TESTING THE BILINGUAL ADVANTAGE HYPOTHESIS:

LANGUAGE BALANCE AND SELF-REGULATION

by

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A THESIS

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Eric Pakulak

It is proposed that bilingual individuals have advantages in executive function (EF) and self-regulation, which is referred to as the Bilingual Advantage Hypothesis (BAH). To examine this hypothesis in a novel way, this thesis examines a group of bilingual preschool-aged children, rather than comparing bilinguals to monolinguals. With this approach, this study aims to understand whether language balance in bilinguals affects self-regulation. The present study examined this question using a battery of behavioral measures of EF, in addition to an event-related potential (ERP) paradigm that assesses brain function for selective attention. Children were divided into three groups: more balanced, English dominant, and Spanish dominant. No relationship between language balance and behavioral results were found. Results from the ERP paradigm revealed a trend toward a significant relationship between language balance and brain function, specifically for distractor suppression. A follow-up between-group analysis suggested that English dominant children had poorer brain function for distractor suppression, as compared to more balanced and Spanish dominant children. While speculative, this pattern of results suggests that level of acculturation and parenting culture may be associated with bilingualism and selective attention in preschool-aged children.

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Introduction

Bilingual Advantage Hypothesis

Language is the primary form of human communication that allows individuals to develop intellectual skills and gives rise to the exchange of knowledge within human societies. Proficiency in two languages, or being bilingual, provides opportunities for individuals to communicate across cultures and the world. Of the bilingual population in the United States, over 62% are Spanish-English bilinguals (Rosselli, Ardila, Lalwani, & Vélez-Uribe, 2016). Spanish is one of the fastest growing languages spoken in the US, with more than 37 million speakers (Ortman, 2011).

The brain has the capacity to manage more than one language, which is a focal point of research investigating the implications bilingualism has on cognition; defined as knowledge through thought and experience. This management is proposed to require active inhibition of at least one language, as many bilinguals are constantly interpreting and ignoring stimuli in two languages (Antón et al., 2014). One theoretical possibility is that this continuous suppression will result in the strengthening of specific brain function, similar to lifting weights for muscle strength. It is proposed that bilingual individuals have advantages in executive function and self-regulation compared to monolinguals, which is referred to as the Bilingual Advantage Hypothesis (BAH).

The proposed cognitive advantages originate from dual language processing and inhibitory control (IC). The IC model proposes multiple levels of language control (Green, 1998). For bilinguals, the IC model theorizes that when two languages are simultaneously activated, one language is inhibited in order to produce the appropriate speech for the linguistic context. For example, when seeing an apple, it is hypothesized that a bilingual individual will associate two mental representations with the object, apple (English) and *manzana*, (Spanish) (Costa & Sebastián-Gallés, 2014). In order to produce output in the desired language, it is necessary to inhibit the mental connection that is irrelevant at the moment. If the context of this scenario required the bilingual individual to produce the word for apple in Spanish, *manzana*, the English word would need to be suppressed in accordance with IC model (Green, 1998). Bilingual individuals differ in their degree of proficiency in the two languages they speak, and it is consequently hypothesized that a more balanced bilingual suppresses stimuli more regularly. Independent of age, some evidence suggests that being a more balanced bilingual contributes to the improvement of inhibitory processing (Birdsong, 2014). For more balanced individuals who use more than one language regularly, bilingualism thus requires the brain to regularly exercise inhibitory processes. Therefore, this process is theorized to result in stronger non-linguistic cognitive abilities, compared to monolinguals.

Early BAH Studies

Early studies of the BAH sought to understand potential differences between monolingual and bilingual individuals and determine the nature of this hypothesized bilingual advantage. This early research suggested that bilingualism is related to differences in specific aspects of cognitive processing. The first studies pertaining to the BAH demonstrated group differences in attentional control, a subset of self-regulation, between monolingual and bilingual children (4-7 years old) (Bialystok, 1999; Bialystok, 1988). However, these studies failed to account for socioeconomic status (SES), which has been associated with differences in many aspects of cognitive and psychological development, including executive function (EF) and self-regulation (Bialystok, 2009; Ursache & Noble, 2016). Moreover, the effect of bilingualism on cognitive functioning, as evidenced by executive control and working memory, is part of a growing body of research demonstrating the powerful role of experience on cognitive ability and organization (Bialystok, 2009). Experience is not limited to skills specifically associated with language development and can include broader environmental differences as a function of SES, which is associated with individual differences in brain structure, function and cognition.

Socioeconomic Status

Relationships between early adverse experiences and development can be studied by looking at differences as a function of SES, a proxy variable that is often measured as a function of parental education and occupation. There are profound associations with early adversity and multiple neurobiological systems, particularly those important for language and EF (Pakulak, Stevens, & Neville, 2018; Ursache & Noble, 2016). A large body of evidence shows that children from lower SES backgrounds perform below children from higher SES backgrounds on tests of intelligence and academic achievement (Kishiyama et. al, 2009; Stevens et. al, 2009; White & Greenfield, 2017; Morton & Harper, 2007). Disparities related to SES are associated with differences in brain function, specifically aspects of attention, such as sustained selective attention (Stevens et. al, 2009; Neville et. al, 2013). Stevens and colleagues have studied differences in brain function for selective attention as a function of SES, using the paradigm employed in this thesis, to examine the BAH in bilingual preschoolers. They demonstrated that children whose mothers had lower levels of educational attainment (no college experience) showed reduced effects of selective attention on neural processing, compared to children whose mothers had higher levels of educational attainment (some college) (Stevens et. al, 2009). The differences were related to distractor suppresion, a specific aspect of attention, as children whose mothers had lower levels of education had a reduced ability to filter irrelevant information. These data provide evidence for differences in brain function for selective attention in children from different socioeconomic backgrounds (Stevens et. al, 2009). Similarly, evidence from several other studies suggests that selective attention is reduced in children from lower SES backgrounds (Kishiyama et. al, 2009; D' Angiulli & Herdman, 2008). Based on these studies, there is a strong motivation to understand how experiences associated with SES interact with bilingualism to affect cognitive development (Morton & Harper, 2007). Controlling for SES in future studies investigating the BAH is thus essential, due to the established relationship between SES and EF.

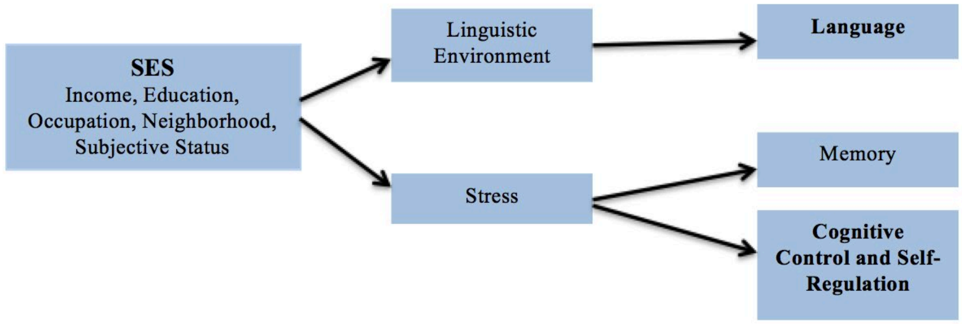


Figure 1. Hypothesized mechanisms by which SES operates to influence neurocognitive functioning (Adapted from Ursache & Noble, 2016). Bolded words indicate focal points of this thesis.

Recent Studies of BAH

The more recent studies of the BAH demonstrate inconsistent results amongst one another. The conflicting evidence provided by these studies either support, or do not show significant results in regard to the BAH. For example, a study focusing on bilingual preschoolers (ages 3-5 years) found that performance on executive function tasks was significantly higher in bilinguals as compared to monolinguals, while controlling for SES (White & Greenfield, 2017). These results differed in the Spanish-dominant emerging bilingual group, in which there was no significant difference between the emerging group and monolingual English, or bilingual group. This suggests that classifying the language dominance of children with more specificity may provide insight into the BAH. However, between-groups analyses can fail to take into account the complexity of bilingualism, as White & Greenfield suggest that a certain level of language proficiency may be needed to experience advantages in EF (White & Greenfield, 2017).

The intricate nature of bilingualism is best characterized in terms of language balance, proficiency and exposure. Language balance refers to the relative proficiency an individual has in either language. For example, on measures assessing accuracy on a specific aspect or aspects of language proficiency in each language, a relatively unbalanced bilingual could have language balance scores of 80% in Spanish and 20% in English. Language balance and proficiency exist on a spectrum, as individuals can have varying degrees of both aspects in either language(s). Children can have varying levels of exposure to languages in the home, schools and community spaces. Individual differences in language balance, proficiency and exposure add to the complexity of bilingualism.

Another important issue in BAH research is publication bias: the tendency for scientific journals to favor and publish studies with an outcome as opposed to a null finding that does not support a specific hypothesis like BAH. A meta-analysis examined abstracts from studies of the BAH conducted between 1999-2012 and found that 63% of the studies supporting the bilingual advantage were published, compared to 36% that challenged the existence of the BAH (de Bruin et al., 2014). They suggest that this publication bias is not due to overwhelming evidence in favor of the BAH, but rather due to the limited number of EF tasks used in experiments. The limited battery of tasks may fail to accurately depict EF, from a wholistic approach. Abstracts that challenge the BAH reported more executive control tasks, as compared to abstracts supporting this hypothesis (de Bruin et al., 2014). Publication biases may have inflated the frequency at which this bilingual advantage may occur, which does not provide a complete and accurate depiction of research on the BAH.

Moreover, there is a growing body of literature that suggests bilinguals do not have an advantage in EF (Duñabeiti et al., 2014; Antón et al. 2014; Paap et al., 2015; Paap & Greenberg, 2013; Gathercole et al., 2014). Duñabeiti and colleagues provide evidence that bilingual children do not exhibit an advantage in inhibitory control of auditory stimuli, as compared to monolinguals (Duñabeiti et al., 2014). This study considered language proficiency and had strong statistical power, with 252 participants in each group (monolingual and bilingual). However, researchers speculated that a bilingual advantage could exist at a general functioning level and did not specifically examine the factor of relative dominance within the language(s). Furthermore, a study comprised of 180 Spanish monolingual and 180 bilingual children (2^{nd}-5^{th} grade) were matched in SES and cognitive measures (IQ, math and reading scores) (Antón et al. 2014). Language proficiency measures were taken in both Basque and Spanish (the languages examined). These researchers tested the BAH via a child friendly version of the Attention Network Test (ANT), and no bilingual advantage was demonstrated (Antón et al. 2014). The lack of evidence for a bilingual advantage in recent studies suggests researchers should more closely consider language balance in bilinguals, and what type of bilingual individual might demonstrate the reported advantages of the BAH, in addition to the conditions under which these benefits are observed (Gathercole et al., 2014).

Levels of Bilingualism

As mentioned above, bilingualism exists on a spectrum, as bilingual individuals vary in levels of language balance, proficiency and exposure. Some research on the BAH more carefully considers these factors. For example, a recent study examined the effect of language proficiency on executive function in balanced and unbalanced Spanish-English bilinguals (Rosselli et al., 2016). Proficiency was defined as functional language ability pertaining to real-world situations, and language balance referred to the relative levels of fluency in both languages. In this study, language proficiency was measured in both languages using Bilingual Verbal Ability Tests, which examined picture and oral vocabulary, and verbal analogies. This 30-minute assessment quantified participants' language comprehension and speaking abilities. They found that high proficiency balanced bilinguals performed better than low proficiency balanced bilinguals (Rosselli et al., 2016). Another study demonstrated similar results, (Iluz-Cohen, 2013) which emphasizes the importance of considering variability in both language balance and proficiency when examining potential correlations between bilingualism and EF.

Additionally, results from a meta-analysis suggest that language dominance is relative, meaning a bilingual who is dominant in one language does not necessarily have high proficiency in that language, only lower proficiency in the other language (Birdsong, 2014). Overall, bilingualism and language dominance are constructs that exist on a spectrum, which is crucial to account for when conducting research on the BAH.

Self-Regulation and Executive Functioning

This thesis will focus on two aspects of self-regulation, 1) selective auditory attention, and 2) executive function (EF). The subcategories of interest for selective auditory attention are: signal enhancement and distractor suppression. Moreover, EF is a broad term for fundamental cognitive skills that are involved in regulating attention, determining what to do with new information or information retrieved from long-term memory, planning, and behaving flexibly. As such, EF involves a set of related set of information processing abilities that include working memory, inhibitory control, and cognitive flexibility. The structure of executive function in young children, specifically 3-year-olds, appears to be a unitary process, although their EF skills are still developing (Wiebe et al., 2011). The preschool years are a time of accelerated development of self-regulation and EF, thus an important developmental period in which to study the variables that effect self-regulation. This period of great neuroplasticity in children, makes this an ideal period in development in which to study the BAH.

This project will examine the BAH by considering multiple aspects of self-regulation, with a primary focus on selective auditory attention. It will also incorporate behavioral measures of working memory and inhibitory control. Working memory involves the maintenance of information that guides ongoing and future behaviors (Wiebe et al., 2008). Inhibitory control allows individuals to control impulsive behavioral responses and keep irrelevant information from altering their performance (Wiebe et al., 2008).

A skill related to inhibitory control is selective attention, which refers to the ability to select which competing auditory stimuli to either attend to, or ignore (Stevens et al., 2009). An illustrative example would involve a student who is sitting in a lecture hall and is distracted by people chatting behind her. In order to focus on the lecture, she would need to selectively attend to the presenter and ignore the distracting stimuli, the other students. Evidence suggests that two neural mechanisms are involved in this process: signal enhancement and distractor suppression. Signal enhancement involves the heightening of relevant stimulus and distractors suppression, in which people ignore the distractor stimuli. For bilinguals consistently exposed to two auditory language stimuli (e.g., Spanish and English), the BAH would predict that the enhanced ability to selectively attended to certain stimuli and suppress distracting stimuli is enhanced.

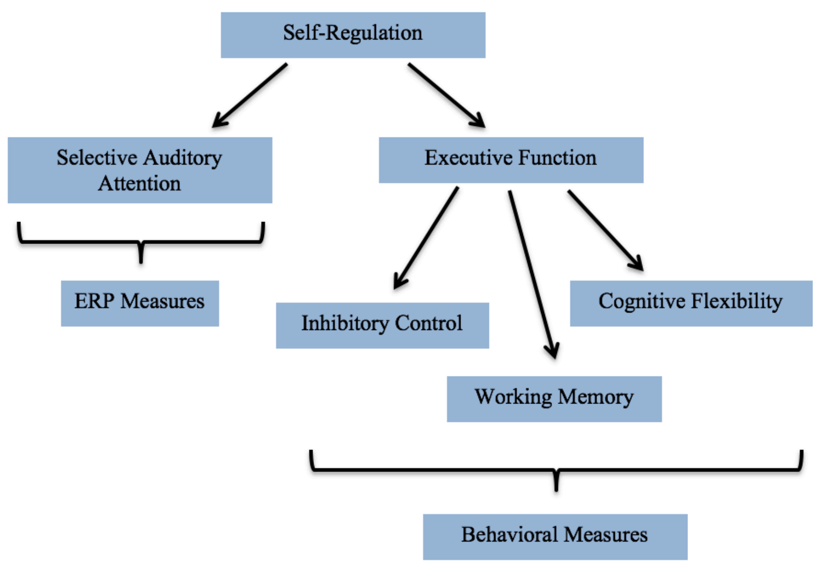


Figure 2. Overview of the aspects of self-regulation in relation to this thesis.

The Present Study

For this project my research question is: How is language balance in bilingual children related to brain function for auditory selective attention, as measured by ERPs, and to behavioral measures of EF? This thesis will examine self-regulation and executive function within a group of bilingual children who have varying degrees of language balance but relatively similar SES backgrounds, as all are enrolled in Head Start. We will test the hypothesis that more balanced bilingual children will exhibit neural enhancements in selective auditory attention and executive function, compared to relatively unbalanced bilinguals. This thesis focuses within a group of bilingual individuals, rather than between monolinguals and bilinguals, as it is a novel way to examine the potential implications of the BAH. Therefore, by controlling for SES, this study aims to understand whether language balance affects self-regulation.

Method

Participants

A total of 160 children were recruited from Eugene, Salem and the surrounding communities, and were given monetary compensation for their time. Participants were recruited as a part of two larger studies, with slight differences in procedure as described below: 101 individuals from a study funded by the Institute of Education Sciences (IES) grant research, and 59 from a study funded by the Department of Health and Human Services (HHS). Both studies acquired data using the behavioral and ERP assessments described below. These datasets were combined in this analysis to provide more statistical power and greater variability language balance.

All participants were Spanish-English bilinguals, ranging in age from 3.21 years to 5.54 years (M age = 4.40 years, SD = 0.573). In order to measure their relative proficiency in each language, participants completed a brief language screening assessment in both languages to assess and determine their dominant language (Spanish or English), as described below.

Table 1. Demographic information for all 160 participants.

	Bilinguals (N = 160)
Age (years)	4.40 ± .572
Gender (females)	76
Hollingshead SES Score (N = 150)	22.15 ± 7.58
PLS Spanish	.6989 ± .227
PLS English	.5546 ± .268

Measures

Language Balance. In order to determine the language of assessment, the Preschool Language Screener (PLS) was used. This test has six sections: language, articulation, connected speech, social/interpersonal, fluency, and voice (Zimmerman, Steiner & Pond, 2002). For these studies, the language portion of the PLS was used. The subcategories for this portion of the evaluation are: recognizing action in pictures, understanding negatives in sentences, naming a variety of pictured objects, using plurals and producing one four- or five-word sentence. For example, a researcher would show a child a picture and say, "Look at all the animals. Which one has a tail?" Similarly, this example in Spanish would be as follows, "Mira todos los animales. ¿Cuál tiene un rabo?" (Zimmerman, Steiner & Pond, 2002). The child would receive a point if they indicated the correct picture. Language percentages were calculated by dividing the number of correct responses by total questions. From these percentages, a raw language balance score was calculated by dividing the percentage correct in Spanish from the percentage correct in English; for correlational analyses, these raw values were converted to absolute values.

Language proficiency. The Clinical Evaluation of Language Fundamentals-Preschool: 2nd Edition (CELF-P2), is an individually administered assessment that pinpoints a child's language strengths and weaknesses (Wiig, Secord & Semel, 2004). There are validated versions in both Spanish and English; the version administered was determined based on PLS scores as detailed below. For example, if the child scored higher in Spanish on the PLS, than they would be tested in Spanish for CELF exam. From the battery of CELF subtests, a receptive language score was calculated. Receptive language assesses how well the participant understands what is being said and is comprised of tasks that involve sentence structure, concepts and following directions, and depending on the age group either basic concepts or word classes. For example, a child would be presented with a picture showing four babies, three of who are crying. The experimenter would say, "Look at all the babies. Show me the baby who is not crying," which is an example of understanding negatives in sentences. Similarly, testing negatives in sentences in Spanish would be as follows: the child would be presented with a picture of two children who are sleeping, and one who is not. The experimentor would say, "Mira lost niños. Enséñame al niño que no está durmiendo." In English, it translates to "look at the boys. Show me the boy who is not sleeping."

Executive Function (EF). Behavioral tasks assessed three aspects of EF: working memory (WM), inhibitory control (IC), and cognitive flexibility. These tasks were administered their dominant language as based on PLS scores.

WM. The Noisy Book task (Hughes, Dunn & White, 1998) assesses WM by asking participants to recall a sequence of animal names and touch corresponding boxes on a touch screen in the correct order. In addition to the Noisy Book task, participants also completed two measures of memory span: word forward and digit forward. In each span task, children heard and were asked to repeat in the same order a sequence of words or digits until children were unable to correctly repeat a given sequence (Wechsler, 2004). A composite working memory score was calculated by averaging Noisy Book total accuracy, and word forward and digit forward span. A composite working memory score was calculated by averaging Noisy Book total accuracy and two measures of memory span: word forward and digit forward.

IC. To assess IC, we administered the Snack Delay task (Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996). In this task, candies under a transparent cup were placed in front of the child. They were instructed to stand still in silence with their hands resting on the table until the tester signals that the candies could be eaten. During the delay period of this task, a series of distractions, for example coughing or dropping a pencil, were introduced; later, the tester left the room for the last 90 seconds. Each five-second interval is scored (1 point for sitting still, 1 point for keeping hands on the mat, and 1 point for not talking), and these scores were summed across all epochs, a 5 second time interval, until the child either ate the snack or the total of 240 seconds had elapsed. Higher scores indicate the child had high IC.

Cognitive flexibility. To assess cognitive flexibility, we administered the Shape School task (Espy, 1997). In addition to cognitive flexibility, this task also assesses IC because children are required children to suppress their initial prepotent, or dominant, response. In this task, a prepotent response is instilled by teaching children the initial response to a color-naming pattern in which the child names characters (red or blue) with neutral faces. In story format, children were then taught the "inhibit rule," meaning they were required to name the color of a happy face but remain silent when the character had a sad face. Children are then taught to name characters by shape (circle or square), and in subsequent blocks are asked to switch between the color- and shape-naming tasks; switching between tasks is an assessment of cognitive flexibility. This task was scored using the total percentage accuracy across inhibition and switching tasks.

Selective Attention. To measure brain function for selective attention, we employed the ERP paradigm that has been used successfully with both child and adult participants in the Brain Development Lab (BDL). Electroencephalograms (EEGs) were recorded using a Biosemi Active Two system from electrodes secured in an elastic cap, in a soundproof booth. In this paradigm, participants watched a story on a computer monitor, while different auditory stimuli were delivered from two speakers to the left and right of participants. Participants selectively attend to one of two simultaneously presented stories that differ in location (left/right), voice (male/female), and content.

ERPs are recorded to identical 100 msec probes embedded in stories when attended and unattended, and the effects of selective attention are quantified by comparing the brain response to probes embedded in the attended story with the response to identical probes embedded in the unattended story.

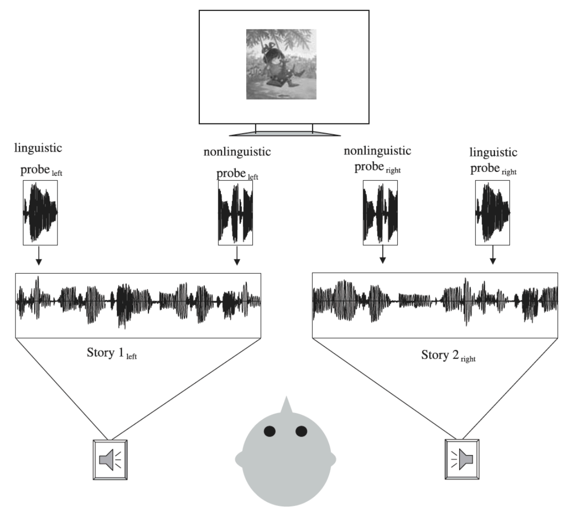


Figure 3. Schematic representation of the experimental paradigm. Children were instructed to attend to the story presented from either the left or right speaker (Stevens et al., 2009).

The neurological events within an electroencephalogram (EEG), which records the electrical activity of the brain, are averaged to create ERPs (Luck, 2005). The methodology of ERPs is widely used to examine brain function in young children and provides a multidimensional array of cognitive processes with excellent temporal resolution.

Quantification of ERPs was performed using EEGLAB/ERPLAB software. Measurement and analysis of ERP components includes averaging the EEG based on the target probe at the 500 msec epoch and a 100 msec pre-stimulus baseline. Consistent with previous research using this task that has found a fronto-central distribution of this attention effect between 100-200 ms in preschoolers (e.g., Stevens et al., 2009), analyses were limited to fronto-central channels (F3-4, FC5-6, C3-4, C5-6, Fz, Cz). Mean amplitude of the brain response to probes in attended and unattended channels was measured within a 100-200 ms time window and averaged across these channels to form an aggregate measure of brain function for each participant.

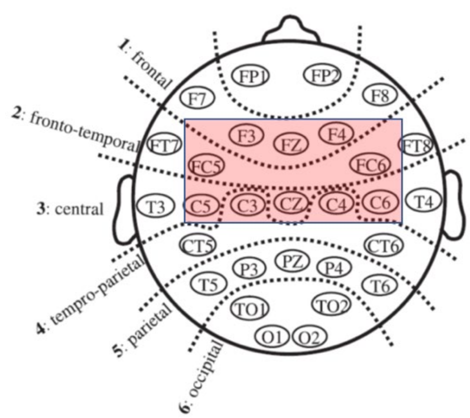


Figure 4. Electrode placement of the cap for EEG acquisition; channels used in analysis are highlighted (fronto-central channels).

Socioeconomic Status. Participants' childhood socioeconomic status was measured using the Hollingshead Four-Factor Index of Socioeconomic Status (Hollingshead, 1975), which uses parental educational attainment and occupation.

Education level is rated on a 7-point scale ranging from graduate/professional training as the highest score, and 7^{th} grade or lower as the lowest score. Occupational level is evaluated on a 9-point scale for which the Hollingshead manuscript provides a detailed list of occupations and their point value. A socioeconomic score is then calculated based on these scores. To control for SES within this group analysis, it was used as a covariate.

Procedure

After giving written informed consent, bilingual participants were first given the quick screening measure (PLS) in both English and Spanish to determine the dominant language, in which subsequent assessments were performed. The following criteria were used: if the participant scored higher in English, assessments were performed in English; if the participant scored more than 5% higher in Spanish, assessments were performed in Spanish; and if the participant scored within 5% accuracy in Spanish and English, assessments were performed in English.

Behavioral measures of executive function were administered by trained research assistants in a quiet room in the laboratory. All behavioral measures were performed in a separate testing session, with the exception of the Snack Delay measure. Participants from the HHS project were given this assessment in the same testing session as the ERP paradigm, with the ERP assessment always performed first.

The ERP assessment was performed in a separate room in the laboratory. Children were fitted with an elastic electrode cap, and then seated in a sound-attenuated booth. Children were presented with two simultaneous stories and instructed to attend selectively to one story, while ignoring the story in the opposite speaker. The language the story was told in was determined by the PLS scores and the dominant language of the child. Inside the booth, a trained research assistant sat next to the child to monitor behavior, movements, and administer comprehension questions after each story. Children first heard instructions in a practice listening session that introduced them to the two voices and overlapping stimuli. During the practice, participants received instructions to listen to a single story while ignoring the distracting story presented in the opposite audio channel (e.g., Stevens et al., 2009). Stories varied in content, speaker location and narration voice (male/female) (e.g., Stevens et al., 2009). Throughout the study, a camera transmitted the session so that other researchers and the caregiver(s) could observe from outside the booth. Children heard a total of four narratives and after each story the experimenter asked the participant basic comprehension questions about the story the child was asked to attend to, and children were given short breaks as necessary. During the task, corresponding illustrations from the to-be-attended story and arrows indicating the direction of the narrator's voice were shown on a monitor.

Design

To test the primary hypothesis on the effects of balanced bilingualism, we conducted partial correlations in order to control for participant age and SES. Any significant or marginally significant relationships were followed up by between-group analyses in which children were divided into three groups: more balanced, English dominant, and Spanish dominant, as detailed below in the results section. We hypothesized that children who are more balanced bilinguals (i.e., relatively equal

Spanish and English percentage scores) would exhibit neural enhancements in selective auditory attention, as measured by the ERP paradigm, and better behavioral performance on executive function tasks.

After inspection of data and removal of outliers, partial correlations controlling for age and SES were conducted to examine the relationship between language balance (using the absolute language balance value) and behavioral measures of EF and three ERP measures: the difference in mean amplitude between attended and unattended channels (i.e., the attention effect) and the average mean amplitude of attended and unattended channels independently, averaged across fronto-central sites as described above.

Results

First, the relationship between language balance and proficiency in the participant's dominant language was analyzed. No significant relationship between language proficiency and language balance was found $r(146) = .028$, $p = .733$; Figure 5), and so language proficiency was not included in subsequent analyses.

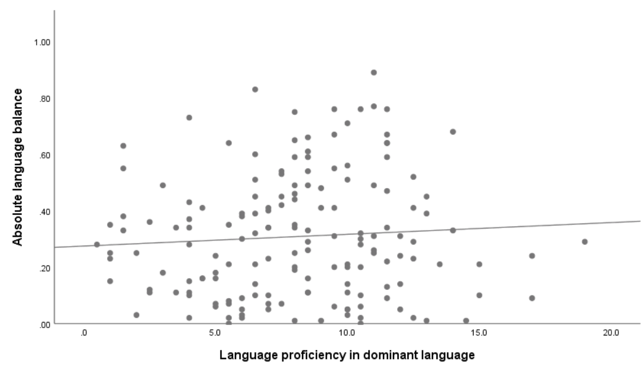
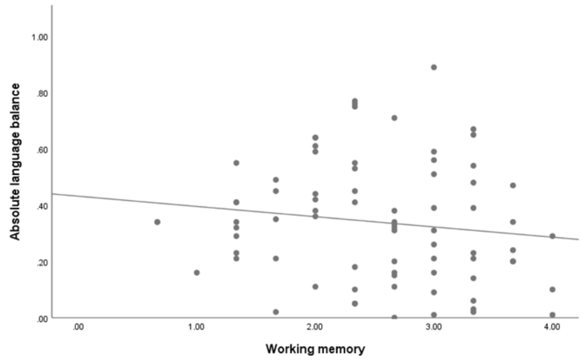


Figure 5. Scatterplot showing the relationship between absolute language balance and language proficiency in dominant language.

Next, the relationship between language balance and behavioral measures of EF was examined. Controlling for age and SES, there were no significant relationships between language balance and performance on the behavioral tasks examined: WM composite $r(65) = .028$, $p = .733$, Snack Delay $r(81) = .084$, $p = .451$, and Shape School $r(86) = .129$, $p = .230$. These relationships are depicted in scatterplots in Figure 6.



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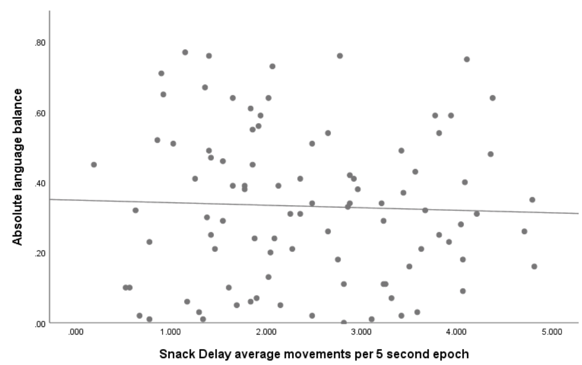

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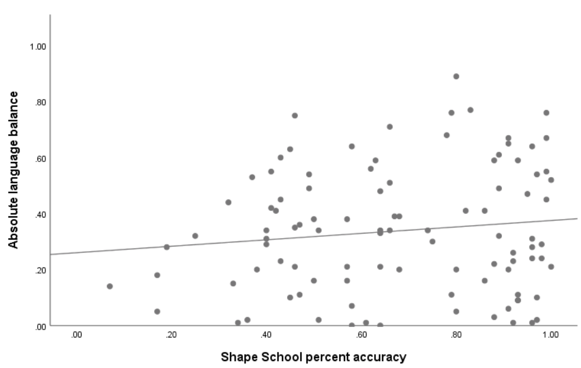


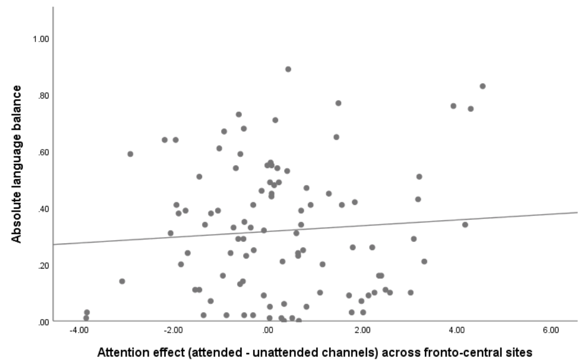
c)

Figure 6. Scatterplots showing relationships between absolute language balance and a) the working memory composite; b) the Snack Delay measure of inhibitory control; and c) the Shape School measure of cognitive flexibility.

Finally, the relationship between language balance and brain function for selective attention was examined, utilizing the fronto-central aggregate measure for correlational analysis (see Figure 7a). Children with ERP data (N = 101, 52 male) were older than children without ERP data ($F(158) = 3.35$, $p < .001$), consistent with other ERP studies with children that find more data loss due to movement and other artifacts in younger children. There were no differences between groups in language balance or language proficiency ($p > .39$). As shown in Table 2 and Figure 7b, while there was no significant relationship between the attention effect or the response to attended probes, there was a near-significant trend for a negative correlation between language balance and the brain response to unattended stimuli (Figure 7c). This negative relationship suggested that less language balance was associated with better suppression of distracting stimuli, contrary to what the BAH would predict.

Table 2. Correlation for ERP measures, controlling for age and SES, in attended and unattended channels during selective auditory attention task.

	Attention Effect (Attended Channel – Unattended Channel)	Attended Channel	Unattended Channel
Language Balance	.097	-.113	-.201
p-value	.358	.284	.055



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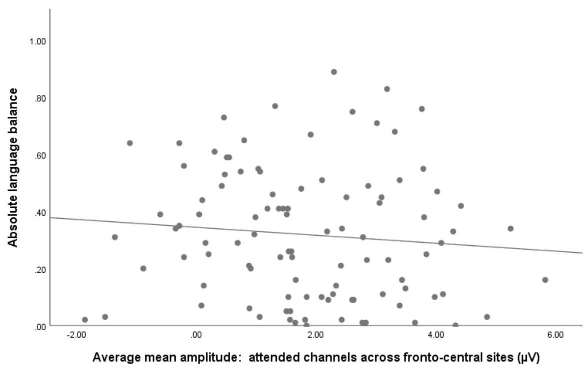

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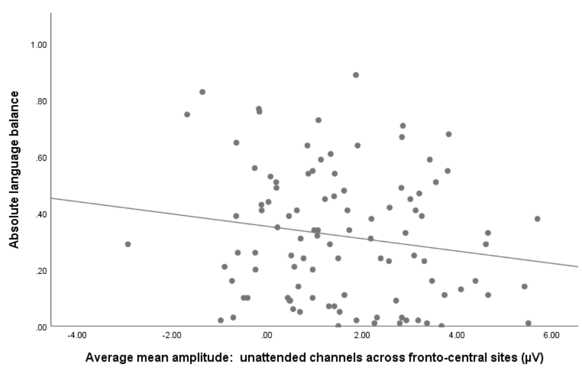

c)

Figure 7. Scatterplots showing relationships between absolute language balance and the brain response to attended and unattended stimuli mean amplitude (µV) between 100-200 ms across fronto-central sites: a) the attention effect (attended-unattended channels); b) attended channels; and c) unattended channels.

In order to explore this trend, three groups were formed by dividing using tertile cutoffs on the raw language balance measure: English dominant bilingual, balanced bilingual, and Spanish dominant bilingual. Average percentage correct on PLS measures in English and Spanish for each group are shown in Table 3., and ERP grand average waveforms across fronto-central sites are shown in Figure 8.

Table 3. Means and standard deviations of PLS scores in both languages.

	English Dominant (N = 52)	Balanced Bilinguals (N = 53)	Spanish Dominant (N = 55)
PLS English	.7494 ± .199	.6319 ± .199	.2960 ± .160
PLS Spanish	.4971 ± .218	.7955 ± .171	.7965 ± .143

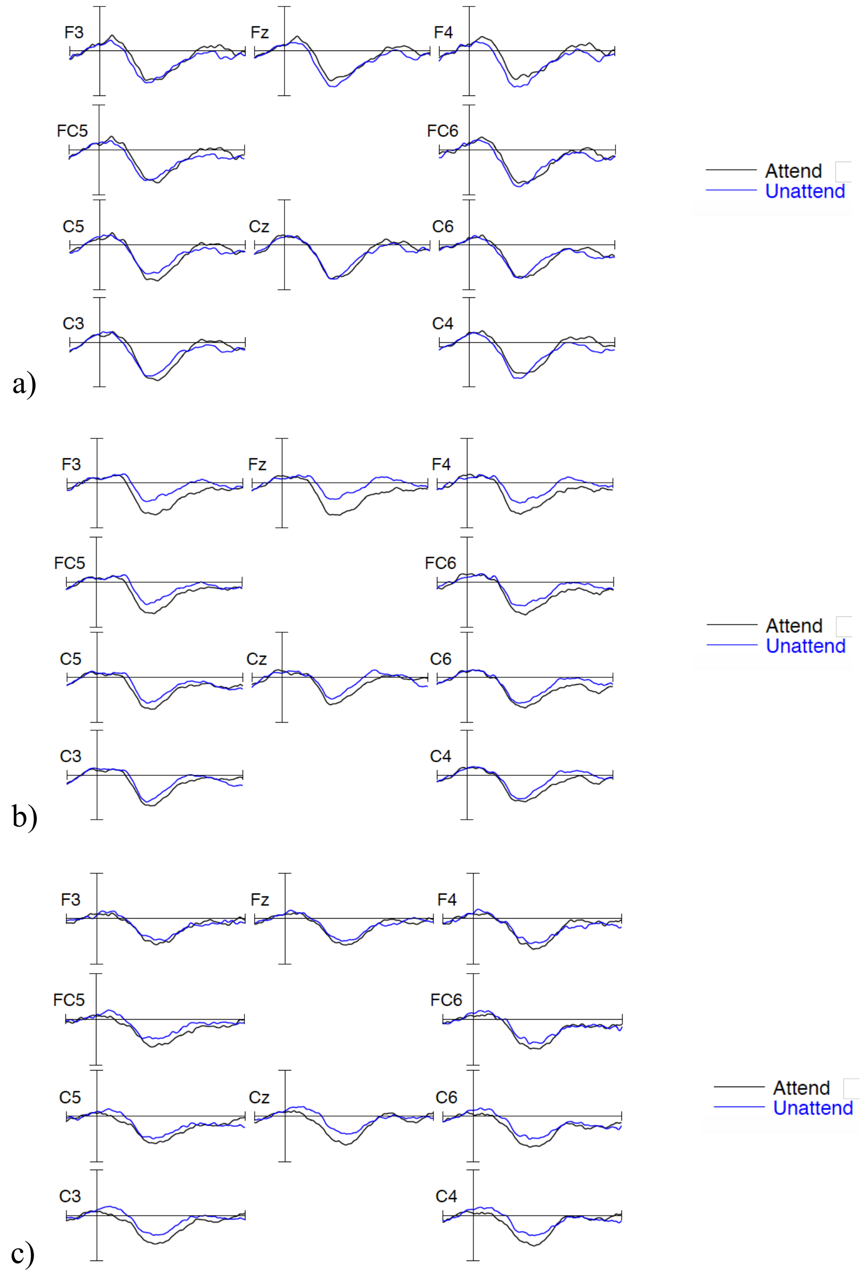

Figure 8. Grand average evoked potentials for attended and unattended stimuli across fronto-central sites (μV), for a) the English dominant group; b) the balanced bilingual group; and c) the Spanish dominant group. Vertical lines indicate stimulus onset, and the post-stimulus time range is 0-500 ms.

As seen in Figure 8 and highlighted in Figure 9, subtle differences in mean amplitude were evident between the unattended and attended channel in English dominant bilinguals compared to the two other groups. To follow up the near-significant trend in the correlational analysis, a one-way ANOVA was conducted on the average mean amplitude of the unattended channel, and groups significantly differed ($F(2, 98) = 5.25$ $p <.01$). The English dominant group had greater average mean amplitude to the unattended channel than the Balanced ($t(70) = 2.91$, $p < 01$) and Spanish dominant ($t(62) = 2.60$, $p < 05$), while there was no difference between the balance and Spanish dominant groups ($t(64) = -.016$, ns). This is illustrated in Figure 10. This pattern of results suggests that children in the balanced and Spanish dominant groups have better brain function for distractor suppression than children in the English dominant group.

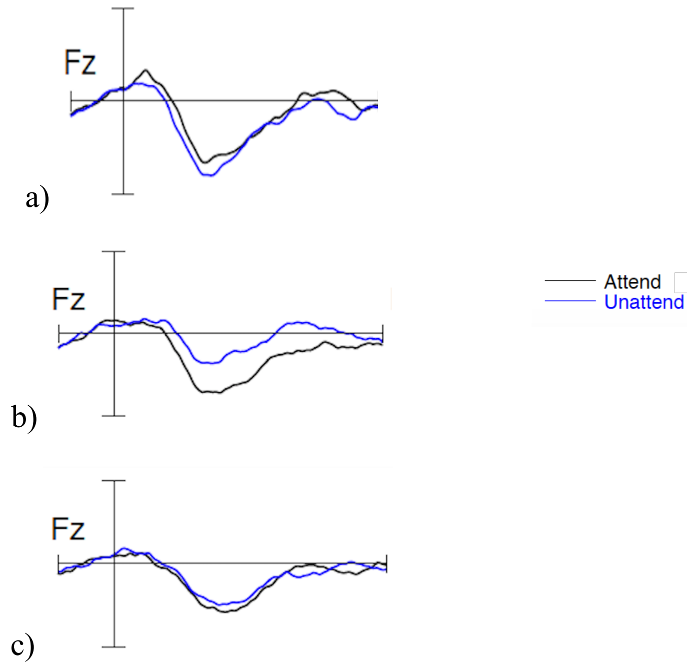

Figure 9. Averaged ERP response at representative channel Fz for a) the English dominant group; b) the balanced bilingual group; and c) the Spanish dominant group. Vertical lines indicate stimulus onset, and the post-stimulus time range is 0-500 ms.

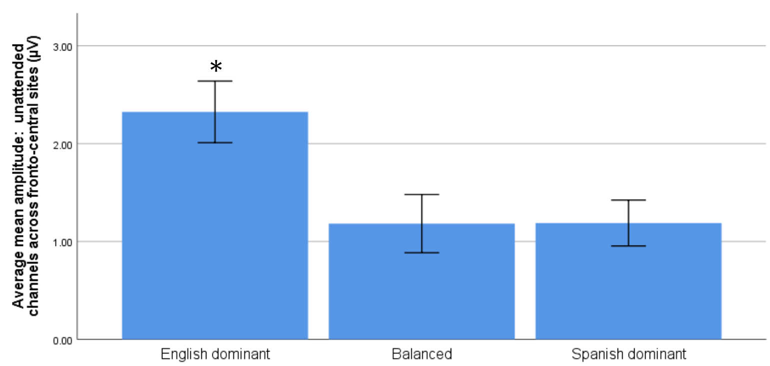

Figure 10. Average mean amplitude in the unattended channel across fronto-central sites (μV) in each balance group.

Discussion

According to the Bilingual Advantage Hypothesis (BAH), bilingual individuals may have advantages in self-regulation because they are able to manage two languages at a time. This hypothesis predicts that bilingual individuals will outperform monolinguals who are matched on factors such as IQ, age, and SES, in tasks that measure executive function (EF). Previous research testing this hypothesis has yielded inconsistent and sometimes biased results. The aim of this study was to test the BAH in a novel way, by examining a bilingual group with varying levels of Spanish and English language balance, rather than monolinguals versus bilinguals. The present study controlled for age and SES, as these variables have been correlated with differences in EF (Pakulak, Stevens, & Neville, 2018; Ursache & Noble, 2016) and selective auditory attention (Kishiyama et. al, 2009; D' Angiulli & Herdman, 2008; Stevens et al., 2009).

The proposed cognitive advantages originate from dual language processing and inhibitory control (IC). For bilinguals, the IC model theorizes that when two languages are simultaneously activated, one language is inhibited in order to produce the appropriate speech for the linguistic context. Bilingual individuals differ in their degree of proficiency in the two languages they speak, and consequently a more balanced bilingual in theory suppresses stimuli more regularly. Some evidence suggests that, independent of age, being a more balanced bilingual contributes to the improvement of inhibitory processing (Birdsong, 2014). For more balanced speakers who use more than one language regularly, bilingualism thus requires the brain to regularly exercise inhibitory processes.

Behavioral Results

Contrary to our hypothesis, no significant relationship was found between language balance and behavioral measures of EF. One interpretation is that the lack of evidence to support the BAH in behavioral analyses is that language balance does not affect EF, the behavioral measure of self-regulation for this study. However, in comparison to neuroimaging measures such as ERPs, behavioral measures may not be as precise or sensitive in quantifying self-regulation. Thus, an alternative interpretation is that no significant relationships were found because the behavioral measures lacked the sensitivity necessary to detect more subtle differences. However, it is also important to note that in this sample there was lower statistical power for the behavioral data available (Ns between 61-86) in relation to the ERP data available (N = 101).

ERP Results

A skill related to inhibitory control is selective attention, which refers to the ability to select which competing auditory stimuli to either attend to, or ignore (Stevens et al., 2009). Signal enhancement involves the heightening of relevant stimulus, whereas through distractors suppression individuals ignore distracting stimuli. For bilinguals consistently exposed to two competing auditory language stimuli (e.g., Spanish and English), the BAH would predict that the ability to selectively attend to certain stimuli and suppress distracting stimuli is enhanced. This study tested the hypothesis that more balanced bilingual children would exhibit neural enhancements in selective auditory attention, compared to relatively unbalanced bilinguals.

In contrast to the behavioral results, ERP results revealed a trend toward a significant negative correlation between absolute language balance and the average mean amplitude of unattended channels. However, this correlation was not in the direction predicted by the BAH, which would predict better distractor suppression (a more negative response to unattended stimuli) positively correlating with absolute language balance (more negative values representing more balance). Between-group analyses revealed that children who were more English dominant showed a significantly greater positive response in the unattended channel compared to balanced and Spanish dominant bilinguals. These data provide novel evidence for variation in distractor suppression of stimuli between bilingual groups. Stevens and colleagues (2009) examined neural mechanisms of selective attention in monolingual English speakers as a function of SES and found that differences related to SES were specific to the unattended probes. Due to the known relationship between SES and selective attention our study controlled for this variable, which suggests our results are independent and not correlated with SES. This suggests that other factors may be affecting distractor suppression in bilingual children.

Other Possible Contributing Factors

Additionally, recent research on the BAH speculates that the relationship between EF and bilingualism could be bidirectional (White & Greenfield, 2017). It is possible that higher initial levels of EF promote the development of bilingualism in children learning two languages (White & Greenfield, 2017). Findings from this project raise the possibility that children with poor distractor suppression may be more likely be an English dominant bilingual, although the mechanism by which this might occur is unclear and requires more investigation.

While the BAH has primarily been tested between monolingual and bilingual groups, the ERP results suggest that Spanish dominant and balanced bilinguals may be better able to suppress distracting stimuli compared to English dominant bilinguals. These differences in unattended channel specific to the English dominant group warrant cautious speculation. Some evidence suggests that the level of parental acculturation may be related to language dominance (Schwartz et al., 2013). Acculturation is defined as, the process of two different cultures competing with each other and involves the social, and psychological changes that occur to individuals as a result (Schwartz et al., 2013). A child may shift between Spanish and English to accommodate different social situations, an example of inhibitory control. If the child continues to use one of the two languages repeatedly, it could affect language balance. It is thus reasonable to speculate that acculturation may be related to language balance in bilingual children. For example, consider a family that immigrated to the United States from Latin America. If the parents had a higher level of acculturation, it could be hypothesized that the child would have a higher proficiency in English, as compared to a child whose parents had lower levels of acculturation. If the parents had lower levels of acculturation, it is possible that they may be more likely to embrace aspects of traditional Latino parenting culture. For example, some aspects include the values of *respeto* (respect for parents and expectation of politeness and obedience) and *familismo* (placing the family before the self) (Calzada, Fernandez & Cortes, 2010). In children this age, adhering to the values of *respeto* and *familismo* require attention as well as modulation and inhibition of specific behaviors, which has the potential to affect their self-regulation. With regard to the BAH, these traditional values and accompanying behavioral expectations would suggest that balanced or Spanish dominant bilinguals may have an advantage in at least some aspects of self-regulation. While the broader pattern of results does not demonstrate this, the relationship between language balance and suppressor distraction raises the possibility that self-regulation in bilingual children may be influenced by other factors, such as parenting style.

A relationship between aspects of bilingualism and distractor suppression would potentially have broader implications. Difficulties with selective attention could be deleterious in learning environments, such as classrooms (e.g., Stevens et al., 2009). Children who have trouble filtering distracting sounds, such as the English dominant group in this study, could have a more challenging time focusing on assignments or instructions from the teacher in a classroom with distractions from classmates or other sources. This implies that children who have poor distractor suppression, may not do as well in the classroom as their peers, and may even fall behind. Researchers should investigate the effectiveness of intervention-based programs, as related to a child's distractor suppression.

Limitations

The primary limitation of this thesis was that these data were acquired in previous studies that were not intended to test our specific hypothesis. Language balance was central to this thesis, and so ideally participants would have undergone a more extensive language-screening task for a longer period of time. CELF, behavioral tasks and auditory attention tasks were administered in one language, which does not provide a full breadth of bilingualism and language balance.

As discussed above, it is possible that parental attitudes about parenting culture may be a factor in explaining this pattern of results. Another limitation in this study is thus a lack of information regarding parental attitudes toward traditional values. Finally, a study designed to examine the BAH would ideally acquire more data about the language environment, such as the language or languages spoken at home.

Another limitation in this thesis is statistical power, as there were an unequal number of participants for both behavioral and ERP measures; while patterns in the behavioral data did not suggest possible relationships, it is still possible that we did not have a large enough sample size to detect more subtle relationships.

Conclusion

The unexpected finding of differences in distractor suppression within a group of bilingual preschool-aged children suggests that future research on this question might benefit from using sensitive measures that permit an evaluation of possible differences in mechanisms such as distractor suppression. Using such measures in combination with precise measures of language balance, acculturation, and parenting behaviors are necessary to further examine the possibility of a bilingual advantage in distractor suppression. Further research is necessary to determine whether bilingualism is strongly linked to distractor suppression.

Overall, this thesis did not find statistical evidence to support the hypothesis that more balanced bilingual children would exhibit neural enhancements in selective auditory attention and executive function, compared to relatively unbalanced bilinguals. Thus, this thesis does not support the Bilingual Advantage Hypothesis positing advantages in self-regulation for balanced bilinguals.

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