop-trials, the participant is instructed to not press the button in response to the direction of the arrow if they hear the auditory stop cue. The participant is instructed to go as fast as possible without making mistakes. The stop-signal consists of two parts. In the first part, the participant completes 16 practice go trials. In the second part, there are go trials with stop trials occurring 25% of the trials in random order. There are five blocks of 64 trials each. After each block, a feedback histogram is shown to the participant, and the participant is encouraged to go faster. The histogram shown after the first block is the same for all subjects. In subsequent blocks, relative performance feedback is presented, the participant's go reaction time relative to the first block, in a histogram containing the first block and performance for all completed blocks. The stop-signal delay (SSD) is the delay between the onset of the arrow and the auditory stop signal cue. The SSD changes adaptively throughout the test so that responses are inhibited approximately 50% of the time for each participant. The stop-signal reaction time (SSRT) measure is then estimated using the race model by subtracting the SSD where subjects are able to inhibit 50% of their responses, from the median go reaction time. The stop-signal reaction time (SSRT) is calculated as the main outcome measure, and it is an estimate of how much time a participant needs to inhibit a cued response. The SSRT scores are estimated from the last half of the trials, after the participant has become familiar with the auditory stop-signal cue. Higher SSRT scores would be interpreted as worse performance, i.e. longer reaction times to inhibit a response. The SSRT scores were inverted so that higher scores indicated better performance on the stop-signal task.

Analysis Plan

A measure of overall executive function (EF) was calculated by averaging the z scores of the Flanker computed scores, DCCS computed scores, and SSRT inverted scores. A categorical variable of language group was constructed to identify the bilingual and monolingual groups. The main measure was examined for effects of age, sex, and SES. Linear regressions were constructed using JMP Pro 13 (64-bit). To test group differences in executive function performance between the bilingual and monolingual groups, a linear regression model was constructed in which language group was entered as a predictor of overall executive function, while controlling for age, age², and sex. The mediating effect of SES was tested by entering SES as an additional predictor to the model.

Results

Age, Sex, and SES Effects

There were no significant differences in age or sex between the bilingual and monolingual group. The monolingual group had significantly higher household income and parent education than the bilingual group ($ps < 0.001$). Across both groups, there was a significant effect of age ($t = 11.04, p < 0.001$), age² ($t = -2.68, p = 0.009$), and SES ($t = 2.08, p = 0.041$) on overall EF performance. There was no significant effect of sex on overall EF performance. There was a significant effect of age on performance on all three EF measures: SSRT ($t = 6.24, p < 0.001$), flanker ($t = 10.46, p < 0.001$), and DCCS ($t = 7.55, p < 0.001$). For DCCS, there was a significant effect of SES ($t = 3.05, p = 0.003$), and a trend for sex ($t = -1.76, p < 0.082$). All linear regression models controlled

for age, age², and sex.

Table 2.2

Means and Standard Deviations for Overall EF Scores and Executive Function Scores by Task.

	English-Spanish Bilinguals Mean (SD) N = 50	English Monolinguals Mean (SD) N = 49
Overall EF Z-scores	-0.15 (0.91)	0.15 (0.71)
Stop-signal SSRT Inverted ^a	-268.15 (126.28)	-247.27 (86.10)
Flanker Computed Score ^b	6.86 (1.47)	7.26 (1.45)
DCCS Computed Score ^b	5.71 (1.90)	6.44 (1.45)

^aSSRT scores were inverted so that higher scores reflected faster reaction times.

^bComputed scores are out of 10.

Overall Executive Function in Bilinguals Compared to Monolinguals

The means and standard deviations for the overall EF measure and each of the three executive function tasks are presented in Table 2.2. There was a significant effect of group on overall EF performance, such that monolinguals outperformed bilinguals, controlling for age, age², and sex ($R^2 = .61$, $df = 101$; age: $\beta = 0.76$, $t = 12.06$, $p < 0.001$; age²: $\beta = -0.19$, $t = -2.98$, $p = 0.004$; sex: $\beta = -0.04$, $t = -0.64$, $p = 0.52$; language group: $\beta = 0.17$, $t = 2.74$, $p = 0.007$). When entering SES as an additional predictor, the effect of language group was no longer significant but still trending ($R^2 = .61$, $df = 93$; age: $\beta = 0.74$, $t = 11.28$, $p < 0.001$; age²: $\beta = -0.20$, $t = -3.02$, $p = 0.003$; sex: $\beta = -0.6$, $t = -0.84$, $p = 0.402$; language group: $\beta = 0.17$, $t = 1.79$, $p = 0.077$; SES: $\beta = 0.02$, $t = 0.24$, $p =$

0.811). Although SES accounted for some of variance in overall EF performance, SES did not appear to completely mediate the group differences in overall EF.

Executive Function Measures

Planned follow-up analysis were conducted to test for groups differences and SES effects on the individual measures of overall EF: SSRT inverted scores, flanker computed, and DCCS computed scores. In separate linear regression models, language group was entered as a predictor of each of the EF measures, controlling for age, age², and sex. There was a significant effect of language group for flanker inhibitory control ($R^2 = .60$, $df = 94$; age: $\beta = 0.72$, $t = 10.89$, $p < 0.001$; age²: $\beta = -0.33$, $t = -4.89$, $p < 0.001$; sex: $\beta = 0.04$, $t = 0.65$, $p = 0.520$; language group: $\beta = 0.12$, $t = 2.54$, $p = 0.013$), DCCS cognitive flexibility ($R^2 = .43$, $df = 94$; age: $\beta = 0.61$, $t = 7.80$, $p < 0.001$; age²: $\beta = -0.12$, $t = -1.49$, $p = 0.139$; sex: $\beta = -0.10$, $t = -1.24$, $p = 0.217$; language group: $\beta = 0.20$, $t = 2.58$, $p = 0.011$), but not for the SSRT response inhibition measure ($R^2 = .31$, $df = 94$; age: $\beta = 0.54$, $t = 6.32$, $p < 0.001$; age²: $\beta = -0.06$, $t = -0.76$, $p = 0.448$; sex: $\beta = -0.06$, $t = -0.91$, $p = 0.366$; language group: $\beta = 0.08$, $t = 0.95$, $p = 0.347$).

In separate linear regression models, the mediating effect of SES was tested by entering SES as an additional predictor of each of the EF measures, controlling for age, age², and sex. The results of the linear regressions are presented in Table 2.3. There was no significant effect of language group for DCCS and SSRT performance, after controlling for age, age², sex, and SES. There was a significant effect of language group for flanker performance, such that monolinguals outperformed bilinguals, even after controlling for age, age², sex, and SES.

Table 2.3

Linear Regression Models Testing Group Differences in EF Measures.

	SSRT		Flanker		DCCS	
	β	p	β	p	β	p
Age	0.55	<0.001**	0.72	<0.001**	0.59	<0.001**
Age ²	-0.07	0.402	-0.33	<0.001**	-0.01	0.213
Sex	-0.06	0.457	0.05	0.456	-0.13	0.116
Language Group	0.14	0.264	0.20	0.031*	0.07	0.508
SES	-0.07	0.521	-0.58	0.582	0.19	0.093

* $p < 0.05$, ** $p < 0.01$

The interaction of SES by language group was then entered as an additional predictor in the models for SSRT, flanker, and DCCS. The interaction of SES by language group was not significant for DCCS ($\beta = -0.13$, $t = -0.80$, $p = 0.425$) or flanker ($\beta = 0.21$, $t = 1.51$, $p = 0.135$). There was a significant interaction of SES by language group for SSRT performance, such that SES was related to SSRT negatively in the bilingual group and not in the monolingual group ($R^2 = .35$, $df = 92$; age: $\beta = 0.52$, $t = 6.06$, $p < 0.001$; age²: $\beta = -.09$, $t = -1.03$, $p = 0.306$; sex: $\beta = -0.06$, $t = -0.66$, $p = 0.510$; language group: $\beta = 0.21$, $t = 1.68$, $p = 0.097$; SES: $\beta = -0.45$, $t = -2.12$, $p = 0.037$; SES by language group interaction: $\beta = 0.37$, $t = 2.12$, $p = 0.037$).

To further understand the interaction of SES by language group on SSRT performance, linear regressions were constructed to test the association between SES and SSRT performance for the bilingual group and the monolingual group separately. A negative association between SES and SSRT performance was confirmed in the bilingual

group, such that lower SES bilinguals outperformed higher SES bilinguals, controlling for age, age², and sex ($R^2 = .46$, $df = 45$; age: $\beta = 0.61$, $t = 5.34$, $p < 0.001$; age²: $\beta = -.30$, $t = -2.59$, $p = 0.013$; sex: $\beta = -0.02$, $t = 0.17$, $p = 0.866$; SES: $\beta = -.27$, $t = -2.33$, $p = 0.024$). The residual plot of the association between SES and SSRT performance in the bilingual group is shown in Figure 2.1. Within the monolingual group, there was no association between SES and SSRT performance, although there was a modest positive trend ($R^2 = .38$, $df = 44$; age: $\beta = 0.52$, $t = 4.25$, $p < 0.001$; age²: $\beta = 0.14$, $t = 1.51$, $p = 0.182$; sex: $\beta = -0.11$, $t = -0.91$, $p = 0.367$; SES: $\beta = 0.18$, $t = 1.45$, $p = 0.154$).

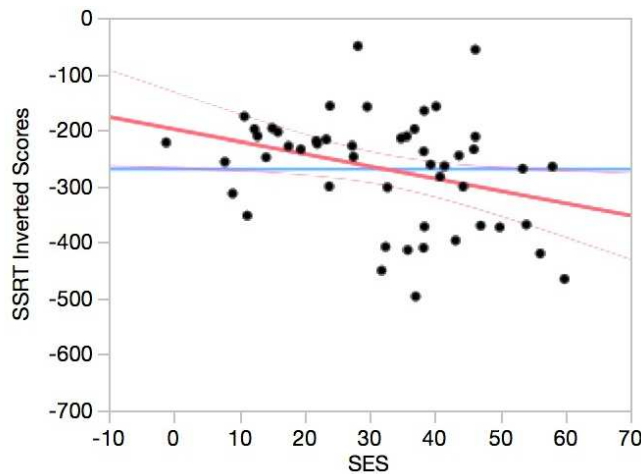


Figure 2.1. Residual plot showing association between SES and SSRT inverted scores in the bilingual group, controlling for age, age², and sex.

Discussion

Bilingual children did not outperform monolingual children on any of the executive function measures, even after controlling for SES. In the bilingual group, the average parent education did not even reach a high school diploma, and in combination

with a low household income, the effects of low SES on executive function performance may have offset any effects of bilingualism. While SES appeared to mediate, at least in part, group differences in cognitive flexibility performance on the DCCS, it did not appear to mediate group differences for inhibitory control performance on the flanker task. Further an interaction of SES by language group was observed for response inhibition performance on the stop-signal task. These findings suggest the effects of SES on executive function performance in bilinguals is more complex than in monolinguals.

Response Inhibition

The finding that bilinguals did not differ from monolinguals on inhibitory control performance, is not surprising. One study that compared adult bilinguals and monolinguals on performance on the stop-signal task found no differences in performance between groups (Colzato et al., 2008). Other studies in children that have examined other measures of inhibitory control involving inhibition of a cued response also found no differences between bilinguals and monolinguals on these tasks (Bonifacci, Giombini, Bellocchi, & Contento, 2011; Martin-Rhee & Bialystok, 2008; Thomas-Sunesson et al., 2016). However, the interaction of SES by language group on SSRT performance suggested that response inhibition varied differently in the bilinguals than in the monolinguals as function of SES. Specifically, in the bilingual children, response inhibition performance decreased with higher SES, while in the monolingual children, the association was not observable. In contrast, we would have expected a positive relationship between SES and inhibitory control performance, given the reported negative effects of SES on executive function performance (Noble et al., 2007).

There could be other differences between the low SES and higher SES bilinguals that may account for performance on response inhibition. In this bilingual sample, all were from Hispanic ethnicities, however, differences between parenting styles within Hispanic cultures have been found (Okagaki & Sternberg, 1993). Some Hispanic parenting styles favor an authoritarian environment, where there is an emphasis on rule following. It is unknown whether such differences existed between the low SES and high SES bilingual groups. Another possibility is that the low SES bilinguals differed from the high SES bilinguals in language experience and practice. A few studies on bilinguals suggest that language experience, such as the degree of language switching in the environment, may differentiate bilinguals on executive function skills, such as task-switching costs and inhibitory control (Prior & Gollan, 2011; Verreyt et al., 2016). The relationship between bilingual language experience and response inhibition, in the context of delaying a cued response, has not yet been examined.

Inhibitory Control

Group differences on flanker performance persisted even after controlling for age, sex, and SES, such that monolingual children outperformed bilingual children. It is possible that other characteristics within the bilingual group, such as language experience and practice, may contribute to differences in performance on inhibitory control. One limitation of this study is that the flanker computed score from the NIH Toolbox is not used by other studies examining the effects of bilingualism on inhibitory control. This makes it difficult to compare the results from the present study to previous findings. While some studies have reported a reduction on the interference effects in bilinguals compared to monolinguals, i.e. reaction time to incongruent trials, various studies have

found a bilingual advantage for global reaction time, that is bilinguals outperform monolinguals in reaction time to both incongruent and congruent trials (*for a review see* Hilchey & Klein, 2011; Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Costa, Hernández, & Sebastián-Gallés, 2008; Engel de Abreu et al., 2012). Engel de Abreu et al. (2012) reported low SES bilinguals outperformed low SES monolinguals on a control measure that combined reaction times to incongruent trials on the flanker task with performance on a selective attention task. Calvo and Bialystok (2014) reported bilingual children outperformed monolingual children on an executive function measure that included overall accuracy on the flanker task. Since the NIH Toolbox flanker computed scores combine both overall accuracy and the median reaction time of incongruent trials, it is difficult to compare findings from the present study to previous studies.

Cognitive Flexibility

Group differences between bilinguals and monolinguals in cognitive flexibility as measured by the DCCS seemed to be mediated in part by SES. This suggests that differences in performance between monolinguals and bilinguals on cognitive flexibility, with monolinguals outperforming the bilinguals, is attributable to differences in SES. These findings are consistent with previous studies that suggest that there are disparities between low SES and high SES children in executive function skills, including cognitive flexibility (Noble et al., 2007; Sarsour et al., 2011). Ardila et al., (2005) conducted a large study with children in a similar age range, 5 – 14 years, from diverse socioeconomic backgrounds in Mexico and Columbia, and found no effect of parent education on a task of cognitive flexibility. The present study included Hispanic children living in

the U.S., and accounted for both household income and parental education, a more robust measure of socio-economic status.

Previous studies have reported low SES bilingual children outperformed monolingual children on tasks of cognitive flexibility (Carlson & Meltzoff, 2008; White & Greenfield, 2016). Carlson & Meltzoff (2008), reported low SES bilinguals outperformed higher SES monolinguals on a similar cognitive flexibility task, after controlling for SES. A very recent study examining executive function, including cognitive flexibility, in low SES pre-school aged children, reported that the highly proficient bilingual children outperformed monolingual children, while Spanish dominant bilinguals did not differ in executive function performance from either group (White & Greenfield, 2016). Various studies suggest that the positive effect of bilingualism on executive function requires a bilingual sample that is proficient in both languages to observe effects of an advantage in executive function performance (Bialystok & Barac, 2012; Carlson & Meltzoff, 2008; Luk, Bialystok, et al., 2011). One limitation to the present study is the sample size and the distribution of English dominance in the bilinguals. The bilingual group while diverse across English and Spanish proficiency, was small, limiting the possibility to examine groups within the bilinguals to examine language proficiency as a contributing factor. Previous studies reporting a performance advantage in low SES bilinguals in cognitive flexibility, have been done with preschool to kindergarten aged children. The present study examined a much wider age range, 5 to 13 years of age, in which children are at different developmental stages of executive function. It is difficult to know whether the effects of bilingualism on cognitive flexibility are most observable in certain developmental age groups.

Summary

Given the wide age range, diversity of SES and language proficiency, it is possible that other characteristics within the bilingual group may contribute to observed group differences in executive function performance. In particular, while SES appeared, in part, to mediate the effect of group differences between monolinguals and bilinguals on cognitive flexibility, it did not appear to mediate group differences for inhibitory control and response inhibition. Investigating other factors among bilinguals that may contribute to executive function performance merits attention. A future study with a more homogeneous bilingual group more closely matched to a monolingual group on both household income and parent education would be necessary to further investigate the contribution, if any, of bilingualism on executive function in the case of lower SES bilinguals.

Chapter 2, in part, will be prepared for submission of publication of the material. Co-author: Terry L. Jernigan. The dissertation author was the primary investigator and author of this material.

Chapter 3: Individual Differences in Language Experience in Relation to Executive Function in Bilinguals

Findings from chapter 2 revealed an effect of SES on response inhibition within the bilingual cohort, such that lower SES bilinguals outperformed higher SES bilinguals. Given that many studies have reported effects of SES, with higher SES predicting better executive function performance, it is plausible that other characteristics within the low SES bilingual group could have contributed to response inhibition performance. Further, while SES appeared, at least in part, to mediate group differences between bilinguals and monolinguals on tasks of cognitive flexibility, it did not appear to mediate group differences in inhibitory control performance. Similarly, it is unknown whether other characteristics within the bilingual group contributed to such group differences in inhibitory control. Studies suggest language experience may be an important contributing factor to executive function performance in bilinguals (Bialystok & Barac, 2012; Festman & Münte, 2012; Festman et al., 2010; Hartanto & Yang, 2016; Prior & Gollan, 2011; Verreyt et al., 2016). This chapter examines the associations between individual differences in language experience and measures of response inhibition and inhibitory control in a cohort of bilingual children diverse in language experience. Specifically, two language experience measures are examined: the degree of balance between language experience in the environment and the frequency of language mixing in speech. I hypothesized that balanced bilinguals would outperform unbalanced bilinguals on executive function performance, while controlling for age. Green's Inhibitory Control Model of bilingualism posits that bilinguals recruit executive function

skills to achieve language control. Studies in adults suggest better language control is associated with better executive function performance. I hypothesized that bilinguals with a higher frequency of language mixing within and between utterances, i.e. poorer language control, would demonstrate poorer executive function performance compared to bilinguals with a lower frequency of language mixing.

Methods

Participants

Fifty-three of the bilingual participants described in chapter 2 completed the CANTAB stop-signal task, the NIH Toolbox Flanker task, and the Bilingual Language Experience Questionnaire (BLE-Q).

Materials and Procedure

Executive function measures. The stop-signal reaction time (SSRT) inverted score described in chapter 2 was used as a measure of motor response inhibition. Cognitive control was measured using the Flanker computed scores described in chapter 2. The SSRT is an estimate of the time needed to suppress a primed motor response after an auditory “stop” cue, while the Flanker computed score is a measure that combines accuracy across congruent and incongruent trials, and response time to incongruent trials from a classic “flanker” task.

Language experience measures. A balance index score (BLE-Q index) was derived as a measure of balance of experience and usage between languages. The English language experience and Spanish language experience measures described in chapter 1 were used. Briefly, the proportion of English language experiences was the total number of responses for ‘English primarily’ plus half of the responses to ‘Both’ English-Spanish over the total number of responses. The proportion of Spanish language

experience was calculated similarly. The BLE-Q balance index was the proportion of language experience for the non-dominant language over the dominant language. This balance index was calculated similarly to a previous balance index used to describe balance in vocabulary in bilinguals (Gollan et al., 2012). Gollan et al. (2012) calculated an expressive vocabulary balance index score using the MINT scores by dividing the total number of correct responses in the non-dominant language by the total number of responses in the dominant language. For the present study, the proportions of English and Spanish language experience from the BLE-Q defined the non-dominant and dominant language in calculating the BLE-Q balance index. In contrast to Gollan et al. (2012), the balance index was calculated using proportion scores from the BLE-Q rather than total scores from the MINT, representing the degree of balance between the proportion of language experience in one language relative to the other language. Proportions closer to 1 meant more balance in language experience.

The frequency of language mixing was derived from the BLE-Q, also described in Chapter 1. Specifically, on question 23, parents reported whether their child mixed words or sentences from two languages in his/her own speech, and if so, in question 23a they reported how often (see Appendix A). Responses were scored on a scale of 0 to 4 (0 = never, 1 = rarely, 2 = occasionally, 3 = frequently, 4 = always). A score of zero was designated if the parent responded ‘no’ to question 23.

SES. Five participants were missing household income and parent education. SES was calculated as the average of the ranked scores for household income and parent education for the N = 48 bilinguals in this chapter.

Analysis Plan

The main measures were first examined for age, sex, and SES effects within the bilingual group. Then, to test the associations of BLE-Q balance index scores and the frequency of language mixing to executive function performance, two separate linear regression models were constructed in which the BLE-Q index, frequency of language mixing were entered as predictors of SSRT inverted scores and flanker computed scores, controlling for age and age².

Results

The demographics and performance on the language experience and executive function measures are presented in table 3.1. There was a significant effect of age and age² on SSRT inverted scores (age: $t = 4.80, p < 0.001$; age²: $t = -2.32, p = 0.025$), and inhibitory control flanker computed scores (age: $t = 6.25, p < 0.001$; age²: $t = -2.88, p = 0.006$), with performance increasing with age. There was a significant negative association between age and the BLE-Q balance index, such that balance of language experience decreased with age ($t = -2.32, p < 0.025$). There was a significant negative association between SES and SSRT inverted scores (age: $t = -2.29, p = 0.027$), such that performance decreased with higher SES, and a negative trend for flanker computed scores (age: $t = -1.95, p = 0.058$). There was a negative association between SES and the BLE-Q balance index, such that balance of language experience decreased with higher SES (age: $t = -4.75, p < 0.001$). There were no other age, sex, or SES effects. All linear models controlled for age and age².

Table 3.1

Bilingual Group Demographic Information and Performance on Language Experience and Executive Function Measures.

	Bilingual Group (N = 53)	
	Mean (<i>SD</i>)	Range
Age (years)	8.47 (<i>1.76</i>)	4.94 – 13.75
Household Income ^a	3.94 (<i>1.37</i>) ^c	1 – 7
Parent Education ^b	3.88 (<i>1.54</i>) ^c	1 – 7
Average Ranked SES	24.46 (<i>11.97</i>)	2.5 – 45
BLE-Q Index	0.34 (<i>.27</i>)	0 – 1
Frequency of Language mixing	1.89 (<i>1.31</i>)	0 – 4
SSRT Inverted Scores	-266.30 (<i>122.93</i>)	-666.03 – -76.53
Flanker Computed Scores	6.92 (<i>1.43</i>)	1.63 – 8.65

^aHousehold income: 1 (less than \$5,000); 2 (\$5 - 9,999); 3 (\$10 - 19,999); 4 (\$20 -29,999); 5 (\$30 - 39,999); 6 (\$40 - 49,999); 7 (\$50 - 99,999); 8 (\$100 - 199,999); 9 (\$200 - 249,999); 10 (\$250 - 299,999); 11 (\$300,000 or more).

^bParent education: 1 (Less than 7 years); 2 (7 - 9 years); 3 (10 -11 years); 4 (High School Diploma); 5 (1 – 3 years of college); 6 (Bachelor's Degree); 7 (Professional Degree e.g., Masters, Doctorate, MD, JD).

^cN = 48.

Language Experience Balance and Response Inhibition

Main hypothesis. There was a moderate positive association between the BLE-Q balance index and response inhibition SSRT inverted scores, controlling for age and age², such that bilinguals more balanced in language experience performed better on the stop-signal response inhibition measure ($R^2 = .44$, $df = 48$; age: $\beta = 0.67$, $t = 5.89$, $p < 0.001$; age²: $\beta = -0.28$, $t = -2.48$, $p = 0.017$; BLE-Q balance index: $\beta = 0.25$, $t = 2.20$, $p = 0.033$; frequency of language mixing: $\beta = -0.07$, $t = -0.69$, $p = 0.493$). The association between BLE-Q balance index and the SSRT inverted scores was no longer significant after

controlling for SES in the model (BLE-Q balance index: $\beta = 0.11$, $t = 0.74$, $p = 0.465$; SES: $\beta = -0.20$, $t = -1.38$, $p = 0.175$). There was no association between frequency of language mixing and SSRT inverted scores.

A follow up linear regression tested for an interaction effect of SES by BLE-Q balance, by adding the interaction as an additional predictor to the model predicting SSRT inverted scores, controlling for age and age². An interaction between SES and BLE-Q balance index was observed, such that the association between BLE-Q language balance and SSRT performance related differently as a function of SES ($R^2 = .50$, $df = 42$; age: $\beta = 0.62$, $t = 5.14$, $p < 0.001$; age²: $\beta = -0.36$, $t = -3.07$, $p = 0.004$; BLE-Q balance index: $\beta = 0.21$, $t = 1.40$, $p = 0.169$; SES: $\beta = -.24$, $t = -1.72$, $p = 0.092$; BLE-Q balance index by SES interaction: $\beta = 0.28$, $t = 2.22$, $p = 0.032$).

Post-hoc exploratory analysis. To follow up on the interaction of SES by BLE-Q balance index, a median split on the distribution of the SES measure (< 27.5) was used to form a low SES bilingual group (mean household income: 4.91; mean parent education: 4.78) and a higher SES bilingual group (mean household income: 2.91; mean parent education: 3). The higher SES bilingual group fell in the working-class category while the low SES group fell below the US Census (2015) poverty threshold. Using a linear regression, a categorical variable for bilingual SES groups was entered as a predictor of SSRT inverted scores, controlling for age, age², and sex. First, a group effect was confirmed such that the low SES bilinguals outperformed the working-class bilinguals on the SSRT response inhibition measure, independent of age ($R^2 = .43$, $df = 44$; age: $\beta = 0.58$, $t = 4.99$, $p < 0.001$; age²: $\beta = -0.27$, $t = -2.31$, $p = 0.025$; bilingual SES group: $\beta = 0.25$, $t = 2.15$, $p < 0.037$). Then a linear regression tested for group effects on

the BLE-Q balance index, controlling for age, and age². The results confirmed low SES bilinguals were more balanced in language experience than the working-class bilinguals, independent of age ($R^2 = .30$, $df = 44$; age: $\beta = -0.27$, $t = -2.12$, $p < 0.040$; age²: $\beta = 0.03$, $t = 0.27$, $p = 0.785$; bilingual SES group: $\beta = 0.50$, $t = 3.90$, $p < 0.001$).

Post-hoc exploratory analysis: Low SES balanced bilinguals versus working class unbalanced bilinguals. The high SES group was composed of mainly unbalanced bilinguals, while the low SES group was composed of balanced and unbalanced bilinguals. The distribution of the BLE-Q index by SES for the low SES and working class bilingual groups is shown in Figure 3. An exploratory group analysis was conducted to further investigate the contribution of language experience to differences in SSRT performance between SES groups. A median split on the distribution of the BLE-Q balance index scores was applied to the low SES bilingual group, forming a low SES balanced group (median BLE-Q > .44; $N = 12$; 7 female) and a low SES unbalanced

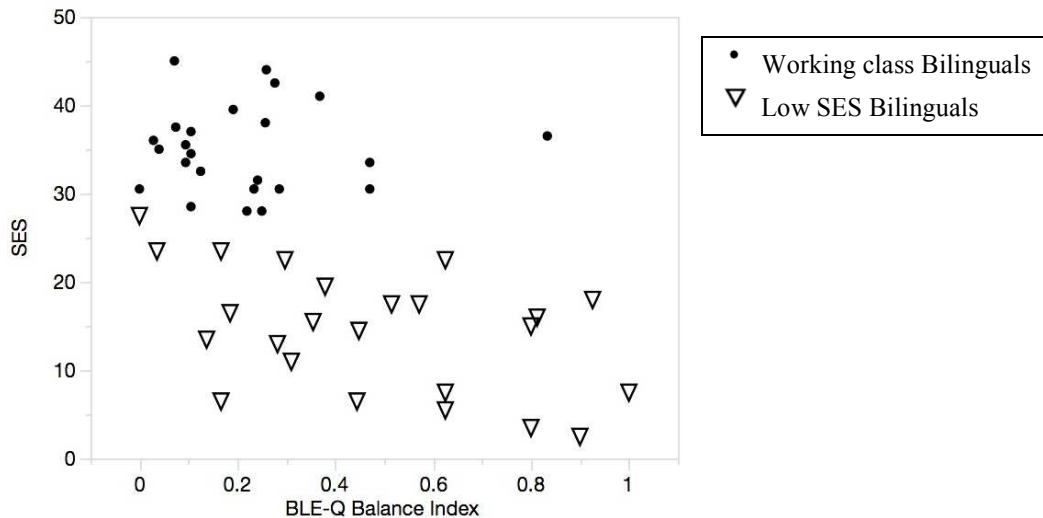


Figure 3.1. Distribution plot of the BLE-Q balance index by SES for working class SES bilinguals and low SES bilinguals.

group (N = 11; 6 female). In the high SES bilingual group, only one participant was above a BLE-Q index of 0.44 (Figure 3.1), subsequently, the rest of the subjects formed the working class SES unbalanced bilingual group (N = 23; 9 female). It was not possible to form a high SES balanced bilingual group. Table 3.2 shows the means and standard deviations for SSRT inverted scores and BLE-Q index by group. A categorical variable describing the low SES balanced bilinguals and working class unbalanced bilinguals was entered as a predictor of SSRT inverted scores, controlling for age, and age². Since there were no significant effects of sex, it was not included in the model. There was a group effect such that the low SES balanced bilingual group outperformed the working class SES unbalanced bilingual group on the SSRT response inhibition measure ($R^2 = .64$, $df = 31$; age: $\beta = 0.63$ $t = 5.72$, $p < 0.001$; age²: $\beta = -0.49$, $t = -4.35$, $p < 0.001$; SES bilingual group: $\beta = 0.38$, $t = 3.36$, $p = 0.002$). There was no effect of group when comparing low SES unbalanced bilinguals to high SES unbalanced bilinguals ($R^2 = .50$, $df = 31$; age: $\beta = 0.61$ $t = 4.06$, $p < 0.001$; age²: $\beta = -0.31$, $t = -2.16$, $p < 0.039$; SES bilingual group: $\beta = 0.23$, $t = 1.63$, $p = 0.114$), nor when comparing low SES balanced bilinguals to low SES unbalanced bilinguals ($R^2 = .52$, $df = 20$; age: $\beta = 0.75$ $t = 4.13$, $p < 0.001$; age²: $\beta = -0.37$, $t = -2.29$, $p = 0.033$; SES bilingual group: $\beta = 0.07$, $t = 0.45$, $p = 0.660$).

Table 3.2

Demographics and Measures for Low SES Balanced and Unbalanced Bilinguals, and Working Class Unbalanced Bilinguals.

	Low SES Balanced Bilinguals N = 12 Mean (SD)	Low SES Unbalanced Bilinguals N = 12 Mean (SD)	Working Class Unbalanced Bilinguals N = 23 Mean (SD)
Age	7.86 (1.81)	9.54 (1.70)	8.40 (1.31)
BLE-Q Balance Index	0.72 (0.18)	0.23 (0.14)	0.19 (0.13)
SSRT Inverted Scores	-260.64 (147.26)	-200.14 (66.70)	-301.59 (131.11)
Household Income	2.83 (0.94)	3.00 (0.74)	4.91 (0.10)
Highest Parent Education	2.50 (1.31)	3.50 (1.24)	4.78 (1.20)

Language mixing and Inhibitory Control

There was a significant negative association between frequency of language mixing and inhibitory control performance on the flanker ($R^2 = .51$, $df = 48$; age: $\beta = 0.64$, $t = 5.98$, $p < 0.001$; age²: $\beta = -0.36$, $t = -3.37$, $p = 0.002$; BLE-Q balance index: $\beta = 0.08$, $t = 0.77$, $p = 0.447$; frequency of language mixing: $\beta = -0.27$, $t = -2.50$, $p = 0.016$). Bilinguals with a higher frequency of language mixing performed worse on the flanker inhibitory control measure than bilinguals with lower frequencies of language mixing. There was no association between BLE-Q balance and flanker inhibitory control performance. When entering SES as an additional predictor to the model, the association between frequency of language mixing and performance on the flanker inhibitory control measure remained significant (Table 3.3). Figure 3.2 shows the residual plot of the linear

regression model in which frequency of language mixing predicts flanker computed scores, controlling for age, age², and SES.

Table 3.3

Linear Regression Models Testing Associations between Language Experience Measures and Flanker, Controlling for Age and SES.

Flanker Computed Scores				
	β	t	p	
Age	0.54	4.75	< 0.001**	
Age ²	-0.38	-3.55	0.001**	
SES	-0.27	-1.99	0.053	
BLE-Q Balance Index	-0.07	-0.47	0.638	
Frequency of Language mixing	-0.30	-2.74	0.009**	

* $p < 0.05$, $p < 0.01$

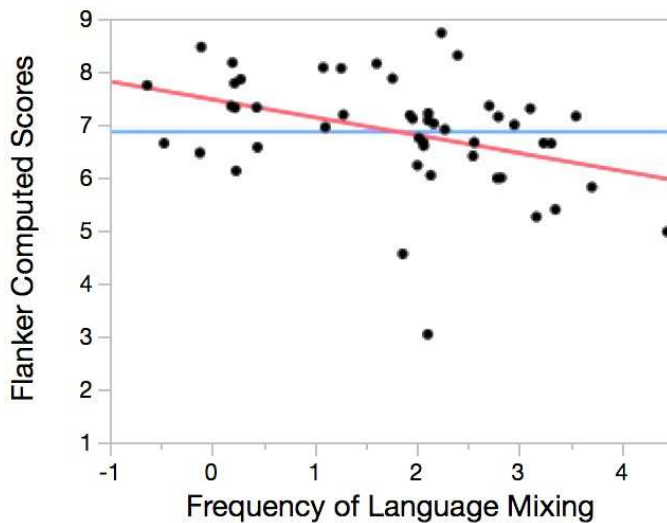


Figure 3.2. Residual plot of rate of language mixing predicting flanker computed scores, controlling for age, age², and SES.

Discussion

While many studies have examined executive function performance in bilinguals compared to monolinguals, this study examined individual differences in language experience in bilingual children in association to executive function performance. Two measures of executive function performance were examined, response inhibition in the stop-signal task and inhibitory control in the flanker task.

Balanced Language Experience and Executive Function

From chapter 2 we learned that lower SES bilinguals performed better on the response inhibition stop-signal task than higher SES bilinguals. This chapter aimed to investigate a possible association between language experience and response inhibition that could possibly account for differences in performance between the low and high SES bilingual groups. In the present study, low SES bilingual children were more balanced in language experience than the working-class SES bilingual children. Although in the bilingual group, higher language balance experience was associated with better response inhibition performance, SES was a mediating factor, such that the association was no longer significant after controlling for SES. An interaction effect between language experience by SES on response inhibition performance suggested that the relationship between language experience and response inhibition differed as a function of SES. *Post-hoc* exploratory analysis revealed that low SES balanced bilinguals outperformed higher SES non-balanced bilinguals. However, it is acknowledged that the bilingual sample had notable limitations, and it is difficult to draw any strong conclusions from the exploratory analysis. A very recent study examined language experience in low SES

Hispanic bilingual children by measuring the degree of balance between receptive vocabulary in English and Spanish (Thomas-Sunesson et al., 2016). The study examined sixty four bilinguals and found a positive association between balanced vocabulary and reaction time performance on the flanker (Thomas-Sunesson et al., 2016). One limitation of the present study is that while, in the lowest SES bilinguals, there was a fair distribution of unbalanced to highly balanced bilinguals, the sample size was very small. Another limitation of the present study is that there were no highly balanced bilinguals among the high SES bilinguals. An interesting question to investigate in future research is the extent to which executive function skills like response inhibition increase as a function of SES and balanced bilingual experience in the environment. Notably, about half of the bilingual children in our sample fell below the U.S. poverty threshold. Considering, the known negative effects of low SES on executive function, further study is needed to investigate whether a more balanced bilingual experience counters the negative effects of low SES on executive function. In a larger cohort, with equal representation of SES and language experience among bilinguals, I would expect that higher SES bilinguals who are also highly balanced in language experience, are likely to outperform higher SES unbalanced bilinguals in response inhibition.

However, as discussed in chapter 2, there could be other characteristics of the low SES bilinguals in this sample that may have contributed to better response inhibition performance compared to the working-class bilinguals. Although all bilinguals were from Hispanic households, differences in parenting styles within the Hispanic culture have been documented. For example, it is possible that children from authoritarian environments, where rule following is strictly enforced, may be better at response

inhibition, since inhibition of responses is commonly practiced in their environment. While Hispanic parenting styles center around parental control, emphasizing discipline and respect within the hierarchy of the family structure (Halgunseth, Ispa, & Rudy, 2006), one study found that U.S. born Mexican American mothers favored development of autonomy in their children, while Mexican immigrant mothers enforced rule following (Okagaki & Sternberg, 1993). It is unknown whether the low SES group and the working class bilingual group differed on such parenting practices. While the sample size in this study was small, a larger study with equal diversity of bilinguals in language experience, parental practices, and SES, would be informative to assess whether association between the degree of balance of language experience and response inhibition holds, and whether other cultural factors may be involved.

Language mixing and Executive Function

Frequency of language mixing was significantly associated with worse performance on conflict resolution, independent of age, language balance, and SES. The conflict resolution measure reflected performance on overall accuracy to both congruent and incongruent trials, and reaction time for only correct responses to incongruent trials. Successful responses to incongruent trials require inhibition of the interfering effects of conflicting perceptual information. Within the framework of Green's (1998) Inhibitory Control Model of bilingualism, bilinguals recruit inhibitory control processes to achieve language control. The findings from this study suggest a relationship between skill in inhibiting conflicting information during a task that presents competing information and a similar inhibitory control skill in inhibiting one language to select a target language. One interpretation is that bilingual children who often mix languages in their speech may be

more susceptible to interference from the other language, especially since inhibitory control skills are still developing. The bilingual children in this study were within the age range where executive function skills are still developing, including skills recruited for language control.

Some studies that have examined language switching practices in adult bilinguals report a positive association between frequency of language switching and performance on tasks of executive function (Hartanto & Yang, 2016; Prior & Gollan, 2011; Verreyt et al., 2016). Verreyt et al. (2016) asked bilinguals to report how often they were in situations in which they switched languages, and found an association between faster reaction times on the flanker and balanced bilinguals with higher frequencies of language switching. Verreyt et al. (2016) reported that none of the unbalanced bilinguals reported switching languages often. Hartanto and Yang (2016) reported that bilinguals who switched between languages within the same context demonstrated smaller switch costs in a task-switching paradigm compared to bilinguals who rarely switched languages within the same context. Further, Hartanto and Yang (2016) did find that while higher inter-sentential language switching was associated with reduced switching costs, higher intra-sentential language switching showed the opposite effect. The interpretation from Hartanto and Yang (2016) was that inter-sentential switching placed higher demands on language control and required the cognitive control system to adapt, while intra-sentential switching did not. It is likely that the bilinguals in the Verreyt et al. (2016) study were also reporting language switching behavior within the same context, however, it was not something that was directly assessed.

What is common across all three studies that have found a relationship between higher language switching and better executive function is that the results have been reported for balanced bilinguals who demonstrated equal proficiency in both languages (Hartanto & Yang, 2016; Prior & Gollan, 2011; Verreyt et al., 2016). Balanced bilingual adults are more likely to switch flexibly and voluntarily, and may need to resolve a higher demand for competing language activation. It is possible that the type of language switching reported among the bilinguals in these studies was voluntary. In which case, when voluntary language switching is more highly exercised among balanced bilinguals, bilinguals may demonstrate better performance on non-linguistic executive function tasks that involve mechanisms that support language control, such as inhibitory control and task-switching.

Festman et al. (2010) and Festman and Münte (2012), examined language mixing behaviors in adults by assessing language interference errors during a picture naming task. These studies reported an association between higher rates of language switching, or failures to switch to the correct language, and poorer executive function performance. In particular, the results from the present study were co-current with results from Festman and Münte (2012), which suggested that bilinguals with higher rates of language mixing demonstrated poorer inhibitory control performance on the flanker task compared to bilinguals with lower rates of inadvertent mixing. While the present study did not measure the underlying reasons for language mixing in children, in the Festman and Münte (2012), the bilinguals with higher rates of switching between languages were unintentionally switching, possibly as a result of poor language control. One interpretation for the findings in the present study, is that bilingual children with higher

rates of language mixing may have been mixing unintentionally or due to a failure in language control. Thus, the findings from the present study suggest poorer language control may be related to poorer non-linguistic inhibitory control in bilingual children.

From the existing studies on language switching and language mixing in bilinguals, two possibilities arise. One possibility is that language switching in bilinguals may exhibit experience-dependent effects on non-linguistic cognitive control.

Specifically, voluntarily language switching in balanced bilinguals may imply a higher rate of activation and selection between both languages, which in turn, may be recruiting a cognitive control system that supports both language control and also non-linguistic cognitive control. Another equally plausible scenario is that bilinguals who demonstrate higher rates of inadvertent responses or failures to switch between languages may have a weaker non-linguistic cognitive control system. Findings from the present study support the latter scenario. However, a limitation of the present study is that the circumstances and reasons why the bilingual children mixed languages is undetermined. A follow up study is needed to confirm whether the type of language mixing that was associated with poor non-linguistic inhibitory control was a result of failures to switch between languages. The follow-up study should also consider the role of language mixing behavior at various levels, i.e. at the lexical level, intra- and inter-sentential.

Summary

The present study investigated the relationship between executive function performance and language experience and frequency of language mixing in English-Spanish bilingual children. Findings suggest that non-linguistic response inhibition skills associated with both SES and the degree of balance in language experience, while non-

linguistic inhibitory control associated with linguistic inhibitory control. Although the bilingual sample was diverse in SES and language practices, these findings are relatively novel, and need replication in a larger bilingual sample of children. Future studies should aim to measure the circumstances underlying language switching and language mixing in bilinguals, to understand the relationship between the mechanisms underlying language switching behavior in bilinguals and non-linguistic inhibitory control.

Chapter 3, in part, will be prepared for submission of publication of the material. Co-author: Terry L. Jernigan. The dissertation author was the primary investigator and author of this material.

Chapter 4: Characteristics of White Matter Microstructure and Bilingualism in Childhood

While some studies have examined white matter microstructure in bilinguals compared to monolinguals in young and older adults (Luk, Bialystok, et al., 2011; Pliatsikas, Johnstone, & Marinis, 2014), fewer studies have examined white matter in bilingual children (Mohades et al., 2012, 2015). The present study first compared characteristics of white matter microstructure in bilinguals compared to monolingual children. Three regions of interest were identified from previous findings in the literature examining white matter in bilinguals, the superior longitudinal fasciculus (SLF), the inferior fronto-occipital fasciculus (IFOF), and the anterior cingulum (aCg). I hypothesized that the bilingual children would have more mature values of white matter measures in these three regions compared to the monolingual children. However, findings from a previous study suggest an association between SES and differences in white matter microstructure (Ursache & Noble, 2016). Since the monolingual group was higher in SES than the bilingual group, alternatively, it is possible that the monolingual group would have higher FA than the bilingual group, or that the effects of bilingualism and SES would counter, such that differences in FA between groups would not be observable.

Second, individual differences in white matter characteristics in the bilinguals are examined in association to language experience. Green & Abutalebi (2013) proposed the adaptive control hypothesis as a model of the neural network and processes that support

bilingualism. Green & Abutalebi (2013) posited that a single language network maintains the representation of both languages, while an executive control network adaptively mediates cognitive control processes that support language control. They identify a neural network that supports cognitive control and speech production in bilinguals. One important region to bilingual cognitive control is the anterior cingulate cortex (ACC). The ACC has been linked to language control and non-verbal conflict resolution in bilinguals (Abutalebi et al., 2012; Luk, Green, et al., 2011). Interestingly, activation in the ACC has been associated with language switching at the lexical level (Guo, Liu, Misra, & Kroll, 2011). Findings reported in chapter 3 suggest an association between bilingual language experience and executive function mechanisms of inhibitory control. Specifically, the frequency of language mixing in bilinguals was associated with performance on the flanker task, such that higher frequency of language mixing, i.e., less language control, predicted worse performance on the flanker task, while the degree of balanced language experience was positively associated with response inhibition performance on the stop-signal task. The anterior cingulum is the white matter underlying the ACC. Given the important role of the ACC for cognitive control and language production in bilinguals, I hypothesized that more mature values of white matter measures in the anterior cingulum would be associated with a higher balance of language experience and lower frequency of language mixing in bilinguals.

Methods

Participants

Fifty-one of the bilingual participants described in chapter 1 had brain imaging data available. Imaging data for one subject did not meet quality control and imaging data for two subjects had unresolved problems with preprocessing and quality control. A total of $N = 48$ bilingual participants were included in the group imaging analysis. Fifty-three PLING monolingual participants described in chapter 1 had brain imaging data available. The demographics of the bilingual and monolingual group are described in Table 4.1.

Imaging

Imaging Acquisition. As part of the PLING study described in Braddick et al., 2016 and Jernigan et al., 2016, a standardized multiple-modality high-resolution structural MRI protocol was implemented. The protocol included a 3D T1-weighted scan and a set of diffusion-weighted scans, on a GE 3T Signa HDx scanner and a 3T Discovery 750x scanner (GE Healthcare). An eight-channel phased array head coil was used. The protocol consisted of a conventional three-plane localizer scan, a sagittal 3D inversion recovery spoiled gradient echo T1-weighted volume optimized for maximum gray/white matter contrast (echo time = 3.5 ms, repetition time = 8.1 ms, inversion time = 640 ms, flip angle = 8° , receiver bandwidth = ± 31.25 kHz, FOV = 24 cm, frequency = 256, phase = 192, slice thickness = 1.2 mm), and two axial 2D diffusion tensor imaging (DTI) scans (30-directions b-value = 1,000, TE = 83 ms, TR = 13,600 ms, frequency = 96, phase = 96, slice thickness = 2.5 mm, FOV = 24 cm).

Quality control and preprocessing. The raw data were examined by trained technicians for motion artifacts, excessive distortion, and poor image quality. Data showing significant motion artifacts, or whole-slice dropouts were rejected and recommended for rescan. Eddy current distortions were corrected using a non-linear estimation procedure described in Jernigan et al. (2016). White matter tracts were labeled using AtlasTrack, an automated method for labeling white matter based on a probabilistic atlas of fiber tract locations and orientations (Hagler et al., 2009). All white matter tracts labeled using AtlasTrack were inspected for overall quality and rated as acceptable or not. Diffusion parameters of fractional anisotropy, mean diffusivity, longitudinal diffusivity, and transverse diffusivity were calculated using conventional diffusion weighted tensor methods as described in Jernigan et al. (2016).

White matter regions of interest. Three white matter fiber tracts were selected as *a priori* regions of interest (ROIs): the superior longitudinal fasciculus (SLF), the anterior cingulum (aCg), and the inferior fronto-occipital fasciculus (IFOF). AtlasTrack images for the three regions of interest are shown in Figure 4.1. The *a priori* ROIs for the SLF and IFOF included all segments of the fiber tracks. The SLF and IFOF have been previously examined in bilinguals compared to monolinguals (García-Pentón et al., 2016). The aCg is the white matter underlying the anterior cingulate cortex (ACC), which has been implicated in cognitive control and language production in bilinguals (Green & Abutalebi, 2013). Others have reported age-related maturational changes in these three white matter tracts, with increases in FA in the SLF and IFOF, and decreases in MD in the SLF and cingulum from early childhood into late adolescence (Lebel et al., 2008).

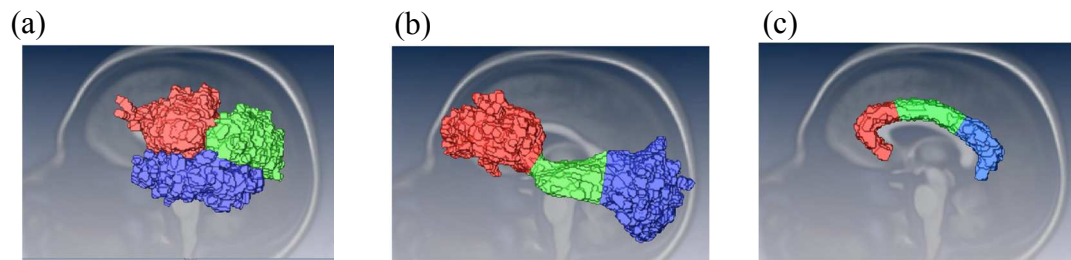


Figure 4.1. Image of the AtlasTrack ROIs: (a) SLF (red: anterior segment, green: middle segment, and blue: posterior segment), (b) IFOF ROI (red: anterior segment, green: middle segment, and blue: posterior segment), and (c) anterior cingulum (red).

White matter measures. Diffusion weighted tensor (DTI) imaging is an MRI imaging method that can be used to measure the diffusion of water molecules in brain tissue (Beaulieu, 2009). DTI can provide measures of the magnitude and directionality of diffusion along organized fiber bundles, white matter tracts. Axonal membranes and myelin sheaths constrain diffusion of water molecules, creating anisotropic diffusion of water molecules. Fractional anisotropy (FA), a measure of the degree of anisotropy, or the degree of net directionality of the diffusion of water molecules (Beaulieu, 2009), was examined as the primary measure of white matter microstructure. Mean diffusivity (MD), the average magnitude of diffusion of water molecules, was also examined. FA and MD are commonly interpreted as measures of white matter integrity in adult populations, while increases in FA and decreases in MD have been associated with fiber tract maturation and better cognitive skills in children (Beaulieu, 2009; Jernigan et al., 2011).

Analyses Plan

Bilinguals compared to monolinguals. To test group differences between the bilingual and monolingual group in white matter microstructure in the *a priori* ROIs,

linear regressions were constructed using JMP Pro 16 (64-bit). Since there were no hypotheses about the specificity of left or right hemisphere fiber tracts, for each ROI, FA and MD were averaged across the left and right fiber tracts. Previous studies have also examined the average of measures across both hemispheres in these tracts (García-Pentón et al., 2016; Mohades et al., 2012). FA and MD in the *a priori* regions were tested for effects of age, sex, and SES. In separate linear regressions, a categorical variable of language group identifying bilinguals and monolinguals, was entered as a predictor of FA and MD for each of the three ROIs, controlling for age and sex. Socio-economic status (SES) was calculated as the average of the ranked household income and parent education across both bilingual and monolingual participants, as described in chapters 1 to 3. Four bilingual participants were missing SES data.

Bilingual language experience and anterior cingulum microstructure.

Individual differences in bilingual language experience were examined in association to FA and MD in the aCg ROI. Bilingual language experience was assessed using the BLE-Q balance index and the frequency of language mixing measures, as described in chapter 3. A total of $N = 43$ participants had data available for the language experience measures as well as imaging data. In separate linear regressions, the BLE-Q balance index and frequency of language mixing were entered as predictors of FA for the aCg, controlling for age and sex. The association between language experience and MD in the aCg was tested using a similar linear regression model. A group specific SES measure was calculated for just the bilingual group as the ranked household income and parent education from the distribution of the bilingual group. Three of the 43 participants did not have SES data.

Results

White matter in Bilinguals and Monolinguals

Age, sex, and SES effects. Across the bilingual and monolingual groups, there was a significant effect of age on FA in the SLF ($t = 4.32$; $p < 0.001$), and FA in the IFOF ($t = 3.06$; $p = 0.003$), such that FA increased with age. There was a significant effect of sex on FA in the IFOF ($t = -2.59$; $p = 0.011$), such that girls had higher FA than boys. There was a significant effect of SES on FA in the SLF ($t = 2.32$; $p = 0.023$), such that FA increased with higher SES, and there was a negative SES trend for FA in the aCg ($t = -1.81$; $p = 0.073$). There were significant age effects on MD in the SLF ($t = -4.51$; $p < 0.001$), the IFOF ($t = -2.71$; $p = 0.008$), and the aCg ($t = -4.67$; $p < 0.001$), such that MD decreased with age. There were significant sex effects on MD in the SLF ($t = 3.04$; $p = 0.003$), the IFOF ($t = 3.00$; $p = 0.004$), and the aCg ($t = 2.05$; $p = 0.044$), such that girls had lower MD than boys. Linear regression models controlled for age, sex, and SES. The demographics and statistics for the primary outcome measures by group are shown in Table 4.1.

Group differences in FA. There were no significant effects of language group on FA in the IFOF or the aCg, controlling for age and sex, nor when adding SES as an additional control variable (Table 4.2). There was a significant effect of language group on FA in the SLF, independent of age and sex, such that the monolingual group had higher FA in the bilateral SLF compared to the bilingual group ($R^2 = .27$, $df = 97$; age: $\beta = 0.40$, $t = 4.64$, $p < 0.002$; sex: $\beta = 0.50$, $t = -1.65$, $p = 0.102$; language group: $\beta = 0.26$, $t = 3.01$, $p = 0.003$). The association held after controlling for SES (Table 4.2).

There were no significant effects of language group on MD for IFOF or the aCg, controlling for age and sex, nor when adding SES as an additional predictor (Table 4.2). There was a trend effect of language group on MD in the SLF, such that monolinguals trended lower in MD in the SLF compared to bilinguals (Table 4.2).

Table 4.1

<i>Demographics and Statistics for Main Measures by Group</i>			
		Bilingual Group N = 48 (24 females) Hispanic 100%	Monolingual Group N = 53 (26 females) Hispanic 22%
		Mean (SD)	Mean (SD)
Age		8.75 (1.72)	8.88 (2.05)
Household Income		3.86 (1.41) ^a	7.19 (2.48)
Parent Education		3.86 (1.62) ^a	6.17 (1.56)
FA			
	SLF	0.426 (0.022)	0.438 (0.020)
	IFOF	0.440 (0.020)	0.444 (0.021)
	aCg	0.376 (0.046)	0.371 (0.035)
MD			
	SLF	0.770 (0.024)	0.767 (0.023)
	IFOF	0.835 (0.021)	0.831 (0.025)
	aCg	0.834 (0.027)	0.848 (0.030)

^a N = 44 participants reported household income and parent education.

Table 4.2

Linear Regression Models Testing Group Differences between Bilinguals and Monolingual in FA and MD in the SLF, IFOF, and aCg.

	R^2	df	Age		Sex		Language Group		SES	
			β	p	β	p	β	p	β	p
FA										
SLF	0.32	89	0.41	< 0.001**	-0.09	0.299	0.40	0.003**	-0.08	0.525
IFOF	0.18	89	0.30	0.003**	-0.24	0.015*	0.09	0.514	-0.02	0.912
aCg	0.07	89	-0.03	0.747	0.17	0.110	0.09	0.573	-0.25	0.106
MD										
SLF	0.30	89	-0.41	< 0.001**	0.26	0.006**	-0.25	0.065	0.21	0.123
IFOF	0.18	89	-.26	0.008**	0.28	0.005**	-0.07	0.619	0.11	0.438
aCg	0.20	89	-0.35	< 0.001**	0.05	0.586	0.04	0.740	0.25	0.085

Note, N = 44 bilingual participants had household income and parent education.

Post-hoc exploratory analysis of IFOF. Mohades et al., (2012) had reported higher FA in the IFOF in bilingual children compared to monolingual children using a different method for analyzing white matter fiber tracts. However, due to methodological differences, it is difficult to assess overlap between the ROI in the present study and Mohades et al., (2012). *Post-hoc* exploratory analysis examined group differences for the anterior, middle, and posterior segments of the IFOF (Figure 4.1 b). The left and right ROIs were averaged for each segment.

Similar linear regressions tested for an effect of language group on FA in the three segments of the IFOF, controlling for age and sex. There was a language group effect for FA in the anterior IFOF segment ($R^2 = .11$, $df = 97$; age: $\beta = 0.10$, $t = 1.05$, $p = 0.295$; sex: $\beta = -0.15$, $t = -1.59$, $p = 0.116$; language group: $\beta = 0.27$, $t = 2.86$, $p = 0.005$), and for the middle IFOF segment ($R^2 = .14$, $df = 97$; age: $\beta = 0.26$, $t = 2.71$, $p = 0.008$; sex: $\beta = -0.15$, $t = -1.53$, $p = 0.129$; language group: $\beta = 0.19$, $t = 2.06$, $p = 0.042$), such that monolinguals had higher FA than bilinguals. Interestingly there was a different language group effect for FA in the posterior IFOF segment ($R^2 = .30$, $df = 97$; age: $\beta = 0.38$, $t = 4.43$, $p < 0.001$; sex: $\beta = -0.28$, $t = -3.24$, $p = 0.002$; language group: $\beta = -0.25$, $t = -2.98$, $p = 0.004$), such that bilinguals had higher FA than monolinguals. There was a negative association between SES and FA in the posterior IFOF segment, such that FA decreased with higher SES ($t = -2.23$, $p = 0.011$), and there was a positive trend between SES and FA for the anterior segment, with higher FA trending with higher SES ($t = 1.81$, $p = 0.074$). When entering SES as an additional predictor to the models, the language group effects were no longer significant (anterior segment: $t = 1.81$, $p = 0.074$; middle segment: $t = 1.13$, $p = 0.262$; posterior segment: $t = -1.43$, $p = 0.157$). It is relevant to note that

degrees of freedom were lost when entering SES since six bilingual participants did not have SES data.

Bilingual Language Experience and Microstructure in the Anterior Cingulum

Age, sex, and SES effects. Within the bilingual group alone, there was a significant effect of sex on FA for the aCg ($t = 2.08$; $p = 0.045$), such that boys had higher FA than girls. There was a significant effect of age on FA in the SLF ($t = 2.49$; $p = 0.018$), such that FA increased with age, and a similar trend was observed for FA in the IFOF ($t = 1.79$; $p = 0.081$). There was a significant effect of age on MD in the aCg ($t = -2.44$; $p = 0.020$), and MD in the SLF ($t = -3.18$; $p = 0.030$), such that MD decreased with age. There were no significant effects of SES on any of the white matter measures. For the BLE-Q balance index, there was a significant effect of age ($t = -2.33$; $p = 0.025$), and a significant effect of SES ($t = -4.17$; $p < 0.001$), such that the degree of balanced language experience decreased with age and also decreased with higher SES. There were no age, sex, or SES effects on the frequency of language mixing.

Language experience and FA in the anterior cingulum. The BLE-Q balance index and frequency of language mixing were not significant predictors of FA in the aCg, controlling for age and sex ($R^2 = .20$, $df = 38$; age: $\beta = 0.25$, $t = 1.65$, $p = 0.106$; sex: $\beta = 0.50$, $t = 2.79$, $p = 0.008$; BLE-Q balance index: $\beta = 0.22$, $t = 1.48$, $p = 0.148$; frequency of language mixing: $\beta = 0.05$, $t = 0.32$, $p = 0.748$). The interaction of the BLE-Q balance index by the frequency of language mixing was entered as an additional predictor in the model. There was an interaction effect of BLE-Q balance index by frequency of language mixing, such that the association between FA in the aCg and the degree of balanced language experience differed as a function of the rate of language mixing ($R^2 =$

.30, $df = 37$; age: $\beta = 0.26$, $t = 1.75$, $p < 0.088$; sex: $\beta = 0.51$, $t = 3.43$, $p = 0.002$; BLE-Q balance index: $\beta = 0.28$, $t = 1.91$, $p = 0.064$; frequency of language mixing: $\beta = 0.08$, $t = 0.52$, $p = 0.604$; BLE-Q index by frequency of language mixing: $\beta = -0.34$, $t = -2.35$, $p = 0.024$). The interaction remained significant after entering SES as an additional predictor (Table 4.3). Figure 4.2 shows the interaction plot of BLE-Q index by frequency of language mixing predicting FA in the anterior cingulum, controlling for age, sex, and SES. The results suggest an association between more balanced language experience and higher FA in the aCg, which was moderated by the rate of language mixing. Specifically, the association between higher FA in the aCg and more balanced language experience was evident in children with reported low rates of language mixing, while the association was weaker in children with reported high rates of language mixing.

Table 4.3

Linear Regression Models Testing Interaction Effect of BLE-Q Balance Index by Frequency of Language Mixing on FA in the aCg.

	aCg (Bilateral) FA		Left aCg FA		Right aCg FA	
	β	p	β	p	β	p
Age	0.34	0.043*	0.41	0.015*	0.21	0.245
Sex	0.52	0.003**	0.50	0.004**	0.45	0.02*
SES	0.12	0.520	0.25	0.179	-0.04	0.822
BLE-Q Balance Index	0.37	0.067	0.50	0.013*	0.16	0.464
Frequency of language mixing	0.07	0.626	0.02	0.891	0.12	0.453
BLE-Q Index by Frequency of language mixing	-0.38	0.018*	-0.36	0.019*	-0.33	0.051

Note N = 40; three bilingual participants in this analysis were missing SES.

* $p < 0.05$, ** $p < 0.01$

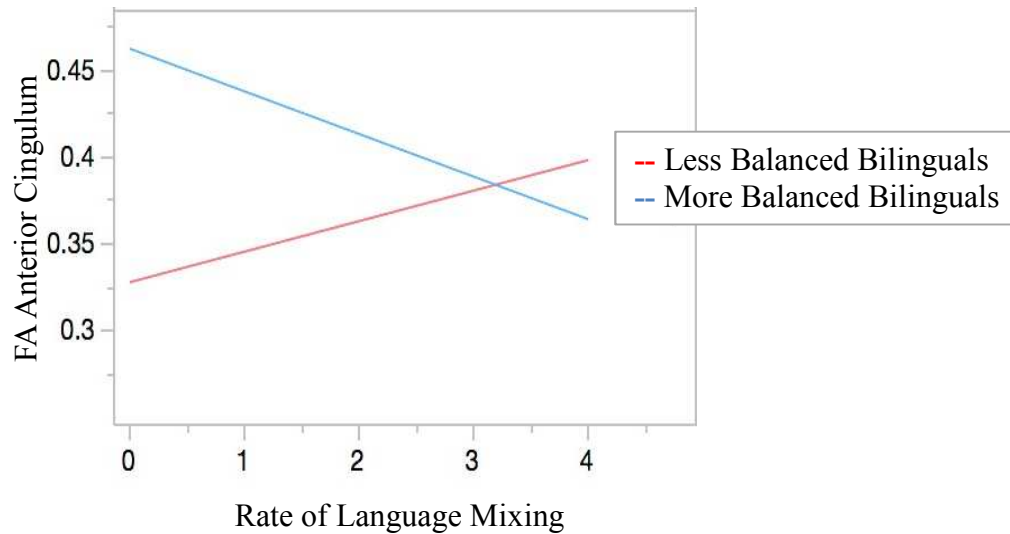


Figure 4.2. Interaction plot of BLE-Q index by frequency of language mixing predicting FA in the anterior cingulum, controlling for age, sex, and SES.

Language experience and MD in the anterior cingulum. A similar linear regression model tested the interaction effect of BLE-Q index by frequency of language mixing on MD in the aCg, controlling for age, sex, and SES. The interaction effect was not significant, but a similar trend (in the opposite direction) was observed, such that lower MD trended with more balanced language experience in bilinguals as a function of language mixing, such that the trend was evident in children with a lower rate of language mixing ($\beta = 0.31$, $t = 1.90$, $p = 0.066$).

Post-hoc analysis for left and right anterior cingulum. Analyses were conducted to test the interaction effect of BLE-Q index by frequency of language mixing on FA in the left aCg and the right aCg. The results are shown in Table 4.3. The *post-hoc* analysis revealed a positive association between the degree of balanced language

experience and FA in the left anterior cingulum, where the interaction effect of BLE-Q index by frequency of language mixing, was also significant. The association between the degree of balanced language experience and FA in the right anterior cingulum was not significant, however, there was a trend effect of BLE-Q index by frequency of language mixing. A similar linear regression model tested the association to MD in the left aCg and MD in the right aCg. There was a modest effect of the interaction of BLE-Q index by frequency of language remixing, such that there was an association between lower MD in the right aCg and more balanced language experience, which was moderated by language mixing, such that the association was evident in children with a low rate of language mixing, while the association was weaker in children with a high rate of language mixing ($R^2 = .26$, $df = 33$; age: $\beta = -0.35$, $t = -2.05$, $p < 0.048$; sex: $\beta = -0.16$, $t = 0.95$, $p = 0.350$; SES: $\beta = 0.23$, $t = 1.21$, $p = 0.236$; BLE-Q balance index: $\beta = 0.05$, $t = 0.25$, $p = 0.802$; frequency of language mixing: $\beta = -0.14$, $t = -0.86$, $p = 0.397$; BLE-Q index by frequency of language mixing: $\beta = 0.33$, $t = 2.08$, $p = 0.045$). The interaction of BLE-Q balance index by frequency of language mixing was not significant for MD in the left aCg.

Discussion

This chapter examined differences in white matter microstructure between bilinguals and monolinguals in two white matter tracts previously investigated in the literature, the SLF and the IFOF (García-Pentón et al., 2016), and in a third white matter tract important for language control in bilinguals, the anterior cingulum. Although the microstructure of the anterior cingulum has not been examined in bilinguals, evidence from studies comparing bilinguals to monolinguals on morphometry (Abutalebi, Guidi,

Borsa, Canini, & Pasquale, 2015) and functional activation (Guo et al., 2011; Luk, Green, Abutalebi, & Grady, 2012) suggest the ACC is an important brain region supporting language and cognitive processing in bilinguals. Thus, this study examined the anterior cingulum, the white matter region underlying the ACC.

Interestingly, the present study did not find significant differences in FA or MD for the IFOF and the anterior cingulum when comparing bilinguals to monolinguals, even after controlling for age, sex, and SES. Adult studies comparing white matter integrity in bilinguals to monolinguals present conflicting findings (García-Pentón et al., 2016). One study on elderly bilingual adults reported higher FA in the bilateral IFOF and SLF in bilinguals compared to monolinguals (Luk, Bialystok, et al., 2011), while another study reported lower FA in the bilateral IFOF in the bilingual group compared to the monolingual group (Gold, Johnson, & Powell, 2013). Pliatsikas, Moschopoulou, & Saddy (2015) also reported higher FA in the white matter extending bilaterally from the corpus callosum into the IFOF and the SLF in bilingual adults compared to monolingual controls. Although studies examining the characteristics of white matter in bilingual children are even more limited, higher FA in the IFOF has been reported in bilingual children compared to monolingual children (Mohades et al., 2012, 2015). However, the Mohades et al. (2012) study examined specifically the left IFOF and the left SLF in children ages 8 to 11 years of age. Mohades et al. (2012) reported that bilingual children who had acquired both languages before the age of 3, showed higher FA in the left IFOF compared to both a group of bilingual children who had acquired their second language after the age of 3, and a monolingual group. The study found no differences in FA for the left SLF between groups.

Different from the present study, the Mohades et al. (2012) bilingual sample was composed of bilinguals who spoke either English or French as their first language, and the second language was a Romance or Germanic language. It is unknown whether specific language characteristics among bilingual children contribute to differences in white matter maturation. The socio-economic status of the children in the Mohades et al. (2012) study was not reported. One possibility is that other demographic factors, such as SES, may result in differences in white matter microstructure between bilinguals and monolinguals. While findings from the present study suggest SES did not appear to mediate differences in microstructure of the SLF between bilinguals and monolinguals, the two groups did differ on other demographic factors, such as ethnicity. While the bilingual sample was solely from a Hispanic ethnicity, the majority of the monolingual group was non-Hispanic. It is unknown whether other demographic factors, such as ethnicity, can account for differences in white matter maturation in the specific sample.

In addition, the SLF has been implicated in both language and cognitive skills in children (Gonzalez et al., n.d.; Vestergaard et al., 2011). Findings from chapter 2, demonstrated that the bilingual children had lower receptive vocabulary scores in English compared to the monolingual children. However, SES appeared to mediate, in part, group differences in receptive vocabulary between bilinguals and monolinguals. Findings from chapter 3 suggest language experience may be a contributing factor to differences in executive function performance among bilingual children. It is possible that in the specific sample of this study, other differences in language or cognitive skill between bilingual and monolingual children may account for the observed group differences in FA in the SLF.

García-Pentón et al. (2016) point out that one limitation to the existing imaging findings on bilinguals is that various studies use different methodologies. One limitation of this study is that a different method from Mohades et al. (2012) was used to examine the white matter fiber tracts. *Post-hoc* analysis revealed that while monolinguals had higher FA in the the anterior and middle segment of the IFOF, bilinguals had higher FA than the monolinguals in the posterior segment of the IFOF. While the IFOF has been implicated in executive function performance as well as semantic language processing (Martino, Brogna, Robles, Vergani, & Duffau, 2010; Peters et al., 2014), the associations were no longer significant after controlling for SES, making it difficult to interpret these findings. In the future, the same method for analyzing white matter tracts used in Mohades et al. (2012) can be applied to the existing data to confirm whether different methods for analyzing white matter yield the same results.

Bilingual language experience and white matter microstructure. Similarly to examining the effects of bilingualism on language and executive function, it is important to consider whether differences in characteristics of bilinguals, such as SES and language experience, contribute to differences in characteristics of white matter microstructure (de Bruin & Della Sala, 2015). This chapter examined the associations between FA in the anterior cingulum and language experience, specifically the degree of balanced language experience and the frequency of language mixing. The results suggest an association between more balanced language experience and more mature microstructure values of the anterior cingulum, which is moderated by the rate of language mixing, such that the effect is weaker, in fact absent, in children with reported high rates of language mixing.

Post-hoc analyses suggested a positive association between the degree of language experience and FA in the left anterior cingulum.

These findings revealed a complex relationship between language experience and the microstructure of the white matter underlying the ACC, a region important for language control and non-linguistic cognitive control. In the context of the adaptive cognitive control hypothesis, it is possible that children in a more balanced language environment more often encounter situations in which their executive function neural network adaptively mediates language control. However, as suggested by the findings from chapter 3, language mixing in these bilingual children may be the result of failures to switch between languages due to poorer inhibitory control skills recruited during language control. While the balanced bilinguals may have likely had more experience in switching between languages due to the demands of the linguistic environment, there were still individual differences in the rate of language mixing, which could possibly reflect individual differences in inhibitory control skills recruited in language control. In this case, balanced bilinguals with a low frequency of language mixing had more experience in successfully inhibiting one language to activate the other language. The findings from this chapter suggest a relationship between experience in successfully switching between two languages when both languages are spoken frequently and fiber tract maturation in the anterior cingulum during childhood.

Summary. The findings from this study add to the limited literature examining white matter characteristics in bilingual children compared to monolingual children. Although the findings are not consistent with previous studies, the findings are informative in the context of the particular bilingual sample. Importantly, this study

examines the contributions of SES and language experience in bilinguals to individual differences in white matter characteristics of the anterior cingulum, a region possibly important for bilingual language control. Future studies examining longitudinal changes in white matter maturation in bilingual children would be informative to examine individual differences in developmental trajectories of white matter maturation in relation to language experience.

Chapter 4, in part, will be prepared for submission of publication of the material.

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General Conclusion

Previous studies examining the effects of bilingualism on cognitive skills and brain microstructure have focused on a categorical comparison between bilingual and monolingual groups. In this dissertation, a categorical approach was used to examine group differences between bilingual and monolingual children in receptive vocabulary, executive function performance, and white matter microstructure. However, given that bilinguals vary among various demographic and language characteristics, this dissertation conducted a comprehensive examination of the associations between individual differences among bilinguals in language experience and SES in relation to language skills, executive function skills, and characteristics of white matter microstructure.

Importantly, findings from chapter 1 demonstrated that individual differences in language skills in both languages can be accounted for by the degree of language usage and practice of one language relative to the other. In contrast, previous studies on monolinguals suggest language skills are impacted by SES, such that lower SES environments are associated with lower language input, and in turn poorer language skills (Hart & Risley, 1995). In the present study, language experience predicted language outcomes in bilinguals, independent of SES. Interestingly, while the bilingual sample in this study ranged from a very low SES to a working-class demographic, all were Hispanic. It is possible that Hispanic Spanish speaking households from this lower SES demographics, may differ from low SES non-Hispanic speaking households on other home environmental factors relating to language input, such as the number of adults and children in the home that speak the minority language. Further, it is known that as bilingual children are immersed in an English-speaking environment at school, children

may shift dominance to English and lose proficiency in the minority language (Gathercole & Thomas, 2009), and this effect was present in the bilingual sample, such that balance between language experience decreased with age. While, these findings elucidate how environmental factors contribute to language skills in bilingual children, future research is needed to investigate what factors enable children to achieve and maintain their language skills in both languages.

Findings from chapter 2 revealed differences in executive function performance between the bilingual and monolingual group, such that the monolingual children outperformed the bilingual children. Given the considerable differences in SES between the groups, SES appeared, at least in part, to mediate group differences in performance for one of the three executive function tasks, cognitive flexibility. Further analyses demonstrated that there was an interaction effect of language group by SES, such that SES and response inhibition were negatively associated in the bilingual group but not in the monolingual group. Specifically, among the bilingual children, lower SES predicted better response inhibition. These findings lead to an investigation of the possible differences in the characteristics of bilinguals that could account for such differences in response inhibition, primarily focusing on the role of language experience.

Findings from chapter 3 suggested that bilingual children with more balanced language experience had better response inhibition performance on the stop-signal task than less language balanced children. In addition, bilingual children with a higher rate of language mixing demonstrated poorer inhibitory control performance on the flanker task. To my knowledge, such findings in children are novel, and link characteristics of language experience in bilingual children to executive function performance.

Importantly, the findings suggest that individual differences in language experience can account for differences in executive function skills among bilingual children.

Chapter 4 examined differences in white matter maturation in bilinguals compared to monolinguals. The findings revealed differences in white matter microstructure in regions of interest previously associated with bilingualism. While the monolinguals demonstrated more mature values of white matter measures in the SLF compared to the bilingual children, *post-hoc* analyses revealed a different pattern of associations in the three segments of the IFOF. Monolingual children had more mature values of white matter characteristics in the anterior and middle IFOF compared to bilinguals, however, bilinguals had more mature values of white matter characteristics in the poster IFOF compared to the monolingual children. Although such findings are not consistent with the previous literature, they highlight the importance of methodology when comparing findings between studies on brain structure in bilinguals, as well a future direction for examining the specificity of the effects for the different segments of the IFOF.

In addition, in chapter 4, individual differences in language experience were examined in association to white matter maturation in the anterior cingulum. The results suggested an association between more balanced language experience and white matter maturation of the anterior cingulum, which was moderated by the rate of language mixing, such that the association was evident only for children with low rates of language mixing. The findings, although novel, suggest an important link between experience in successful language switching in bilinguals who hear and speak both languages

frequently, and white matter maturation in a brain region thought to support language and cognitive control in bilinguals.

In summary, findings from this dissertation link language experience in bilinguals to language outcomes, executive function, and characteristics of developing white matter microstructure in children. The findings emphasize the need to consider language experience in bilinguals as an important contributing factor to language, cognitive, and brain development in bilinguals.

Appendix A

Bilingual Language Experience Questionnaire

PID: _____ AGE: _____ GRADE: _____ Date: _____

Age	L A N G U A G E Y O U R C H I L D H E A R D T H E M O S T				
	Spanish 100%	25% English/ 75% Spanish	50/50%	75% English/ 25% Spanish	English 100%
0-1 yrs	☐	☐	☐	☐	☐
1-2 yrs	☐	☐	☐	☐	☐
2-3 yrs	☐	☐	☐	☐	☐
3-4 yrs	☐	☐	☐	☐	☐

Questions about your child's language practice at School				
Q2	Did your child attend pre-school?	YES	NO	
Q3	If yes, what language(s) were spoken by the teacher in the classroom?	Primarily English	Primarily Spanish	Both
Q4	In what language(s) did your child learn or is learning to read and write?	Primarily English	Primarily Spanish	Both

For the grades your child has or is attending, answer the following questions:				
What languages did the teacher use in the classroom?				
Q5-k	Kinder:	Primarily English	Primarily Spanish	Both
Q5-1	1st:	Primarily English	Primarily Spanish	Both
Q5-2	2nd:	Primarily English	Primarily Spanish	Both
Q5-3	3rd:	Primarily English	Primarily Spanish	Both
Q5-4	4th:	Primarily English	Primarily Spanish	Both
What languages did your child use in the classroom?				
Q6-k	Kinder:	Primarily English	Primarily Spanish	Both
Q6-1	1st:	Primarily English	Primarily Spanish	Both
Q6-2	2nd:	Primarily English	Primarily Spanish	Both
Q6-3	3rd:	Primarily English	Primarily Spanish	Both
Q6-4	4th:	Primarily English	Primarily Spanish	Both
What languages did other children use in the classroom?				
Q7-k	Kinder:	Primarily English	Primarily Spanish	Both
Q7-1	1st:	Primarily English	Primarily Spanish	Both
Q7-2	2nd:	Primarily English	Primarily Spanish	Both
Q7-3	3rd:	Primarily English	Primarily Spanish	Both
Q7-4	4th:	Primarily English	Primarily Spanish	Both

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What languages did your child practice reading and writing?				
Q8-k	Kinder:	Primarily English	Primarily Spanish	Both
Q8-1	1st:	Primarily English	Primarily Spanish	Both
Q8-2	2nd:	Primarily English	Primarily Spanish	Both
Q8-3	3rd:	Primarily English	Primarily Spanish	Both
Q8-4	4th:	Primarily English	Primarily Spanish	Both

Questions about your child's language practice at Home	
Q9	How many adults total live in the home? _____
Q10	How many children total live in the home? _____

How many adults (including yourself) speak the following languages?	
Q11a	Primarily English: _____
Q11b	Primarily Spanish: _____
Q11c	Both: _____

How many children (NOT including your child) speak the following languages?	
Q12a	Primarily English: _____
Q12b	Primarily Spanish: _____
Q12c	Both: _____

Q13	Is any other language other than English or Spanish spoken in the home?	YES NO
Q13a	If yes, what language(s) are spoken and who speaks those languages?	

Q14	In what language do adults in the home speak to your child?	Primarily English	Primarily Spanish	Both
Q15	In what language do other children in the home speak to your child?	Primarily English	Primarily Spanish	Both
Q16	Which language does the child use to speak to adults in the home?	Primarily English	Primarily Spanish	Both
Q17	Which language does your child use to speak to other children in the home?	Primarily English	Primarily Spanish	Both

Q18	Do you read to your child at home? YES NO			
Q18a	If yes, in what language do you read to your child?	Primarily English	Primarily Spanish	Both
Q18b	If yes, how often?	Daily	Few times a Week	Once a Week 2-3 times a month

Q19	Does your child read at home?		YES	NO
Q19a	If yes, in what language does she/he read?	Primarily English	Primarily Spanish	Both
Q19b	If yes, how often?	Daily	Few times a Week	Once a Week 2-3 times a month

Q20	Does your child watch TV?		YES	NO
Q20a	If yes, in what language?	Primarily English	Primarily Spanish	Both
Q20b	If yes, how often?	Less than 3 hours a day	3 or more hours a day	

Q21	Does your child listen to Music?		YES	NO
Q21a	If yes, in what language?	Primarily English	Primarily Spanish	Both
Q21b	If yes, how often?	Less than 1 hour a day	1 or more hours a day	

Q22	Does your child browse the Internet?		YES	NO
Q22a	If yes, in what language?	Primarily English	Primarily Spanish	Both
Q22b	If yes, how often?	Less than 2 hours a day	2 or more hours a day	

Q23	Does your child mix words or sentences from two languages in his/her own speech?				YES	NO
Q23a	If yes, how often?	Always	Frequently	Occasionally	Rarely	

Appendix B

Pearson Correlations Language Outcome Measures Controlling for Age.

	1	2	3	4	5	6	7	8	9
English									
1. TPVT Receptive Vocabulary									
2. MINT Expressive Vocabulary	.48**								
3. Complex Syntax Rate	-.06	-.09							
4. Morphosyntax Error Rate	-.55**	-.74**	-.05						
5. VF	.38*	.47*	.35*	-.46**					
Spanish									
6. TPVT Receptive Vocabulary	.07	-.27	.01	.20	-.28				
7. MINT Expressive Vocabulary	-.23	-.57**	.21	.54**	-.32	.44**			
8. Complex Syntax Rate	-.10	-.28	.62**	.18	.14	.11	.41**		
9. Morphosyntax Error Rate	-.0.10	.27	-.09	-.26	.21	-.49**	-.54**	-.18	
10. VF	-.04	-.17	.28	.21	.13	.14	.58**	.38*	-.08

* $p < 0.05$, ** $p < 0.01$

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