COGNITIVE ADVANTAGE IN BILINGUALS

HONORS THESIS

Presented to the Honors College of
Texas State University
in Partial Fulfillment
of the Requirements

for Graduation in the Honors College

by

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San Marcos, Texas
May 2018

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Acknowledgements

First, I want to thank my husband Tim for being so supportive and loving. Without him and his support, this would have been an impossible job. I am beyond grateful for you and for all your help throughout this project.

Special thanks to my advisor and mentor Dr. Peter Golato. He is not only the best advisor but also an amazing human being. Thank you for all the hard work, the laughs, the interesting conversations, for all the time you put on my project and for always having the right words of encouragement and inspiration.

I want to thank my mom for teaching me that knowledge is the best tool one can possess, and for making me a strong and determined person. To my dad for making me have a curious and logical mind, for teaching me that happiness is the key to success, and for making me a tenacious person. Thank you so much for all your help with Power BI analysis, for all the hours we worked together on it and for reminding me every time "es una carrera, no un sprint".

To my best friends, my sisters Alo & Gun! My biggest cheerleaders! Thank you for always being there for me, for your support and your love! To Mariano and Diego for always having my back, for being so loving and supportive. To Pattish & Mikel for all the cute pictures and smiles when they were the most needed.

To my friends, Lisa & Ron, Ami, and Rikki & Robert, who have been by my side through happy and rough times. Thank you for all your encouragement and help.

I want to thank all the participants that took the survey. Thank you so much!

Finally, but most importantly, to my daughter Charlotte Rae. Thank you for being such a good baby, for your smiles and your patience while mom had to work on her thesis. Te amo!

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Abstract

Recent studies examining effects of bilingualism on executive functions in children and adults have found evidence supporting (a) advantages in executive control and (b) disadvantages in linguistic processing. There is evidence suggesting that bilinguals have better controlled processing and are more efficient at certain cognitive functions. Such findings have led to the hypothesis that there is a bilingual advantage (BA) for various cognitive tasks (Bialystok et al, 2004, 2012; inter alia). Studies examining the BA hypothesis typically time participants as they perform tasks thought to involve executive function. Commonly used tasks include the Stroop, Simon, Antisaccade, and Flanker. For example, the Stroop task includes a condition in which participants name the color of the letters in which a color word is written (e.g., saying "red" when seeing the word GREEN written in red letters). Studies have found that bilinguals were faster and made fewer errors in this condition than age-matched monolinguals (Costa et al. 2009). Some researchers hold however that bilingual advantages in executive function either do not exist (Paap et al., 2013) or are restricted to very specific tasks or experiences (Paap et al., 2014). Although existing studies on both sides have made strong claims, there remain gaps in the data and analyses. This study will attempt to bridge those gaps by seeking evidence of beneficial cognitive effects in bilinguals. Spanish monolingual and Spanish-English bilingual participants (L1 Spanish

has not been examined in BA research) will be tested on the Simon and Flanker tasks. The study will also explore the possible effects of covariates on the Simon and Flanker tasks. Covariates will include second language proficiency, education, age, age of acquisition, gender, occupation, impairments, and frequency of usage of the second language. Overall findings relative to the BA hypothesis will be discussed, along with possible future research directions.

I. Literature Review

For many decades, researchers have attempted to demonstrate how bilingualism affects our brains. Over the years, studies have produced several different hypotheses on how the brain is affected when a person uses more than one language. It has been theorized that bilinguals are in continuous conflict because they have to make quick decisions in order to center their attention on the targeted language. Some researchers believe that this constant conflict leaves marks on a bilingual's brain. Recent studies examining the effects of bilingualism on cognition in children and adults have found evidence that supports the emergence of two propositions: advantages in executive control, a set of cognitive processes which includes problem solving or attentional control, and disadvantages in linguistic processing, including rapid verbal production or picture naming (Bialystok 2010; Kroll and Bialystok 2013). However, according to other researchers (e.g., Paap 2013), bilingual advantages in executive function "either do not exist or are restricted to very specific and undetermined circumstances (Yong 2016)." A review of literature looking at these two opposing views will be presented in order to better understand the bilingual experience and the impact bilingualism might have on executive functions.

After a review of literature addressing the relation between bilingualism and executive functions and cognitive processing in the bilingual language experience, a discussion will follow addressing some of the components that require further research in

order to provide a better answer as to when the bilingual advantage is observed. First, a review of studies providing support for a bilingual cognitive advantage (BCA) will be presented followed by a review of studies that refute the idea of BCA. Additionally, to help improve the reader's understanding of this study, a brief summary of some key components of cognitive processing in bilinguals will be presented.

Bilingualism

Bilingualism has been often defined as the ability to express oneself in two languages. However, the degree of bilingualism is extremely hard to determine because each person has different bilingual characteristics. There exist differences between the ability, proficiency and the use of a language. Moreover, a bilingual might not be equally proficient with both languages in speaking, writing, listening or reading. Usually, bilinguals use each one of their languages in different contexts and domains. Therefore, they are not able to speak both languages equally well. Also, it is believed that bilinguals outnumber monolinguals in the world's population. Even though currently bilingualism is mostly seen as an advantageous skill, as recently as the 1950s in this country, many children were discouraged, often to the point of punishment, from speaking another language in school. However, since the 1960s, evidence has been mounting that rather than stunting intellectual growth, bilinguals may actually exhibit several cognitive advantages (for further discussion, see Bathia and Ritchie, 2016, Costa et al.(2009), Grosjean and Li, 2013, Malakoff and Hakuta, 1990).

Executive Function

Executive function, known as cognitive processing or cognitive control, is a term used to refer to several cognitive processes including problem solving, task switching, working memory, cognitive flexibility, among others. These processes are essential for managing thoughts and behaviors. Consequently, these control processes are partly responsible to achieving daily goals (Paap et al. 2014). It has been said that the executive functions control and command all cognitive skills. These executive functions manage daily life tasks of various types. For example, doing homework, organizing a trip, writing a paper, etc. Organization is one of the most important skills of executive functioning. The mental skills needed to control these processes are controlled by the frontal lobes of the brain, which are connected to other brain areas that coordinate the activities of these regions.

Inhibitory Control

Inhibitory control has been defined as the capacity to inhibit or regulate attentional or behavioral responses (Durston et al., 2002). Inhibitory control allows us to focus on relevant stimuli when irrelevant stimuli is present. Recent neuroimaging studies suggest that regions of the prefrontal cortex connect these abilities. Additionally, these studies revealed that inhibitory control abilities develop in early childhood and continue throughout the life span. Furthermore, behavioral studies suggest that young children are more susceptible to interference from irrelevant stimuli that older children or adults (Ridderinkhof et al., 1997).

Bilingual Cognitive Advantage Hypothesis

Support for the bilingual cognitive advantage hypothesis. Several studies conducted by Ellen Bialystok from York University point to benefits of bilingualism on executive function. In Bialystok et al. (2003) reaction times from the Simon Task, Peabody Picture Vocabulary Test, Raven's standard progressive matrices, Alpha span Task and Sequence Span Task were measured to determine whether the bilingual advantage persists for adults and whether bilingualism attenuates some of the negative effects of aging on cognitive control. Three studies were conducted with groups of younger adults ranging from 38-43 years (mean age 41.25 years) and older adults ranging from 70-72 years (mean age = 71.1 years). Participants were English monolinguals and bilingual participants who spoke diverse second languages such as French, Tamil and Cantonese. The results revealed that even though all participants were comparable on measures of verbal and spatial intelligence, bilinguals were consistently faster in the Simon Task on both congruent and incongruent trials. Most importantly, the older bilingual adults' measurements showed a reduction on the age-related increase in the Simon effect, which implies that the lifelong experience of using two or more languages attenuates the age-related decline in the efficiency of certain cognitive functions.

In Bialystok & Barac (2012), two studies were conducted using the Peabody Picture Vocabulary Test, Wug Test, Flanker Test and Task Switching to measure children's performance on executive control tasks. Monolingual and bilingual children from grade 2 to 5 were timed in order to test their performance on executive control

tasks. The first study tested Hebrew monolinguals and Hebrew-English/Russian-English bilinguals while the second study tested English monolinguals and French-English bilinguals. Results from the first study revealed significant contributions from age, intelligence, and English Vocabulary. On the other hand, for the second study, age was not significant, but metalinguistic performance improved when knowledge of the language increased. Furthermore, with an increased experience in a bilingual educational environment, executive control improved as well.

Other studies were conducted in order to support the bilingual cognitive advantage hypothesis using the Flanker Test. In Costa et al. (2009), reaction times in the Flanker Test were measured to explore in detail the bilingual advantage in conflict resolution tasks. 244 American undergraduate psychology students were tested in two different studies. Overall, bilinguals showed faster reaction times than monolinguals. An effect of bilingual advantage was found but only in the high-monitoring condition. Furthermore, bilinguals outperformed monolinguals only when the participant dealt with several different monitoring resources. From the results, it was concluded that bilingualism might affect monitoring processes in executive control.

Luo et al. (2010) used a series of tests to analyze executive control in bilinguals, as well as their verbal fluency performance. The study aimed to examine the differences between monolinguals and bilinguals in their executive control and their performance on the category and letter fluency tests. Sixty young adults were separated in two groups of bilinguals and one group of monolinguals. The three groups were tested with the Peabody

Picture Vocabulary Test, Expressive Vocabulary Task, Spatial Span subtest from the Wechsler, Memory Scale, Catell Culture Fair Test, and the Verbal Fluency Test from the Delis-Kaplan Executive Function. Bilinguals and monolinguals were tested in English even though participants spoke different languages, such as French, Cantonese, Hebrew, Hindi, Italian and Punjabi. Mixed results were founded. Bilinguals outperformed monolinguals when the vocabulary was controlled, but no group difference was found in category fluency. Monolinguals outperformed bilinguals in the Catell Culture Fair Test.

A longitudinal study was conducted by Ljungberg et al. (2013) to investigate bilingual advantages on episodic memory recall, verbal letter and categorical fluency. A total of 178 monolinguals and bilinguals between 35-70 years (mean= 49.9 years) were tested on several recall tasks, category recall of nouns and focused attention, letter fluency, category fluency, and WAIS-R block design. Monolinguals spoke Swedish and bilinguals spoke Swedish and English. Results from the study showed a bilingual advantage in the verbal episodic recall; the bilingual advantage was observed across age as well. They concluded that bilinguals outperformed monolinguals in this type of task across all ages. On the other hand, no bilingual advantages were found in the categorical fluency task. From this study, two important conclusions were established. First, living in a society where the second language is used daily is not a crucial condition to observe a bilingual advantage. Second, being fluent in a second language might optimize memory performance over the lifespan.

Counter arguments to the bilingual cognitive advantage hypothesis. In order to further explore the BCA, a study was conducted to observe the extent of the bilingual advantage in three different tasks (Gathercole et al. (2014). Welsh-English bilinguals and English monolinguals were tested on three different sets of cognitive and executive function tasks. Participants were aged from 3 years through older adults. 650 participants were tested on card sorting, 557 on the Simon Task and 354 on a metalinguistic judgment task. Results revealed little support for the bilingual advantage. There was no difference in performance across groups. Rather than a bilingual advantage, on some occasions there was in fact better performance by monolinguals or persons dominant in the language tested. The results across the Simon tasks revealed that there was little evidence of a bilingual advantage either in accuracy of performance or in reaction times. The English monolingual group performed better or faster than the bilingual groups. Ultimately, the three sets of executive function tests failed to provide evidence for a bilingual advantage.

Kousaie et al. (2012) presented an investigation that further examines the bilingual advantage using three different tasks. In this study the Simon Task, the Stroop Task and the Eriksen Flanker Task were applied to 56 highly proficient young adults. 25 monolinguals and 26 bilinguals completed the three tasks while electrophysiological recording took place. A bilingual advantage was examined in the three different tasks using both behavioral (reaction time (RT) and accuracy) and electrophysiological (event-related brain potentials, or ERPs) measures. The electrophysiological measures permit the examination of bilingualism-related differences in the neural responses that are associated with the performance of the three tasks. Results revealed a variation in brain

responses across the three tasks. Consequently, there were no language group differences on any of the tasks for the behavioral category. On the other hand, the ERP measures indicated differences between monolinguals and bilinguals on conflict monitoring, resource allocation, stimulus organization, and error processing. However, these differences were not consistent throughout the three tasks. Therefore, a bilingual advantage was not found for the study.

In Paap et al.(2013), three studies compared bilinguals and monolinguals on 15 indicators of executive processing (EP). Each of the three studies includes a series of seven or eight activities. The tasks tested include Antisaccade, Simon, Flanker, Eriksen Flanker Test and Color-Shape switching. Between 90 and 110 psychology student participated in each test. Results revealed that there was no evidence for a bilingual advantage in either inhibitory control or monitoring, no trends for an early bilingual advantage and no support for the hypothesis that the most highly fluent bilingual in the sample enjoy an advantage in either inhibitory control or monitoring. Furthermore, there were no global reaction time (RT) advantages in the Simon tests, and there was no advantage in the Flanker test as well. Paap suggested that individual studies tend to use only one task and one indicator for each executive process component; as a result, there is no test that converge validity.

Several researchers believe that the bilingual advantage is restricted to certain types of bilinguals or depend on specific bilingual experiences. In Paap et al.(2014), a study was conducted in order to show there is no bilingual advantage in executive

processing. The participant pool consisted of 168 bilinguals and 216 monolinguals. The study analyzed differences in: 1) age of acquiring a second language, 2) the relative proficiency of the second language and 3) the number of languages used. Four nonverbal tasks were tested from which 12 different measures of executive functioning were evaluated. Participants were tested on Antisaccade task, Flanker task, Simon Task and Switching task. With each task, no consistent evidence supporting the bilingual advantage was found in either early bilingualism, highly fluent bilingualism or trilingualism.

Many other researchers have studied the bilingual advantage and concluded the bilingual advantage in inhibitory control is rare. That is the case of Hilchey and Klein (2011), in which 31 experiments were conducted and in which no positive evidence for a bilingual advantage in inhibitory control was observed in children or young adults. Moreover, the lack of evidence of a bilingual advantage in inhibitory control has been consistent with neuroscience work. For example, Branzi et. al (2014) reported that highly proficient bilinguals sometimes show differences in language control compared to less proficient bilinguals, however these differences do not rely on inhibitory mechanisms.

For the present project, 21 studies were reviewed in order to further examine evidence supporting as well as opposing the bilingual advantage hypothesis (see Appendix E). In order to observe a bilingual advantage, different tasks that measure executive function were applied to participants. The Simon Task was used 11 times, the Stroop test 4 times, the Antisaccade 5 times and the Flanker Task 6 times. These tasks, among others, are designed to measure executive function through the need to control and

resolve conflict to maintain accuracy. As shown, eight studies found evidence that the bilingual advantage exists. On the contrary, nine of the studies indicated no bilingual advantage. Furthermore, in four studies, both an advantage and a disadvantage for bilinguals was found depending on the task that the participants performed.

Tasks commonly used in BCA research

Several tasks are used as indicators of executive function. The most common tasks used by researchers are the Simon Task, Stroop Task, Flanker Task and Working Memory Task, each of which will be described to further understand the design of some of the studies mentioned above. Moreover, in several studies bilinguals showed an inferior performance in tasks that require lexical access, such as picture naming tasks (as used for example in Gollan et al., 2005). Additionally, studies have pointed to a bilingual disadvantage on verbal memory tasks (Gollan et al. 2002). On the other hand, bilinguals showed a superior performance in nonverbal cognitive tasks of executive functioning (Bialystok et al., 2004).

Simon task. The Simon Task has been related to bilingualism for decades (Simon and Rudell, 1967). In the Simon Task the participant is asked to press a button on the left in response to one stimulus or on the right in response to a different stimulus, regardless of the location of either stimulus. The Simon Task measures response selection, response execution and response conflict, among other processes. There are several variations of the Simon Tasks, however they vary along two dimensions only, color and position. Even so, for task performance testing only color is relevant. Congruent and incongruent trials

are obtained if the location of the stimulus is moved (e.g. stimulus on the right vs. the left of the screen). A congruent trial happens when both stimuli appear on the same side of the screen, whereas an incongruent trial happens when stimuli appear on both sides of the screen, therefore the irrelevant stimulus must be ignored in order to respond correctly. The Simon effect indicates an increase in reaction time (RT) on incongruent trials in relation to the congruent trials. Bilinguals have shown smaller Simon effects (Bialystok, 2006; Bialystok, 2004), which suggest that bilinguals have a better perceptual conflict relative to monolinguals.

Stroop task. The Stroop Task (Stroop, 1935) requires the participant to name the font color of a word as quickly as possible, when the word itself denotes a color (e.g., if the word BLUE is written in green letters). The task also includes a control condition in which participants read color words written in black letters (e.g., if the word BLUE is written in black letters). The Stroop effect refers to the difference in reaction time (RT) between naming font colors and reading color words. The Stroop Task represents a learned response in which the participant has to process a word's meaning while ignoring its physical component. The task measures processing speed and selective attention, among other processes. Like the Simon Task, the Stroop Task is related to the ability to respond to certain stimuli while ignoring others. By using the Stroop Task, an individual's cognitive processing speed and attentional capacity can be determined. In one study (Bialystok et al. 2008), younger and older monolingual adults showed a greater

Stroop effect related to bilinguals. Recent studies showed that bilinguals are more efficient at interference suppression than monolinguals (Zied et al.,2004).

Flanker task. The Flanker Task measures resistance to distractor interference, response conflict, and response execution, among other processes. In the Flanker Task, the participant must indicate the direction in which a target arrow is pointing when it is flanked by other arrows. These so-called flanker arrows are intended to impede or facilitate the indication of the target arrow's direction. A congruent trial occurs when the target arrow is flanked by other arrows all pointing in the same direction as the target arrow. An incongruent trial occurs when the target arrow is flanked by arrows which are pointing in a different direction than the target arrow. In general, RTs to incongruent trials are slower relative to congruent trials. One study (Costa et al., 2008) showed reduced conflict effect for bilinguals in relation to monolinguals. Additionally, bilinguals were faster in both congruent and incongruent trials while performing the Flanker task in general. It has been suggested (Bialystok, Craik and Ryan, 2006) that this effect may impact bilingualism in cognitive processes other than conflict resolution.

Operation span task. The Operation Span Task is thought to measure working memory and attentional focusing. In the Operation Span Task, the participant is asked to perform a simple mathematical operation and then read a word, with a word recall test following. The 'operation span' refers to the maximum number of words that can be recalled. The behavioral indicators (specific quantitative or qualitative variables recorded for analysis) for this task are accuracy and number or percentage of words remembered. For instance, in one study (Prior & MacWhinney, 2009), the Operation Span Task was administered to

measure working memory capacity between monolinguals and bilinguals. The study found no difference between monolinguals and bilinguals on either the mathematical or the verbal components of the task.

Analysis: While there is evidence to support the existence of a BCA, there is also compelling counter evidence suggesting that a BCA, at least as described by Bialystok and her colleagues, may not in fact exist. The field clearly needs additional studies in order to broaden the database with respect to bilingual performance on tasks commonly used in studies exploring the BCA. Further consideration of the studies investigating the BCA also points to their use of participants with a variety of L1 backgrounds (i.e., no effort was made to control for the participants' first language), and to their use of the English language for prompts in the experiment and for background questionnaires and otherwise testing all participants in English. This design feature means that in most previous studies, bilingual participants were tested in their second and/or non-dominant language. As the possible effects of this design characteristic have not been explored and are thus unknown, the present study will follow Boudros (2017) and control for participants' first and second languages, and use prompts both within the experiment and in the questionnaires which are identical translations between participants' first and second languages. Thus, in contrast to virtually all existing BCA studies (again, with Boudros 2017 being the sole exception), participants in the present study will in all cases be tested in their language of choice. Finally, since Spanish has not been a language which has figured prominently in BCA research, the present study will feature Spanish monolinguals for controls together with Spanish-English bilinguals.

II. Methodology

In order to obtain evidence of beneficial cognitive effects in bilinguals, Spanish monolinguals and Spanish-English bilinguals were recruited and asked to complete a Language Proficiency Questionnaire followed by two non-verbal tasks that involve executive function. Both tasks, Simon and Flanker, measure executive function as well as inhibitory control.

It has been suggested that individual studies tend to use only one task and one indicator for each executive process component and, as a result, there is no possibility of obtaining converging evidence (Paap et. al 2016). It has also been claimed that many studies have small numbers of participants and few items used in the experiments. Additionally, many studies compare monolinguals and bilinguals who vary in many ways besides the number of languages they speak, for example, they vary in nationality, education level, socioeconomic background, immigrant status, and cultural traits. After a careful review of the issues raised by researchers who do not support the BCA, and after failing to find a study that specifically considered Spanish speakers, the present study was designed to control for several of these factors by testing monolingual and bilingual participants who are native Spanish speakers, who have lived in México and who have similar socioeconomic backgrounds and levels of education.

Recently, numerous researchers have associated bilinguals with superior performance on tasks that measure executive function (Bialystok 2007, 2009). Evidence for this belief has been deduced from tasks including the Simon Task (Bialystok 2006;

Bialystok et al. 2004) and the Flanker Task (Bialystok et al. 2012.) These tasks, among others, are preferred because of the need to control and resolve conflict to maintain accuracy. Although there is not one task capable of isolating only one aspect of executive function, there are tasks that are useful indicators of certain aspects of it (Boudros 2017). For example, the Simon task is thought to index inhibitory control without the involvement of a linguistic component (Bialystok et al., 2004; 2008).

Hypothesis

If bilinguals indeed possess certain cognitive advantages compared to monolinguals, then Spanish-English bilinguals should produce faster reaction times (RT) than monolinguals in two tasks, the Simon and Flanker Tasks, both of which are frequently used in published studies as proxy measures of executive function.

Recruitment

A recruitment email was distributed to the researcher's personal and professional network in Mexico via email. The recruitment message included a brief description of the project and a request to participate should they posses the necessary requirements. Instructions indicated the participants who were Spanish monolinguals or Spanish-English bilinguals to take the survey by clicking on a link, which directed them to a questionnaire powered by Qualtrics. The message, which was composed in Spanish, clearly stated that participation was completely voluntary, and furthermore did not request any personally identifiable information. (See Appendix C)

Participants

Participants consisted of 8 Spanish monolinguals and 44 Spanish-English bilinguals who were between 23-63 years old and who lived in Mexico. Participants were native Spanish speakers whose second language was English. Several of them spoke other languages including: French, Italian, German, Portuguese and Japanese. However, multi-linguals were grouped with the bilinguals. Participants completed the survey protocol independently and remotely via Inquisit software (Please see Figure 1 for a classification of participants).

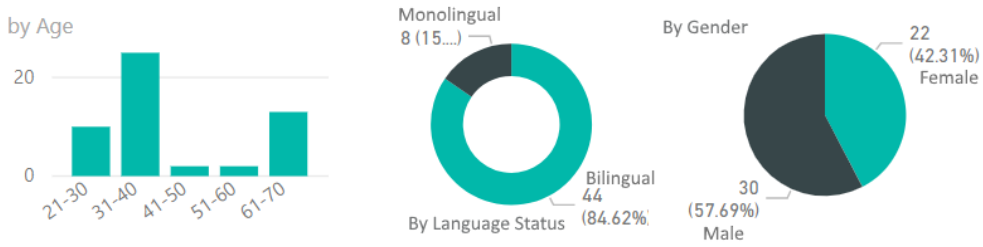


Figure 1. Classification of participants

Materials

After completing a Language Proficiency Questionnaire, participants were tested on two non-linguistic tasks, specifically the Simon and Flanker tasks. Previous studies have tested participants, both bilingual and monolingual, in English. To avoid any possible unwanted effects due to testing participants in their non-native language, this study tested all participants in their native language, which in this case was Spanish. A brief description of the Simon and the Flanker Tasks used in the present study, as well as

a description of the Language Proficiency Questionnaire and experiment generator Inquisit, is provided next.

Language Proficiency Questionnaire

The Language Proficiency Questionnaire was based on The Language Experience and Proficiency Questionnaire (LEAP-Q; Marian et al., 2007). The questionnaire was adapted for a web-based version using Qualtrics. This questionnaire incorporates various demographic questions including age, location, language acquisition information, self-rated proficiency, occupation, instrument and video game use, among others. (See Appendix A). It has been shown that self-rated language proficiency and usage are good predictors of a person's degree of bilingualism (Fishman & Cooper, 1969), and self-rated proficiency measures of various kinds have been widely used in bilingualism research (Boudros 2017). The questionnaire was designed to better understand the bilingual experience and active bilingualism as a predictor of performance, while also offering documentation of active years of bilingualism, analyses of self-rated proficiency, and documentation of socioeconomic background.

Very briefly, according to the questionnaire the bilingual participants demonstrated a range of intermediate to high level of proficiency in their second language. The average self-rated second language proficiency in speaking, reading and listening was around 70%. More than 50% of the participants have lived in other countries for an average of 3 years. Moreover, both monolingual and bilingual participants had similar socioeconomic background and level of education.

Simon Task

As mentioned before, the Simon Task measures response selection, response execution and response conflict, among other processes. In this study's version of the Simon Task, the participant is asked to press a button on the left in response to a stimulus of one color, and to press a button on the right in response to a different colored stimulus, regardless of the location of either stimulus. Specifically, the participant is asked to press the right shift button if a red square appears on the screen, regardless of the position of the square, or the left shift button if a blue square appears on the screen, also regardless of the position of the square. A trial is congruent when the stimulus appears on the same side of the screen as the button corresponding to its color. A trial is incongruent when the stimulus appears on the opposite side of the screen as the button corresponding to its color. (See Figure 2)

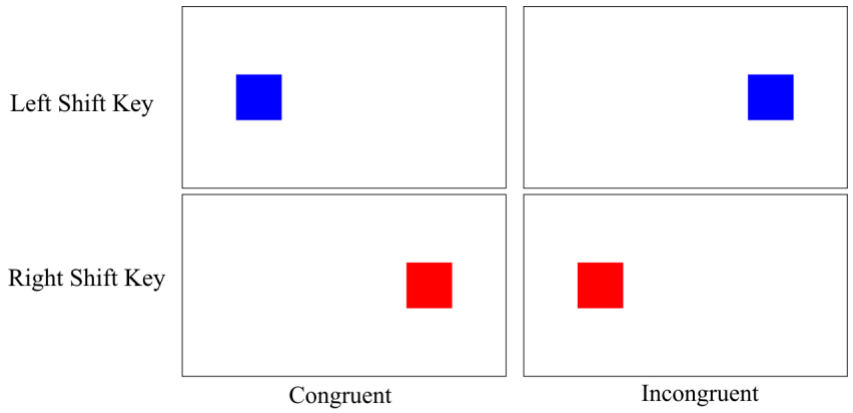


Figure 2. Illustration of Simon Task (congruent and incongruent trials)

The Simon effect is an increase in reaction time (RT) on incongruent trials relative to congruent trials. According to Bialystok, bilinguals have shown smaller Simon effects,

which suggest they have better perceptual conflict resolution relative to monolinguals. It is also the case however that as people age, they tend to have smaller Simon effects overall, meaning that the interference effect may decrease with age (Amso & Casey, 2009). An adapted version based on the original task by Simon and Wolf, 1963 was used in this project. The Simon portion consisted of a practice test followed by one block of 28 trials.

Flanker Task

As mentioned before, the Flanker Task measures resistance to distractor interference, response conflict and response execution, among other processes. In this study's version of the Flanker Task, the participant must indicate the direction of an arrow (the central arrow) surrounded by two arrows on each side. These other arrows are intended to either distract or facilitate the decision. A congruent trial occurs when the central arrow is presented with four other arrows pointing in the same direction. An incongruent trial occurs when the central arrow is pointing in a different direction than the other four arrows (See Figure 3). In general, response times are slower for incongruent trials. Furthermore, several studies have shown that bilinguals were faster in both congruent and incongruent trials, and have shown a reduced conflict effect for bilinguals in relation to monolinguals (Costa et al., 2008). An adapted version based on the original task by Eriksen and Eriksen (1974) was used in this project. The Flanker portion consisted of a practice test followed by one block of 100 trials.

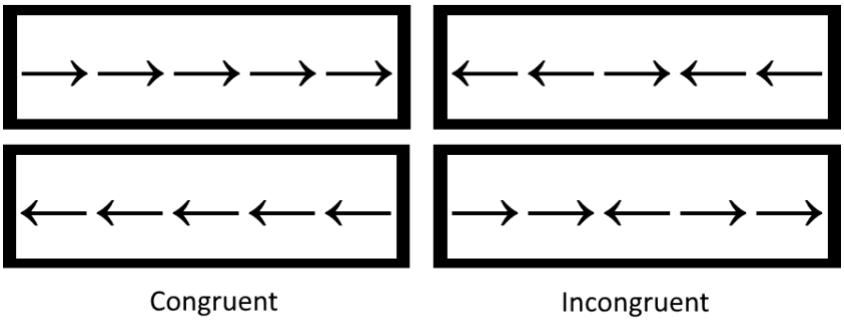


Figure 3. Illustration of Flanker Test (congruent and incongruent trials)

Design

After a careful review of several available studies conducted on the bilingual cognitive advantage (See Appendix F), the present study opted to use the Simon and Flanker tasks, with Reaction Time (RT) as the dependent variable, and Language Status as the independent variable. Language status had two levels: monolingual and bilingual. The experiment began with the Simon block, which consisted of 28 congruent and incongruent trials presented in random order. Half of the trials presented the target on the left with the other half of the targets presented on the right. Thus, the RTs obtained for the two levels of congruency (congruent versus incongruent) were based on one block of 28 trials. Immediately afterward, the Flanker portion followed with one block of 100 congruent and incongruent trials presented in random order. Both the Simon and the Flanker blocks were preceded by a practice test, which included two levels of congruency (congruent versus incongruent) as well.

Procedure

Recruitment of participants began after approval of this research project from the Institutional Review Board of Texas State University. An invitation for participation was sent via email to prospective participants, which included a brief explanation of the purpose of the research and a link to the survey. Upon agreement, the participants completed a language proficiency questionnaire via Qualtrics and both Simon and Flanker tasks via the online experiment generator Inquisit.

The email message contained instructions on how to start the survey and the estimated duration of all tasks. The researcher's email address and phone number were provided to answer any questions at any given time. It was made clear in the email message that participation was voluntary and participants could withdraw at any time. It was also stated that there was no collection of any personally identifiable data during the survey (Please see Appendices C & D for recruitment message). A link was provided to the Language Proficiency Questionnaire, which could be completed via PC, Mac, iPhone or iPad. After completing the questionnaire, the participants received specific instructions from the experiment generator Inquisit on how to download and install the Inquisit Player (or Inquisit Player App on iOS), which was required to run the Simon and Flanker tasks. Typically, research on the bilingual cognitive advantage has tested participants in English regardless of their first language (Bialystok et al., 2003, 2004, 2005, 2014; Paap et al., 2013, 2014). To avoid any possible unwanted effects due to testing participants in their non-native language and because the participants varied in their second language

proficiency, all protocols in this study were presented in the participants' native (and averred preferred) language, which in all cases was Spanish.

Language Proficiency Questionnaire

Participants completed a Language Proficiency Questionnaire, which included demographic questions, language acquisition questions and self-rated proficiency in the second language. The questionnaire provided valuable information for analysis of the participants' data.

The Language Proficiency Questionnaire included questions on the following (please see Appendices A & B for a complete view of the questionnaire):

- Age
- Gender
- Language Status
- Languages known (in order of dominance)
- Languages known (in order of acquisition)
- Percentage of time exposed to each language known
- Age of acquisition and fluency
- Years active in second language
- Self-rated language ability (speaking, listening comprehension, and reading)
- Countries lived in
- Occupation
- Travel frequency

- Reason for travel
- Education level
- Learning disabilities or impairments
- Video game use
- Musical instrument use

Once the Inquisit Player was installed, the following screen with specific instructions for the Simon task appeared (for expository purposes the following prompts are shown in English, however in the present study all were presented in Spanish as mentioned above). (Figures 4)

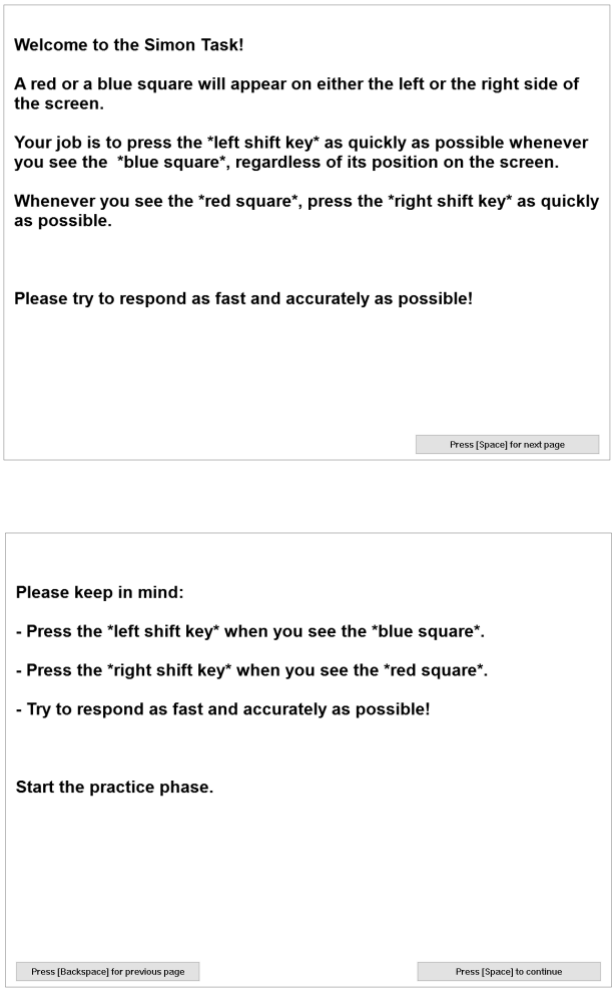
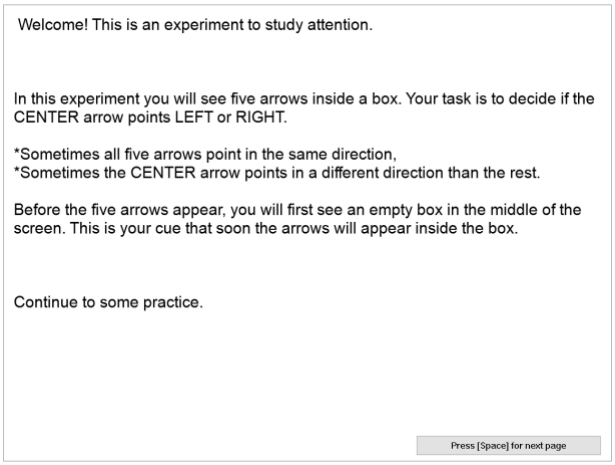


Figure 4. Inquisit Player instructions for Simon Task

After completion of the Simon task, the participant saw the following screen with specific instruction for the Flanker task (Figure 5).



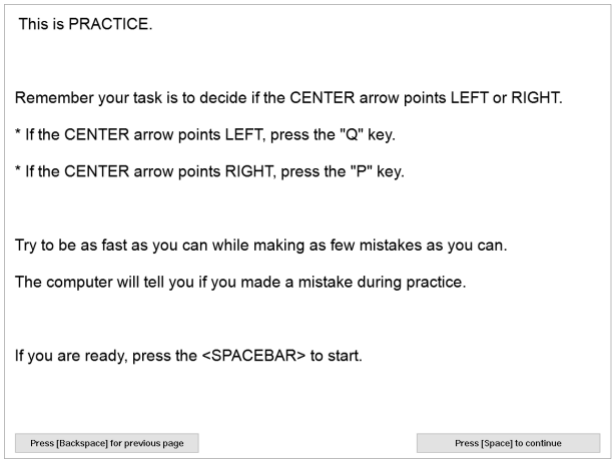


Figure 5. Inquisit Player instructions for Flanker Task

Once all tasks were completed the following message appeared. (Figure 6)

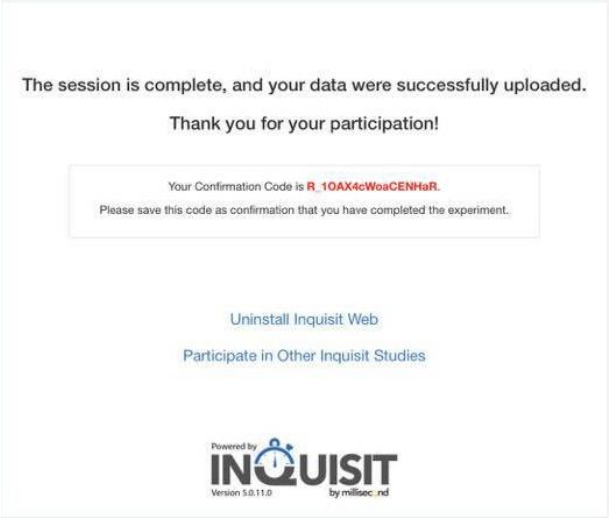


Figure 6. Message upon completion of survey

Technical Description of Data Gathering

In order to apply the Simon and Flanker protocol in an accurate, repeatable and reliable way, two online tools were used. The first, Qualtrics, is a survey creation and deployment tool available free to Texas State students. The second, Inquisit, is an extremely powerful script[1] based tool used for designing and deploying reaction timing

[1] Scripted code is code that is error checked then executed on a statement-by-statement basis. This is in contrast to compiled code whereby the entire body of code is error checked then compiled into a machine-readable program once and then executed multiple times. Compiled

tests over the internet available for a licensing fee. Qualtrics was used to deploy the Language Proficiency Questionnaire. Inquisit was used to administer the Simon and Flanker tasks.

Inquisit, developed by Millisecond Software, LLC, is a tool which is widely used in cognitive testing. Its popularity is attributed to its ability to greatly facilitate the measurement of reaction times with millisecond precision coupled with an easy to learn scripting platform. Inquisit has been used to collect psychological data in an extensive body of peer-reviewed research. It has also been applied in diverse research fields such as cognitive neuroscience, social, clinical, and forensic psychology, brain mapping, human computer interaction, etc.

While the scripts themselves do not run over the Internet due to the technical constraints involved in obtaining millisecond precision, the software can be easily downloaded and run on MacOS, Windows 7, 8 & 10 and iOS. Millisecond has an extensive library of known-good scripts available to use as is or to modify to suit specific

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code generally runs faster, but scripted code is more easily modifiable. A *script* can refer to one line of code or a file of many lines of code.

applications. Being such ubiquitous tests in this field, Flanker and Simon Task scripts were already available.

There were three main tasks to complete in order to conduct the study. First, the questionnaire and tasks instructions from the code were translated into Spanish. Second, a short script to call the Flanker and Simon Task scripts was written. And third, a method to link the questionnaire data to the Inquisit data was created.

Translation of the Language Proficiency Questionnaire was simply a matter of creating a second translated questionnaire, straightforward if only a bit time consuming. Translation of the Inquisit instructions while a bit more involved was also straightforward. This required combing through the scripts to identify and translate any text that a participant might see, including variations for touch devices. A third party verified all the translations to maximize effectiveness of the instructions and eliminate any potential for confusion.

The licensing model Millisecond Software for Inquisit necessitated the second task of writing a script to call the two tests. With an Inquisit Web license, which was purchased for this study, license holders may register only one script at a time. In other words, Millisecond will provide a link to only one script per license at any one time. However, that one registered script may call as many other scripts as the license holder would like. This made it possible to call both the Flanker and the Simon task with one license. A very short script that called the other tasks was registered, then all the code and support elements, such as images, was uploaded to the website.

The final task of linking the Qualtrics and Inquisit data was done in the following way. Each time a participant clicked the link to the Language Proficiency Questionnaire, Qualtrics generated a unique and random identifier to associate with that instance of the questionnaire. This identifier was then passed to Inquisit using a query string, which is a method of passing parameters from one website to another by appending to the URL a question mark as an operator, followed by the name of the parameter, followed by an equals sign and finally by the data itself. Using for example the query string URL"http://www.Example.com/?ParameterName=Parameter," the web server hosting Example.com will pull Parameter from the URL and use it to either modify how the webpage is displayed or interacted with by the user, or otherwise pass it along to an underlying program. For this study, the URL, https://mili2nd.co/fhhb was the link used to run the Simon and Flanker tasks in succession. When finishing the Qualtrics survey, the randomly generated identifier for that instance of the questionnaire, for example, R_1meD0EcI0Egk0Av, was appended to the URL as in the following: https://mili2nd.co/fhhb?SubjectID=R_1meD0EcI0Egk0Av. When the participant follows the link, which was automatic, the Millisecond server pulls R_1meD0EcI0Egk0Av from the URL and passes it to the Inquisit scripts for use as the SubjectID in both tests. This SubjectID is then embedded in all Inquisit data logging. Once data gathering was complete, the data were downloaded from both Qualtrics and Inquisit as several different files. These Inquisit data were then carefully associated with the corresponding Qualtrics data in MS Excel by matching the SubjectIDs.

For the Simon Task the following measures were obtained:

- Reaction times (RT) of correct trials (ms)
- Correct and incorrect trials
- Number of correct congruent and incongruent trials
- Mean RT of correct trials (ms)
- Mean RT congruent (ms)
- Mean RT incongruent (ms)
- Simon Effect (ms)

For the Flanker Task the following measures were obtained:

- Reaction times (RT) of correct trials (ms)
- Correct and incorrect trials
- Number of correct congruent and incongruent trials
- Mean RT of correct trials (ms)
- Mean RT congruent (ms)
- Mean RT incongruent (ms)

Compensation

The first thirty participants who provided a completion code were given a $100MXN Starbucks gift for having participated.

III. Results and Analyses

Simon Task Analyses

An ANOVA with Reaction Time (RT) as the dependent variable and Language Status (with two levels: Bilingual, and Monolingual) as the independent variable revealed a significant difference between RTs, $F(1, 51) = 49.02$, $p < .0001$, with bilinguals responding significantly faster than monolinguals (See Table 1, Figure 7). This finding suggests that overall, the bilinguals were significantly better able to cope with the Simon task than were the monolinguals.

Table 1. ANOVA analyses for Simon Task with Reaction Times (RT) as the dependent variable and language status as the independent variable

ANOVA Table

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	805693	805693	49.0168
Error	1360	22354428	16437	**Prob > F**
C. Total	1361	23160121		<.0001*

Means Table

Level	Std Error	Lower 95%	Upper 95%	Mean RT
Bilinguals	3.78	471	486	478
Monolinguals	8.76	528	562	545
Difference				67

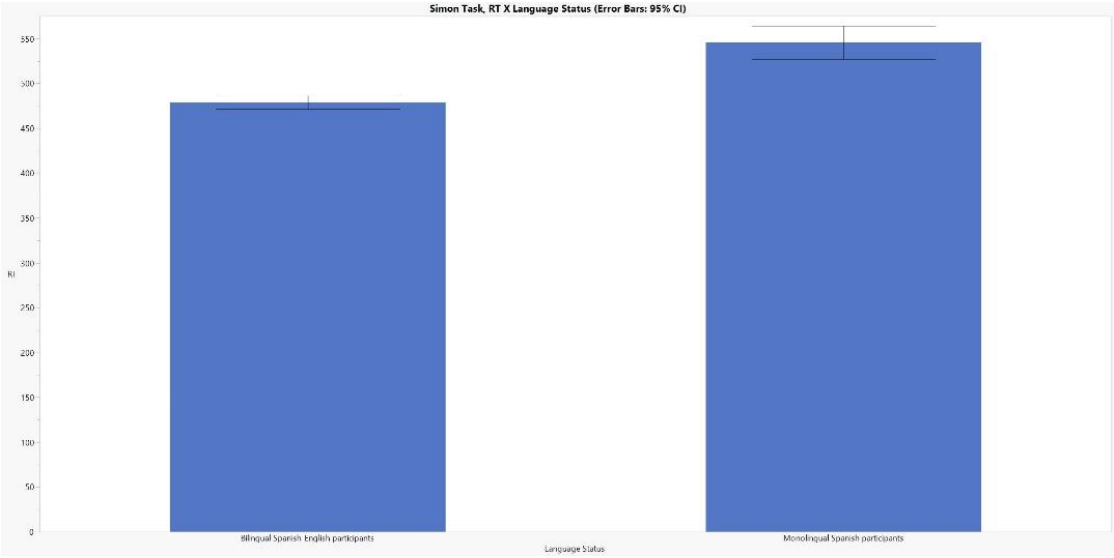

Figure 7. ANOVA analyses for Simon Task with Reaction Times (RT) as the dependent variable and language status as the independent variable

On average, the bilinguals responded faster on congruent trials (464 ms) than on incongruent trials (493 ms). This reaction time difference, or Simon effect, of 29 ms was significant, F (1, 43) = 14.7, p < .0001. On average, the monolinguals responded numerically faster on congruent trials (537 ms) than on incongruent trials (553 ms). However, this reaction time difference of 16 ms failed to reach significance (p > .3). On average, on congruent trials the bilinguals responded faster (464 ms) than the monolinguals (537 ms). This reaction time difference was significant, F (1, 51) = 25.3, p < .0001.Finally, and again on average, on incongruent trials the bilinguals responded faster (493 ms) than the monolinguals (553 ms). This reaction time difference was significant, F (1, 51) = 24.0, p = < .0001. (See Table 2, Figure 8)

These additional analyses indicate that the main initial finding that bilinguals were significantly faster overall was true for their performance in the Simon and for both congruent and incongruent trials.

Table 2. Reaction Time (RT) average for the Simon Task

Reaction Times

	Congruent (average)	Incongruent (average)	Difference	Significant
Monolinguals	464 ms	493 ms	29 ms	Yes
Bilinguals	537 ms	553 ms	16 ms	No
Difference	73 ms	60 ms		
Significant	Yes	Yes		

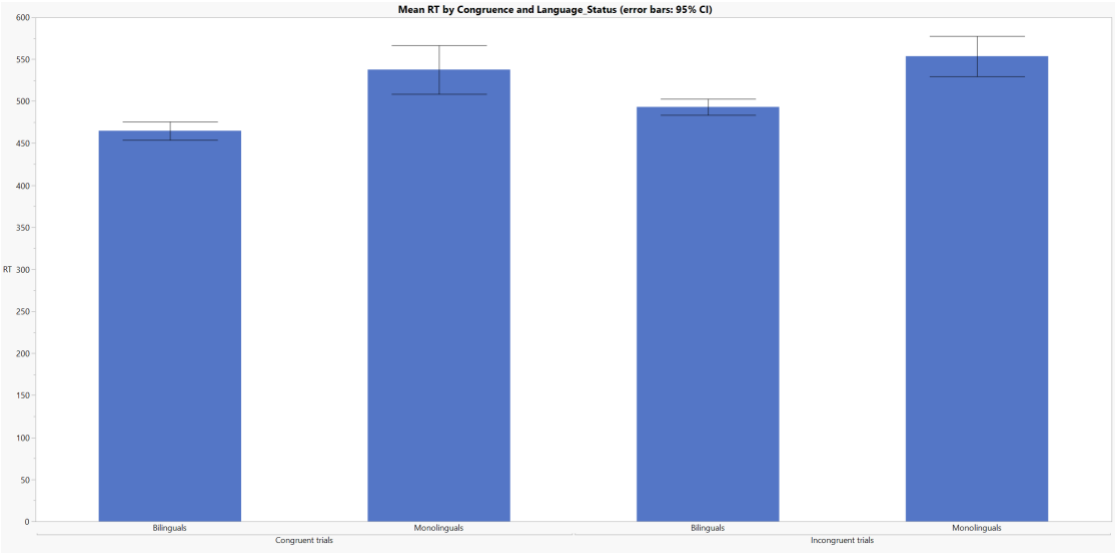

Figure 8. Reaction Time (RT) average for the Simon Task

Flanker Task Analyses

An ANOVA with RT as the dependent variable and Language Status (with two levels: Bilingual, and Monolingual) as the independent variable revealed a significant difference between RTs, $F(1, 51) = 9.68$, $p = .002$, with bilinguals responding significantly faster than monolinguals. This finding suggests that overall, the bilinguals were significantly better able to cope with the Flanker task than were the monolinguals (See Table 3, Figure 9).

Table 3. ANOVA analyses for Flanker Task with Reaction Times (RT) as the dependent variable and language status as the independent variable

ANOVA Table

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	261134	261134	9.6766
Error	5119	138142025	26986	**Prob > F**
C. Total	5120	138403159		0.0019*

Means Table

Language Status	Std Error	Lower 95%	Upper 95%	Mean RT
Bilinguals	2.49	520	530	525
Monolinguals	5.84	533	556	545
Difference				20

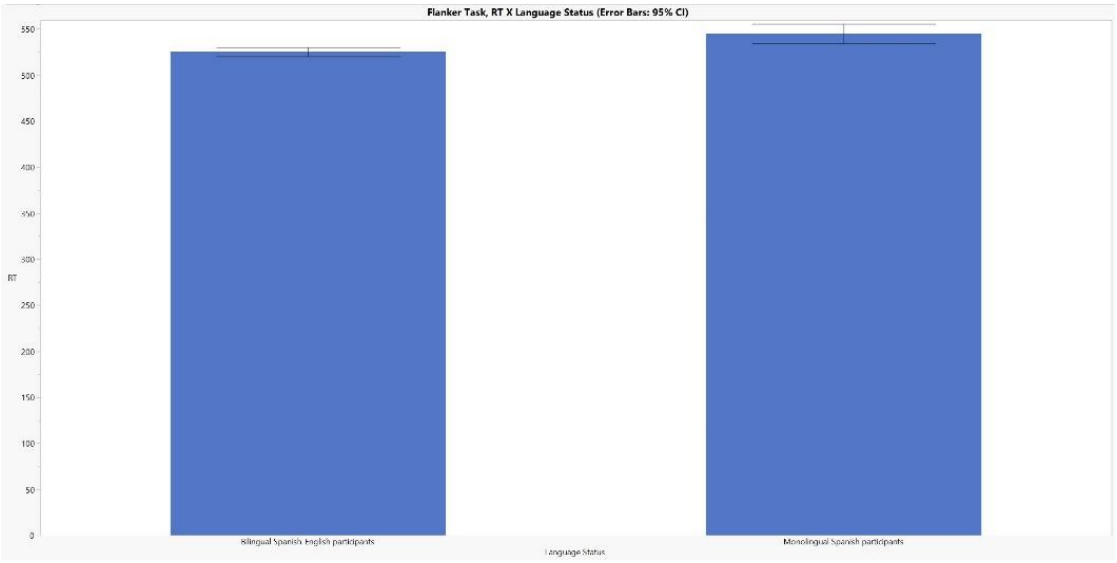

Figure 9. ANOVA analyses for Flanker Task with Reaction Times (RT) as the dependent variable and language status as the independent variable

Additional analyses revealed that on average, the bilinguals responded faster on congruent trials (496 ms) than on incongruent trials (555 ms). This reaction time difference of 59 ms was significant, F (1, 43) = 141.3, p < .0001. On average, the monolinguals responded faster on congruent trials (522 ms) than on incongruent trials (567 ms). This reaction time difference of 45 ms was significant, F (1, 7) = 17.3, p < .0001. On average, on congruent trials the bilinguals responded faster (496 ms) than the monolinguals (522 ms). This reaction time difference of 26 ms was significant, F (1, 51) = 10.5, p = .001. Finally, on average, on incongruent trials the bilinguals responded numerically faster (555 ms) than the monolinguals (567 ms). However, this reaction time difference of 12 ms failed to reach significance (p = .18) (see Table 4, Figure 10 below). These additional analyses indicate that while the bilinguals might have been significantly

faster overall, their reaction time advantage did not extend to incongruent trials in the Flanker, where they were numerically faster on average but not significantly so.

Table 4. Reaction Time (RT) average for the Flanker Task

Reaction Times				
	Congruent (average)	Incongruent (average)	Difference	Significant
Monolinguals	522 ms	567 ms	45 ms	Yes
Bilinguals	496 ms	555 ms	59 ms	Yes
Difference	26 ms	12 ms		
Significant	Yes	No		

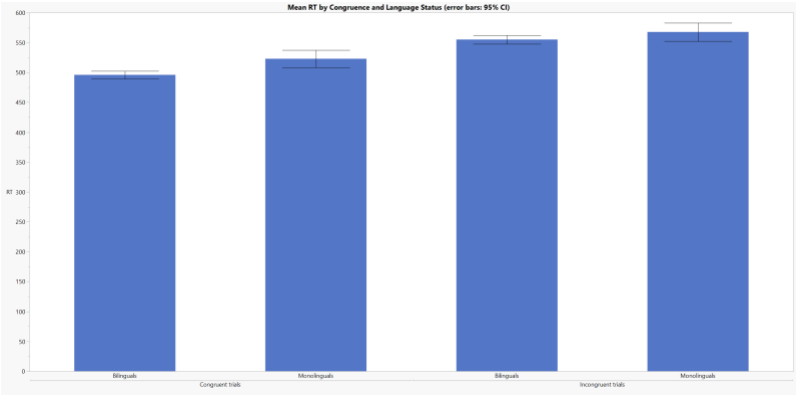

Figure 10. Reaction Time (RT) average for the Flanker Task

Errors

A strong version of a bilingual advantage hypothesis would hold that bilinguals would be both faster and more accurate than monolinguals. In this study, however,

monolinguals committed fewer errors than bilinguals in total, on average, and when compared to a random sampling of bilinguals. Thus, findings do not support a strong version of the bilingual advantage hypothesis. (See Table 5)

Table 5. Number or errors and average errors for monolinguals and bilinguals in the Simon and Flanker Tasks

Errors		
	Number of Errors	Average
Simon Task		
Monolinguals	10	1.25
Bilinguals	84	1.9
Flanker Task		
Monolinguals	11	1.38
Bilinguals	68	1.54
Simon Task (Random sampling of participants)		
Monolinguals	10	1.25
Bilinguals	10	1.25
Flanker Task (Random sampling of participants)		
Monolinguals	11	1.38
Bilinguals	13	1.63

Power BI Analysis

Power BI was used for a deeper analysis of the data gathered from the Language Proficiency Questionnaire and the Simon and Flanker Tasks. Power BI is an analytical tool, which can deliver insights using data from throughout the study. It has the ability to connect hundreds of data sources, simplify data and drive ad hoc analysis, which allows the user to answer specific questions. Because Power BI is a cloud-based analytical tool, it enables anyone to connect, visualize and analyze data with great speed. In the present study, Power BI was used to visualize data from the questionnaire as well as data collected from Inquisit. For instance, age was broken down into five different groups in order to compare Reaction Times (RT) and Mean RTs (Figure 11). Using (three interactive filters, age, gender and language status), the following specific information was provided by a Power BI analysis.

Figure 11. Power BI analysis of data gathered from the Language Proficiency Questionnaire

For the age group between 31-40 years, the average age of acquisition of the second language was 6.36 years of age, the average age of fluency was 13.05 years, the average age of listening comprehension was 7.56 years, and the average length of time speaking the second language was 23.68 years. (Figure 12)

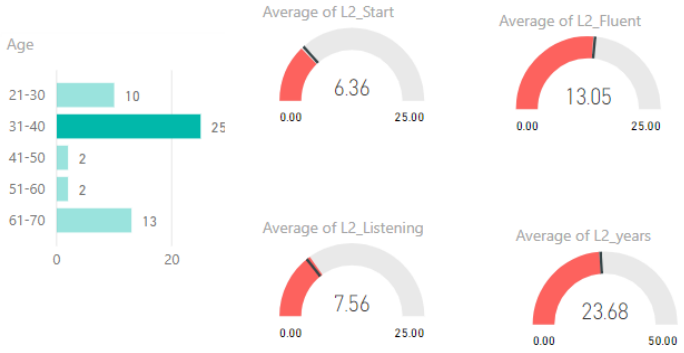

Figure 12. Average age of acquisition of the second language, average age of fluency, average age of listening comprehension and the average length of time speaking the second language in the age group between 31-40 years

For the age group between 21-30 years, the average age of acquisition of the second language was 6.11 years of age, the average age of fluency was 14.40 years, the average age of listening comprehension was 7.78 years, and the average length of time speaking the second language was 18 years. (Figure 13)

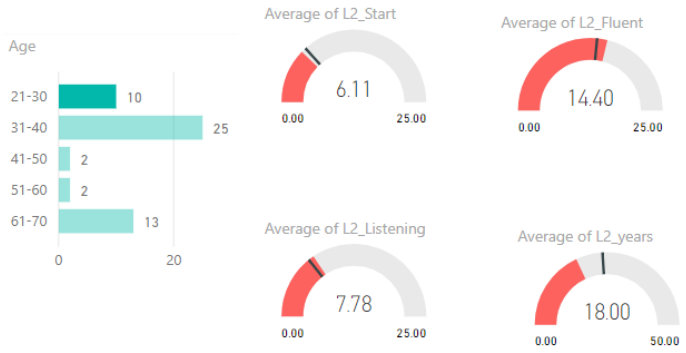

Figure 13. Average age of acquisition of the second language, average age of fluency, average age of listening comprehension, and average length of time speaking the second language for the age group between 21-30 years

As seen below, monolinguals had a smaller Simon Effect compared to their bilingual counterparts. (Figure 14)

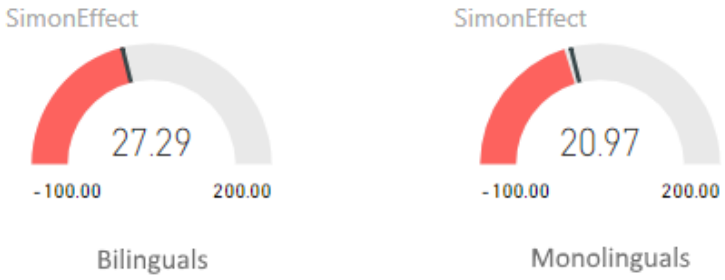

Figure 14. Average Simon Effect for bilinguals and monolinguals

From the analyses above, the following findings were obtained. Overall the bilinguals were significantly faster to respond in both the Simon and the Flanker task than were the monolinguals. Overall, therefore, the results of this study support the hypothesis that being bilingual does confer certain cognitive advantages. As such, its findings are

broadly in line with those reported in studies by Bialystok and her colleagues (See Bialystok et al.,2003, 2004; 2012). However, a strong version of the hypothesis was not supported because bilinguals failed to be both faster and more accurate than monolinguals, as reported in the errors section.

IV. Conclusions and Discussion

The aim of this study was to seek evidence of a cognitive advantage in bilinguals based on previous research that had either supported, or failed to support this hypothesis. More importantly, one of the purposes of this research was to contribute data from Spanish-English bilinguals, which had not yet been collected. The present study explored the hypothesis that if bilinguals possess certain cognitive advantages compared to their monolinguals counterparts, then Spanish-English bilinguals would produce faster Reaction Times (RT) than monolinguals in both the Simon and the Flanker tasks.

Findings

From the different analyses performed, the following findings were obtained:

- Overall, the Spanish-English bilinguals were significantly faster to respond in both the Simon and Flanker tasks than were the monolinguals. However, bilinguals were not significantly faster than monolinguals in the incongruent condition. Thus, the present study's findings are broadly in line with those reported in studies by Bialystok and her colleagues (see Bialystok et al.2003, 2004, 2012) and which were interpreted as evidence supporting the existence of a bilingual advantage.
- Overall, however, the monolinguals committed fewer errors compared to the bilinguals. Therefore, a strong version of the bilingual advantage hypothesis (according to which a bilingual would be both faster and less error-prone than a monolingual) was not supported by the results of the present study.

Future Research

Because research on the bilingual advantage is complicated by so many variables, future research incorporating additional tasks and controlling for more variables is necessary. The Language Proficiency Questionnaire combined with the Power BI analysis provides valuable information for future analysis. To further explore the bilingual cognitive advantage, several variables should be incorporated in the analysis. For example, age of second language (L2) acquisition, age of fluency in the L2, years of L2 use, self-rated proficiency in listening, reading and speaking, education level, and use of video games and/or musical instruments. These variables, among others, have been identified as important when exploring the BCA, therefore all of the analyses of the data in light of the variables mentioned above would be promising for future research (see Kroll & Bialystok 2013). Moreover, to further understand the BCA, thorough analysis and comparison of all available studies to understand why positive results are seen in some studies but not in others is required. For instance, for the present study, in the Flanker Task, the bilinguals were not significantly faster than monolinguals in the incongruent condition. However, previous studies have found that bilinguals were significantly faster in this condition. Additionally, contrary to predicted results, in the present study, the monolinguals had a smaller Simon effect compared to their bilingual counterparts. Bilingualism itself is a complex phenomenon; for this reason, research on the bilingual cognitive advantage has not yet provided definitive conclusions. Thus, much

closer analysis and contribution of more data is needed to better understand the reported effects.

The relationship between bilingualism and cognitive advantage is complicated on so many levels that the possibilities for future research are likely infinite. Both a better understanding of existing behavioral tasks, and the identification of new tasks which measure executive function, inhibitory control and/or comparable behavioral and attentional processes is crucial. Furthermore, two seemingly important questions to bear in mind for future research include the degree to which variation in a participant's second language abilities might influence the results, and whether the Simon Task and Flanker Task are the best means to measure purported effects of the bilingual cognitive advantage.

If validated, the significance of the bilingual advantage could have serious implications for education and welfare. Some possible benefits of a bilingual cognitive advantage include improvement of quality of life in older age, reduction of negative effects of aging on cognitive functions, improvement of cognitive performance in certain tasks, and a protective effect against dementia (Bialystok et al., 2012). Interest in the BCA has increased in recent years. Consequently, as new propositions on the bilingual advantage emerge, the need for new research also increases.

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Appendix A: Language Proficiency Questionnaire—English

Language Proficiency Questionnaire-English

Default Question Block

Date of Birth

_____

Age

_____

Gender

- ○ Male (1)
- ○ Female (2)

Do you speak more than one language?

- ○ Yes (1)
- ○ No (2)

Please list all the languages you know in order of dominance.

- ○ Language 1 (1) _____
- ○ Language 2 (2) _____
- ○ Language 3 (3) _____

Please list all the languages you know in order of acquisition (your native language first).

- ○ Language 1 (1) _____
- ○ Language 2 (2) _____
- ○ Language 3 (3) _____

Please list what percentage of the time you are currently and on average exposed to each of your languages (Your percentages should add up to 100%).

- ○ Language 1 (1) _____
- ○ Language 2 (2) _____
- ○ Language 3 (3) _____

Age when you:

- ○ Began acquiring your second language (1) _____
- ○ Became fluent in this language (2) _____
- ○ Became a fluent reader in this language (3) _____

How many years have you actively used your second language on a daily or near-daily basis?

_____

For each language-related ability, please choose your level of proficiency:

	Very Low (1)	Low (2)	Slightly less than adequate (3)	Adequate (4)	Slightly more than adequate (5)	Good (6)	Very Good (7)	Excellent (8)	Native-like (9)
Speaking (1)	○	○	○	○	○	○	○	○	○
Listening Comprehension (2)	○	○	○	○	○	○	○	○	○
Reading (3)	○	○	○	○	○	○	○	○	○

In which countries have you lived?

- Country 1 (1) _____
- Country 2 (2) _____
- Country 3 (3) _____

How many years have you lived in each country?

- Country 1 (1) _____
- Country 2 (2) _____
- Country 3 (3) _____

What is your current occupation?

_____

Have you traveled frequently to countries that predominately speak languages other than your native language?

- ○ Yes (1)
- ○ No (2)

Reason for frequent travel:

- ○ Pleasure (1)
- ○ Business (2)
- ○ To visit friends or family (3)
- ○ Other (4)

Please select your highest education level.

- ○ Less than High School (1)
- ○ High School (2)
- ○ Some college (3)
- ○ 2-year degree (4)
- ○ 4-year degree (5)
- ○ Masters (6)
- ○ Doctorate (7)
- ○ Other (8)

Have you ever had...

- ○ a vision problem (1)
- ○ a hearing impairment (2)
- ○ language disability (3)
- ○ learning disability (4)

Do you play video games frequently?

- ○ Yes (1)
- ○ No (2)

If you answered Yes to the previous question please indicate how many hours and how many days a week you play video games.

- ○ Days a Week (1) _____
- ○ Hours a Day (2) _____

Do you play a musical instrument frequently?

- ○ Yes (1)
- ○ No (2)

If you answered Yes to the previous question please indicate how many hours and how many days a week you play a musical instrument.

- ○ Days a Week (1) _____
- ○ Hours a Day (2) _____

End of Block

Appendix B: Language Proficiency Questionnaire—Spanish

Cuestionario de habilidad y dominio del lenguaje

Default Question Block

Fecha de nacimiento

_____

Edad

_____

Sexo

- ○ Hombre (1)
- ○ Mujer (2)

¿Te consideras bilingüe?

- ○ Sí (1)
- ○ No (2)

Enlista los idiomas que dominas por orden de fluidez:

- ○ Idioma 1 (1) _____
- ○ Idioma 2 (2) _____
- ○ Idioma 3 (3) _____

Enlista los idiomas que dominas por orden de adquisición (lengua materna primero)

- ○ Idioma 1 (1) _____
- ○ Idioma 2 (2) _____
- ○ Idioma 3 (3) _____

¿Qué porcentaje de tiempo estás expuesto a cada uno de los idiomas ? (los porcentajes deben sumar 100%)

- ○ Idioma 1 (1) _____
- ○ Idioma 2 (2) _____
- ○ Idioma 3 (3) _____

Edad en la que:

- ○ Empezaste a adquirir el segundo idioma (1) _____
- ○ Pudiste hablar este idioma con fluidez (2) _____
- ○ Pudiste leer sin problemas en este idioma (3) _____

¿Cuántos años llevas hablando el segundo idioma?

_____

Escoja el nivel de habilidad en las siguientes categorías:

	Ninguno (1)	Muy Bajo (2)	Bajo (3)	Poco menos que adecuado (4)	Adecuado (5)	Ligeramente más que adecuado (6)	Bueno (7)	Muy Bueno (8)	Excelente (9)
Oral (1)	○	○	○	○	○	○	○	○	○
Compresión auditiva (2)	○	○	○	○	○	○	○	○	○
Lectura (3)	○	○	○	○	○	○	○	○	○

En qué medida está expuesto a este idioma en las siguientes categorías:

	Nunca (1)	(2)	(3)	(4)	(5)	La mitad del tiempo (6)	(7)	(8)	(9)	(10)	Todo el tiempo (11)
Interactuando con amigos (1)	○	(	(	(	(	○	(	(	(	(	○
Interactuando con familiares (2)	○	(	(	(	(	○	(	(	(	(	○
Viendo Televisión (3)	○	(	(	(	(	○	(	(	(	(	○
Escuchando radio/música (4)	○	(	(	(	(	○	(	(	(	(	○
Leyendo (5)	○	(	(	(	(	○	(	(	(	(	○

¿En qué países has vivido y hasta qué edad?

- ○ País 1 (1) _____
- ○ País 2 (2) _____
- ○ País 3 (3) _____

¿Cuál es tu ocupación actual?

_____

¿Has viajado o viajas mucho?

- ○ Sí (1)
- ○ No (2)

¿Por qué has viajado o viajas mucho?

- ○ Por placer (1)
- ○ Por trabajo (2)
- ○ Para visitar familiares o amigos (3)
- ○ Otros (4)

¿Cuál es tu nivel de educación?

- ○ Escuela básica (secundaria y preparatoria) (1)
- ○ Estudios Universitarios (2)
- ○ Maestría (3)
- ○ Doctorado (4)

Alguna vez ha tenido:

- ○ Problemas de visión (1)
- ○ Problemas de oído (2)
- ○ Discapacidad de lenguaje (3)
- ○ Discapacidad en el aprendizaje (4)

¿Juegas video juegos con frecuencia?

- ○ Sí (1)
- ○ No (2)

Si contestaste sí a la pregunta anterior por favor indica cuántos días a la semana y cuántas horas juegas video juegos

- ○ Días a la semana (1) _____
- ○ Horas (2) _____

¿Tocas algún instrumento musical con frecuencia?

- ○ Sí (1)
- ○ No (2)

Si contestaste sí a la pregunta anterior por favor indica cuántos días a la semana y cuántas horas empleas tocando un instrument musical

- ○ Días a la semana (1) _____
- ○ Horas (2) _____

End of Block

Appendix C: Research Participation Invitation—English

To: [Participant's addresses]
From: gabyo@txstate.edu

BCC: [Use for email message to multiple addresses]

Subject: Research Participation Invitation: Cognitive Advantage in Bilinguals

This email message is an approved request for participation in research that has been approved or declared exempt by the Texas State Institutional Review Board (IRB).

Dear [participant's name],

My name is Gabriela O'Connor. I am writing to invite you to participate in my undergraduate research project for my Honor's Thesis at Texas State University in San Marcos, TX, USA. My project will attempt to find evidence of beneficial cognitive effects in bilinguals relative to monolinguals. You have been invited to participate because you are either a native Spanish speaker who has lived in Mexico for most or all of your life, or a bilingual speaker of both Spanish and English. Should you volunteer to take part in my study, you would be asked to answer a web-delivered Language Proficiency Questionnaire and complete two web-delivered standardized cognitive tasks. The total time of your participation would be approximately 20 minutes. In order to maintain your confidentiality as a participant in this study, you would not be asked to supply any personally identifiable information. As a token of my appreciation, the first 30 volunteers who complete all protocols will receive a $50MXN Starbucks gift card as special thanks for their valuable help.

To volunteer to participate in or to ask questions about this research, please contact me at:

gabyo@txstate.edu

Cell: 210-441-2201

This project 2017923 was approved by the Texas State IRB January 30, 2018. Pertinent questions or concerns about the research, research participants' rights, and/or research-related injuries to participants should be directed to the IRB chair, Dr. Jon Lasser 512-245-3413 – (lasser@txstate.edu) or to Monica Gonzales, IRB administrator 512-245-2314 - mailto:(meg201@txstate.edu).

Appendix D: Research Participation Invitation—Spanish

To: [correo del participante]
From: gabyo@txstate.edu

BCC: [Para enviar varios correos]

Subject: Invitación para participar en estudio: Ventajas cognitivas en bilingües

Este Email ha sido aprobado para su participación en este proyecto de investigación o ha sido declarado exento por Texas State Texas State Institutional Review Board (IRB).

Estimado [nombre del participante],

Mi nombre es Gabriela O'Connor. El motivo de este mensaje es invitarte a participar en mi proyecto de investigación para mi Tesis en Texas State University, la cual está ubicada en San Marcos, Texas. En este proyecto se intentará encontrar evidencia de efectos cognitivos beneficiosos en bilingües en relación a monolingües. Has sido seleccionado para participar por alguna de las siguientes razones: 1) eres monolingüe (hispanohablante nativo) y has vivido en México la mayor parte de tu vida o 2) eres una persona bilingüe que habla español e inglés. Si decides participar en mi proyecto de investigación, se te pedirá que contestes un cuestionario para conocer tu nivel de manejo de la lengua, así como completar un Test de habilidad cognitiva. El tiempo total de participación es de 20 minutos aproximadamente. Para mantener tu confidencialidad como participante en este estudio, no se te pedirá que proporciones información de identificación personal. Como muestra de mi agradecimiento, los primeros 30 voluntarios que completen el estudio recibirán una tarjeta de regalo de $ 100MXN de Starbucks por su valiosa ayuda.

Para participar en este estudio de click en este link:

https://txstate.co1.qualtrics.com/jfe/form/SV_6MbniE0rbmYTp2J

Si tiene preguntas acerca del mismo, por favor contáctame.

gabyo@txstate.edu

Cell: 210-441-2201

Este proyecto 2017923 ha sido aprobado por Texas State IRB el 30 de enero de 2018. Para preguntas o dudas acerca del proyecto de investigación, de sus derechos como participante, y/o lesiones relacionadas con la investigación hacia los participantes favor de dirigirse con el presidente del IRB Dr. Jon Lasser 512-245-3413 – (lasser@txstate.edu) o con Monica Gonzales, administradora IRB 512-245-2314 - mailto:(meg201@txstate.edu).

Appendix E: List of Studies on the BCA

Author	Paper	Abstract	Year	Tasks	# of Participants	Mean Age	Language of Participants	Results	Postive/ Negative
Bialystok, Craik, Klein and Viswanathan	Bilingualism, Aging, and Cogntive Control: Evidence From the Simon Task	The present research attempted to determine whether the bilingual advantage persists for adults and whether bilingualism attenuates the negative effects of aging on cognitive control in older adults using The Simon Task.	2003	Simon Task Peabody Picture Vocabulary Test Raven's Standard Progessive Matrices	Study 1: 40	43.0 years - 20 p 71.9 years - 20 p	English Tamil-English	All participants were comparable on measures of verbal and spatial intelligence, but bilinguals were consistently faster in the Simon Task.	P
				Simon Task Peabody Picture Vocabulary Tets Cattell Cultural Fair Intelligence Test Alpha span Task Sequencing span Task	Study 2: 94	42.6 years - 64 p 70.3 years - 30 p	English Tamil-English / Cantonese-English/ French-English	In the Simon conditions, the bilinguals were faster than the monolinguals on both the congruent and incongruent trials	
				Simon Task Peabody Picture Vocabulary Tets Cattell Cultural Fair Intelligence Test Alpha span Task Sequencing span Task	Study 3: 20	40.6 years - 10 p 38.8 years - 30 p	English French-English	Monolinguals and bilinguals who scored equivalently on a set of background measures examining memory and cognitive level differed in their performance on the Simon Task. In this case, however, the	

Author	Paper	Abstract	Year	Tasks	# of Participants	Mean Age	Language of Participants	Results	Postive/ Negative
								performances of the two groups eventually converged.	
Bialystok, Barac	Emerging bilingualism: Dissociating advantages for metalinguistic awareness and executive control	The present study revealed different factors associated with the reported advantages found in fully bilingual children for metalinguistic awareness and executive control. Level of proficiency in the language of testing was	2012	Peabody Picture Vocabulary Test Wug Test Flanker Test Task Switching	Study 1: 100	Children Grades 2 and 3	Hebrew Hebrew/Russian-English	For the metalinguistic task results showed significant contributions from age, intelligence, and English vocabulary. For the Flanker Test of executive control, showed significant contributions from age, degree of balanced bilingualism, and length of time spent in the biiingual educational environment.	P

Author	Paper	Abstract	Year	Tasks	# of Participants	Mean Age	Language of Participants	Results	Postive/ Negative
		related to performance on metalinguistic tasks and length of time in the immersion program was related to performance on executive control tasks.		Peabody Picture Vocabulary Test	Study 2: 80	Children Grades 2 and 5	English French-English	Age was not significant. Metalinguistic performance improved with increased knowledge of the language of testing and executive control performance improved with increased experience in bilingual education environment.	
Costa, Hernández, Costa-Faidella, Sebastián-Gallés	On the bilingual advantage in conflict processing: Now you see it, now you don't	The present study reports two experiments exploring more in detail the BA in conflict resolution tasks. In particular, we focus on the origin of the bilingual advantage on overall reaction times in the flanker task.	2009	Flanker Task	244	Undergraduate psychology students	English Other languages	An effect of bilingualism in overall reaction times was only present in the high-monitoring condition. Results reveal that when task at hand recruits a good deal of monitoring resources, bilinguals outperform monol. This suggests that bilingualism may affect the monitoring processes involved in executive control.	P

Author	Paper	Abstract	Year	Tasks	# of Participants	Mean Age	Language of Participants	Results	Postive/ Negative
Gathercole, Thomas, Kenedd y, Prys, Young, Guasch, Roberts, Hughes, Jones	Does language dominanc e affect cognitive performan ce in bilinguals ? Lifespan evidence from preschool ers through older adults on card sorting, Simon, and metalingu istic tasks	This study exlpores the extent to which a bilingual advantage can be observed for three tasks in an established population of fully fluent bilinguals from childhood through adulthood.	2014	Card Sorting Simon Test Metalinguistic judgment Task	650 557 354	Seven age groups from 3 to 60 years of age	English Welsh-English	Card sorting, Simon and metalinguistic judgment task reveal little support for a bilingual advantage, either in relation to control or globally. The lack of evidence for a bilingual advantage in these simultaneous and early sequential bilinguals suggests the need for much closer scrutiny of what type of bilingual might demosntrate the reported effects, under what conditions, and why.	N

Author	Paper	Abstract	Year	Tasks	# of Participants	Mean Age	Language of Participants	Results	Postive/ Negative
Kousaie , Phillips	Conflict monitoring and resolution : Are two languages better than one? Evidence from reaction time and event-related brain potencial	The present investigation further examines the bilingual advantage using three tasks, Stroop, Simon and Eriksen flanker task.	2012	Simon Stroop Task Eriksen Flanker Task	56	Young adults	Highly proficient Bilinguals	Behaviorally there were no language group differences on any of the tasks. The ERP measures demostrated differences between monolinguals and bilinguals with respect to conflict monitoring, resource allocation, stimulus organization, and error processing; however, these differences were not consistent across tasks. Given the similar behavioral perfomrance acrossthe groups the observed differences in brain responses may not represent an advantage for bilinguals.	N

Author	Paper	Abstract	Year	Tasks	# of Participants	Mean Age	Language of Participants	Results	Postive/ Negative
Luo, Luk, Bialystok	Effect of language proficiency and executive control on verbal fluency performance in bilinguals	We use a time-course analysis to examine the roles of vocabulary size and executive control in bilinguals' verbal fluency performance. Two bilinguals and a group of monolingual adults were tested in English with verbal fluency subtests from the Delis-Kaplan Executive Functon System. We hypothesized that the difference between the two bilingual groups in vocabulary and between the monolingual	2010	Peabody Picture Vocabulary Test Expressive Vocabulary Task Spatial Span subtest from the Wechsler Memeroy Scale Catell Culture Fair Test Verbal Fluency test from the Delis-Kaplan Executive Function	60	Young adults	English French/Cantonese/ Hebrew/ Hindi/Italian/Punjabi	The group difference in both tests was driven by the lower performance of the LV bilinguals. There was also a signficant group difference in Catell Culture Fair Test, with the monolinguals achieving higher standardized scores than the LV bilinguals, and the HV bilinguals not different from either group. No group difference was found in category fluency, but performance in letter fluency differed: bilingual outperformed monolinguals when vocabulary level was controlled.	P

Author	Paper	Abstract	Year	Tasks	# of Participants	Mean Age	Language of Participants	Results	Postive/ Negative
		and bilingual groups in executive control would lead to differences in performance on the category and letter fluency tests and dissociate the roles of vocabulary knowledge and executive control in verbal production.							

Author	Paper	Abstract	Year	Tasks	# of Participants	Mean Age	Language of Participants	Results	Postive/ Negative
Ljungberg, Hansson, Andrés, Josefsson and Nilsson	A Longitudinal Study of Memory Advantages in Bilinguals	This study longitudinally investigated bilingual advantages on episodic memory recall, verbal letter and categorical fluency during the trajectory of life.	2013	Recall Tasks: Recall of actions and sentences, Category recall of nouns and Recall focused attention Letter Fluency Cattegory Fluency WAIS-R Block Design	178	49.9 years	Swedish Swedish-English	The results from this longitudinal model showed a bilingual advantage in the performance of verbal episodic recall, and this benefit persisted across age. No interaction effect between the performance of the bilinguals and monolinguals and age was found indicating that during this period of life (35-85 years), bilinguals outperfomed monolinguals in this type of task the same across all ages.	P
Paap, Greenberg	There is no coherent evidence for a bilingual advantage in	Three studies compared bilinguals to monolinguals on 15 indicators of executive processing (EP). Most of	2013	Simon Task Color-shape switching Task Antisaccade Task Ravens advanced progressive matrices Task	Study 1: 90	College students	Englisgh Spanish/Cantonese/Mandarin/Tagalog	Simotn Task: Small but signtificant bilingual advantage in both Study 3 adn int he combined anaylisis (the effect sizes associated with these deisadvantages were	N

Author	Paper	Abstract	Year	Tasks	# of Participants	Mean Age	Language of Participants	Results	Postive/ Negative
	executive processing	the indicators compare a neutral or congurent baseline to a condition that should requiere EP. The critial marker for a bilingual advantage, Group x Condition interaction, was significant for only one indicator, but in a pattern indicative of a bilingual disadvantage.		Eriksen Flanker Task Trial Definition	Study 2: 86 Study 3: 110	College students College students		extremely small). There were no significant main effects (Global RT or accuracy differences) across the three studies and in two of the three cases the trend is toward a bilingual disadvantage. Flanker Test: there are no trends for an early bilingual advantage and each block shows a very small and non-significant bilingual disadvantage. Antisaccade Task: the differences in mean RT favor monolinguals, but the difference is non-significant. Switching Task: None of the group differences approached significance and the largest individual difference trends toward a bilingual	

Author	Paper	Abstract	Year	Tasks	# of Participants	Mean Age	Language of Participants	Results	Postive/ Negative
								disadvantage. Ravens advanced progressive matrices Task: The difference was not significant.	
Paap, Johnson, Sawi	Are bilingual advantages dependent upon specific tasks or specific bilingual experiences?	The present study takes a complementary approach by examining a sample that is quite homogeneous in terms of current life experiences, but heterogeneuous in terms of its exporsure to second languages. The composite database of 168	2014	Antisaccade Simon Task Flanker Task Colour-shape switching	384	College students	English Other languages	Across 12 different measures of executive function, derived from 4 different nonverbal tasks, there was no consistent evidence supporting the hyptheses that either early blingualism, highly fluent balanced bilingualsm, or trilingualism enhances inhibitory control, monitoring or switching.	N

Author	Paper	Abstract	Year	Tasks	# of Participants	Mean Age	Language of Participants	Results	Postive/ Negative
		blinguals and 216 monolinguals is used to explore for differeces based on: (1) age of acquiring a second languages, (2) the relative profiency of an L2 and (3) the number of languages used.							

Author	Paper	Abstract	Year	Tasks	# of Participants	Mean Age	Language of Participants	Results	Postive/ Negative
Prior, Macwhinney	A bilingual advantage in task switching	This study investigated the possibility that lifelong bilingualism may lead to enhanced efficiency in the ability to shift between mental sets. We compared the performance of monolingual and fluent bilingual college students in a task-switching paradigm.	2009	Peabody Picture Vocabulary Test Operation Span Task Color Flanker Task Simon Task	44	Psychology college students	English Mandarin/Cantonese/ Korean/ Spanish/Russian	Bilinguals incurred reduced switching costs in the task-switching paradigm whem compared with monolinguals, suggesting that lifelong experience in switching between languages may contribute to increased efficiency in the ability to shift flexibly between mental sets. On the other hand, bilinguals did not differ from monolinguals in the differential cost of performing mixed-tasks as opposed to single-task blocks. These results indicate that BA in executive function most likely extend beyond inhibition of competing responses, and encompass flexible mental shifting as well.	

Appendix F: Tasks used in BCA studies

Study	Task	Number of participants	Bilingual effect?
Bialystok et al. (2004)	Standard Simon Simon Task (4 colors: 2 to 1 stimulus-response mapping)	Study 1: 20 monolinguals 20 bilinguals Study 2: 47 monolinguals 47 bilinguals Study 3: 10 monolinguals 10 bilinguals	Y/N
Bialystok, Craik, et al. (2005)	Standard Simon	Study 1: 10- monolingual 19- bilingual	YES
Bialystok, Martin, and Viswanathan. (2005)	Standard Simon	Study 1: 17 monolinguals 17 bilinguals Study 2: 22 monolinguals 18 bilinguals Study 3: 80 monolinguals 112 bilinguals	YES
Bialystok (2006)	Standar Simon Spatial Stroop	Study 1: 48- monolingual 49- bilingual	NO
Bialystok et al. (2006)	Antisaccade Task	Study 1: 24- monolingual 24- bilingual	YES
Morton and Harper (2006)	Standard Simon	Study 1: 17- monolingual 17- bilingual	NO
Martin-Rhee and Bialystok (2008)	Standard Simon	Study 1: 17 monolinguals 17 bilinguals Study 2: 20 monolinguals 21 bilinguals Study 3: 19 monolinguals 13 bilinguals	Y/N
Bialystok et al. (2008)	Spatial Stroop Task	Study 1: 24- monolingual 24- bilingual	NO
Costa, Hernández, and Sebastián-Gallés (2008)	Antisaccade Task	Study 1: 100- monolingual 100- bilingual	YES

Carlson and Meltzoff (2008)	Antisaccade Task	Study 1: 17- monolingual 12- bilingual	NO
Colzato et al. (2008)	Stop Signal Task	Study 1: 16- monolingual 16- bilingual	NO
Costa, Hernández,Costa-Faidella, and Sebastián-Gallés (2008)	Antisaccade Task	Study 1: 60 monolinguals 60 bilinguals Study 2: 62 monolinguals 62 bilinguals	Y/N
Emmorey et al. (2009)	Flanker interference with a Simon component	Study 1: 15- monolingual 15- bilingual	YES
Prior and Macwhinney (2010)	Switching Flanker Task Simon Task	Study 1: 44- monolingual 44- bilingual	Y/N
Abutalebi et al. (2012)	Flanker	Study 1: 17 monolinguals 14 bilinguals Study 2: 17 monolinguals 14 bilinguals	YES
Duñabetia et al. (2012)	Numerical Congruency Vebal Stroop Task	Study 1: 252-monolingual 252- bilingual	NO
Engel de Abreu et al. (2012)	Flanker	Study 1: 40- monolingual 40- bilingual	YES
Kousaie and Phillips (2012)	Simon TaskFlanker Task	Study 1: 25 monolinguals 26 bilingualsStudy 2: 25 monolinguals 26 bilinguals	NO
Paap and Greenberg (2013)	Antisaccade Task Simon Task Switching Flanker	Study 1: 34 monolinguals 46 bilinguals Study 2: 36 monolinguals 50 bilinguals Study 3: 52 monolinguals 52 bilinguals	NO
Ljungberg, Hansson, Andrés, Josefsson, Nilsson (2013)	Letter Fluency Cattegory Fluency WAIS-R Block Design	Study 1: 74- monolingual 104- bilingual	YES

Gathercole et al. (2014)	Simon Task	Study 1: 148 monolinguals 60 bilinguals Study 2: 274 monolinguals 73 bilinguals	NO