2014

Examining the Intersection of the Cognitive Advantages and Disadvantages of the Bilingual Brain

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A Thesis Presented

by

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To the Keck Science Department

Of Claremont McKenna, Pitzer, and Scripps Colleges

In partial fulfillment of

The degree of Bachelor of Arts

Senior Thesis in Neuroscience

April 21, 2014

Table of Contents

Abstract

Two conflicting findings characterize cognitive processing accompanying bilingualism. The "bilingual advantage" refers to improved cognitive performance for bilingual compared to monolingual participants. Most bilingual advantages fall under the umbrella of cognitive control mechanisms, most frequently demonstrated using the Stroop task and the Simon task (e.g., Bialystok, 2008; Coderre, Van Heuven, & Conklin, 2013). The "bilingual disadvantage," on the other hand, refers to bilinguals' diminished performance on tasks that require word retrieval or switching between languages. This study examined the intersection of the bilingual advantage and the bilingual disadvantage to investigate whether they stem from a single cognitive control process. The bilingual advantage was measured as speech onset time differences between monolingual and bilingual participants in the Stroop task after being primed in the same language (i.e., English prime and English Stroop for monolinguals, and either English prime and English Stroop or Spanish prime and Spanish Stroop for bilinguals). The bilingual disadvantage was measured as differences in bilingual participants' speech onset times between the same-language conditions described above and cross-language conditions (i.e., either English prime and Spanish Stroop or Spanish prime and English Stroop). Monolinguals performed better than bilinguals did on the same-language Stroop [$F(3,1) = 83.5$, $p < 0.001$, $MSE = 15415$], so a bilingual advantage was not demonstrated. However, bilinguals did perform better in same-language blocks than cross-language blocks [$F(7,3) = 24.6$, $p < 0.001$, $MSE = 22648$]. This suggests that the current protocol successfully elicits the bilingual disadvantage. Further research is needed to evaluate whether the same cognitive control processes are responsible for the two effects. Possible extensions of this work include observing a larger number of participants to rule out between-subjects effects and using a button press rather than spoken response during the Stroop task.

Introduction

Over the past few decades, there has been an increase in research into bilingualism—the ability to speak, read, and comprehend more than one language. The differences in cognitive function that have been observed between bilingual and monolingual individuals have given insight into not only those processes directly related to language use, but also to those involved more broadly in cognition: e.g. memory, cognitive control, and attention, among others. Most of these differences have been categorized under "bilingual advantage" or "bilingual disadvantage"—positive and negative effects associated with knowing multiple languages. Although one could use the terms "monolingual disadvantage" and "monolingual advantage" to describe the same phenomena, the bilingual perspective is used throughout the literature and so is used in this thesis.

Because it is clear that both the bilingual advantage and the bilingual disadvantage occur as a result of knowing multiple languages, there is no denying that the two are related; however, the intersection of their cognitive pathways has not been widely studied. This thesis looks at the bilingual advantage within the context of the bilingual disadvantage in order to answer the question of whether the two result from the same cognitive effects of bilingualism. This is achieved through a novel experimental paradigm that combines the Stroop task, a task that has been canonically used to demonstrate increased cognitive control in bilinguals over monolinguals, with conditions in which bilingual participants are primed to one language and asked to complete a task in another. This forces the bilinguals to overcome global inhibition, one example of the bilingual disadvantage.

Historical Background

Bilingual vs. Monolingual Brain

In a recent review of methods in bilingualism research, Kroll and Bialystok state as given that “bilingualism alters the structure and function of the mind” (2013). The study of the cognitive advantages and disadvantages found in bilingual individuals, they argue, should be informed by this fact—it is not just that bilingual brains are different from monolingual brains; they are changed as a result of holding and using information about multiple languages. These changes occur at both the physiological and cognitive levels.

The most compelling evidence for physiological changes due to bilingualism comes from diffusion tensor imaging (DTI) studies, which allow researchers to view the structural organization of the brain; namely of white matter tracts. For example, in a study comparing adult monolingual English speakers with adult bilingual English-Spanish speakers Kuhl and colleagues found that the monolinguals had higher fractional anisotropy (a measure of directionality of diffusion believed to reflect levels of myelination and axon density in white matter) in the right posterior limb of the internal capsule, the right sagittal stratum, and the right thalamus than did bilinguals (2013). They also found increased radial diffusivity in the cerebellum, inferior frontal occipital fasciculus, and superior longitudinal fasciculus of the bilinguals. These differences in diffusivity, the authors argue, could be responsible for the flexibility often associated with the bilingual brain (see “Bilingual Advantage” and “Bilingual Disadvantage” sections below).

Importantly, white matter tract differences have been found not only between bilingual and monolingual adults, but also between bilingual and monolingual children—suggesting that these changes are a direct result of bilingualism rather than of learning that occurs later in life. Mohades and colleagues compared the left arcuate fasciculus/superior longitudinal fasciculus (lAF/lSLF), the left inferior occipitofrontal fasciculus (lIFOF), the bundle projecting from the corpus callosum to the orbital lobe (AC-OL), and the fibers that associate the premotor and motor cortices of the corpus callosum (AMB-PMC) in monolingual, simultaneous bilingual (those who were exposed to L1 and L2 at the same time), and sequential (those who learned L1 before being exposed to L2) bilingual children (2012). All of these areas are associated with various aspects of language use. Mohades et al. found that, while the fractional anisotropy of the three groups did not differ in the lAF/lSLF or the AMB-PMC tracts, the simultaneous bilinguals had higher fractional anisotropy in the lIFOF and lower fractional anisotropy in the AC-OL than did the monolinguals. Interestingly, the fractional anisotropy for these areas in sequential bilinguals fell in between those of the monolinguals and simultaneous bilinguals, although the difference did not reach significance. Since the bilingual groups were not matched for proficiency—the cut-off for language proficiency in any language on the Bilingual Aphasia Test was 50%—it is impossible to say what caused the white matter tracts of sequential bilinguals to differ from those of the simultaneous bilinguals.

It has also been shown that bilinguals recruit different brain regions when accessing their different languages. In a 2011 study, Garbin and colleagues used functional magnetic resonance imaging (fMRI) to look into the neural substrates of language control in speech production in early high-proficiency bilingual adults. A language switching paradigm was used: participants were asked to name images; a cue to respond in the first language (L1) or second language (L2) preceded each image. Data analysis focused on trials in which participants had to switch between languages. Garbin et al. found that, when switching from

L1 to L2, participants recruited the left caudate significantly more in switch trials than non-switch trials. However, when making the switch from L2 to L1, the supplementary motor area (SMA) and pre-SMA/anterior cingular cortex (ACC) cluster were recruited significantly more. The authors posit that the left caudate plays a role in language selection, whereas the SMA plays a role in inhibition. Neither of these processes is necessary during language production in the monolingual brain.

Differences in neural substrate recruitment for different languages within the same participants suggest that the differences in structure and function between bilingual and monolingual brains may be caused directly by the use of multiple languages. After all, if different neural pathways are recruited in order to use different languages, there is no way that organization in a brain that uses multiple languages can be the same as organization in a brain that uses only one. These organizational changes, in turn, lead directly to changes in function.

Bilingual Advantage

Because language use is not an isolated phenomenon in terms of cognition, it is unsurprising that the differences between monolingual and bilingual brains described above lead to differences in cognitive function—differences that have been well documented over the last few decades. Some of these differences, those that are considered a positive effect of bilingualism, have been labeled “the bilingual advantage.” While it would be difficult to quantify the distinct advantages associated with bilingualism, the majority of research has focused on functions associated with executive control, especially with regard to inhibition.

Indeed, bilinguals consistently outperform monolinguals on tasks that require inhibition of a more automatic process over a less automatic one. The tasks used most often to test this are the Simon task (e.g. Bialystok, 2008) and the Stroop task (Stroop, 1935). In the Simon Task, participants are asked to press a button in response to the color of a stimulus. Generally, response buttons are placed on opposite sides of the body; that is, the correct response to a blue stimulus might be a button press with the right hand, while the correct response to a red stimulus might be a button press with the left hand. Stimuli are then presented randomly with regard not only to color, but also location on the screen. Response times and error rates on trials for which the stimulus appears on the same side as its response button (matched) are compared to those trials for which the stimulus appears on the opposite side from its response button (unmatched). Because people associate sides of their body with corresponding directionality (i.e. left to left, right to right), but not to any particular color, the unmatched condition requires inhibition of that association. The bilingual advantage in the Simon task manifests as a smaller response time difference between the matched and unmatched conditions, as well as faster overall response times.

Participants must also respond to the color of a stimulus in the Stroop task. In this task, however, the inhibited process is reading. A stimulus consists of a color name written in ink the color of which may or may not match the word; participants are instructed to name the ink. Response times and error rates on trials where the word and ink match (congruent) are compared to those where the word and ink do not match (incongruent), since inhibition of reading is only required on incongruent trials. Differences in response times between congruent and incongruent conditions are referred to as the Stroop effect. The Stroop task has been used as a test of many aspects of executive control, with the size of the Stroop effect viewed as a proxy for executive control ability.

With regard to bilingualism in particular, many studies have shown that bilinguals outperform matched monolinguals on the regular Stroop task, having both a smaller Stroop effect and faster overall reaction times (see MacLeod, 1991 for a review). In fact, the bilingual advantage in the Stroop task is not questioned in the literature. Although Kroll and Bialystok argue that using this task as a measure of differences in inhibitive processes is an oversimplification of the underlying mechanisms (2013), the Stroop task has been repeatedly adapted in order to test processes specific to bilinguals, particularly those involved in inhibition. The paradigm used in the present study involves one such adaptation of the Stroop task.

As early as 1969, Preston and Lambert used a bilingual version of the Stroop task to show that bilinguals experience both intralingual and interlingual interference. In the intralingual condition, participants were asked to name colors in the same language as the stimuli were presented; in the interlingual condition, they were asked to name colors in the other language. Within each condition, reaction time differences between congruent and incongruent stimuli were used as a measure of interference. Preston and Lambert found that, while interference was present in both conditions, it was significantly higher in the intralingual conditions. This was some of the first evidence to support the "dual activation hypothesis"—that both languages are constantly active in the bilingual brain, and that the bilingual must suppress one language in order to produce the other (see Kroll, Bobb, Misra, & Guo, 2008 for a review).

Since 1969, many studies have offered support for the dual activation hypothesis. For example, a 2003 study by Marian and Spivey showed that lexical distractors from the non-target language interfered with bilinguals' reaction times even in a monolingual environment.

The sum of these and similar findings suggest that the mechanism behind the bilingual advantage comes from the dual activation of languages—since bilinguals are constantly inhibiting one language in order to use, produce, and comprehend the other, they have much more practice with inhibition than do monolinguals (see Bialystok & Craik, 2010 for a review). Thus, improved performance by bilinguals on tasks that require executive control are essentially the result of practice.

Bilingual Disadvantage

The dual activation hypothesis can also be used to explain some aspects of the bilingual disadvantage—those differences between bilingual and monolingual brains that are considered to be negative effects of bilingualism. The bilingual disadvantage is best documented as decreased efficiency in word retrieval and difficulty when language switching is necessary.

With regard to word retrieval, competition between words in the two languages can account for reaction time lags in experiments where participants are asked to generate the name of an object (see Bialystok & Craik, 2010 for a review). The Marian and Spivey study discussed above showed that lexical concepts from multiple languages are activated during comprehension (2003). It is not a leap to assume that the same is true during production—words are activated in both languages, and the time necessary to inhibit the incorrect word accounts for the production lag. In fact, when Hoshino and Thierry asked participants immersed in an L2 environment to name pictures in L2 while in the presence of semantic distractors, L1 phonological distractors, L2 phonological distractors, or unrelated distractors, reaction times were significantly faster when the distractors were unrelated to the target, as compared to the other three conditions (2011). The distractors increased competition, making participants have to work harder to inhibit incorrect responses. This conclusion was corroborated by electrophysiological data—N2 and early N3 amplitudes were significantly higher for unrelated distractors than other distractor types.

Having to switch languages during a picture-naming task decreases participant performance further and requires increased cognitive control (see Abutalebi, 2008 for a review). When participants were asked to perform such a task in a mixed condition (i.e. language changed between trials within the block), areas involved in inhibition—superior parietal lobule, precentral gyrus, and SMA, among others—were significantly more activated than during blocked trials (Hernandez, 2009). Language switching also increases accent during word production, which suggests that inhibition is involved in language production beyond the cognitive level (Goldrick, Runnquist & Costa, in press).

The additional difficulties caused by language switching suggest that the mechanism of dual activation is less cut-and-dry than inhibition at the word level, but rather also involves a more global inhibition of one language over another. In a study of bilinguals immersed in an L2 environment, Linck, Kroll, and Sunderman found that L1 access was significantly lowered in these bilinguals as compared to L1 access of similar bilinguals who were only exposed to L2 in the classroom (2009). It is important to note that L1 access in the immersed bilinguals did not disappear: both languages were always activated; L1 was just slightly less so.

To some extent, this more global inhibition occurs whenever a bilingual is in an environment where exclusively one language is spoken. It explains why unintentional code switching is so rare in proficient bilinguals, and offers evidence for why intentional code switching (as in word naming studies) is difficult. In the present study, we attempt to induce a specific language environment in order to access global inhibition in a laboratory setting (Paulmann, Elston-Guttler, Gunter & Kotz, 2006).

Intersection of Bilingual Advantages and Disadvantages

As is made clear above, the cognitive advantages and disadvantages of bilingualism are prominent and numerous. The accepted explanations of the presence of the phenomena are related: practice due to interlingual competition from multiple lexicons leads to better performance in tasks that rely on inhibition and attention; that same competition leads to difficulty in online language switching and word production. Yet, there is no direct evidence that the bilingual advantages and bilingual disadvantages are mechanistically related.

The present study looks at the processes underlying both the bilingual advantage and the bilingual disadvantage through an experimental procedure wherein the two overlap. In this protocol, the bilingual advantage is measured as the difference between bilingual and monolingual participants' performance on the Stroop task (see "Bilingual Advantage" section above) in a same-language environment (i.e. listening to a story and performing the Stroop task in the same language). The bilingual disadvantage, in this case, is induced through global inhibition. In the cross-language blocks of the study, bilingual participants are asked to perform the Stroop task in L1 after attending to a story in L2, and vice versa. Since previous studies have found that switching languages is difficult, particularly when in a single-language environment (see "Bilingual Disadvantage" section above), the effects of bilingual disadvantage should be evident under these conditions.

If the bilingual advantage and the bilingual disadvantage are as closely related as the literature would suggest, then bilinguals should perform significantly worse, both in terms of speech onset times and the Stroop effect, in the cross-language conditions than the same-language conditions. In fact, while they should have faster speech onset times and a smaller Stroop effect in the same-language conditions than monolinguals, bilingual performance on the Stroop task in the cross-language conditions should match or dip below monolingual performance. If, however, there is no interaction between participant type, language type, and congruent, the bilingual advantage and disadvantage—at least with regard to executive control and global inhibition—are unlikely to result from the same cognitive pathways.

Participants and Methods

Participants

Six monolingual English speakers (2 male, 4 female; mean age = 19, *SD* = 1) and six bilingual English-Spanish speakers (1 male, 5 female; mean age = 22, *SD* = 5) participated in this study. All participants were undergraduate college students at the Claremont Colleges.

Of the bilingual participants, one reported being exposed to English and Spanish simultaneously and two reported being exposed to Spanish before English (mean age of English acquisition = 6, *SD* = 2). The rest reported being exposed to English first, with a mean age of Spanish acquisition of 12 (*SD* = 1). Although all of the participants reported having studied at least one other language for a minimum of one year, none of the monolingual participants reported fluency in any other language other than English. Two of the bilingual participants reported being fluent in one other language, and a third reported being exposed to another language from birth but did not identify as fluent in that language.

Apparatus and Materials

All stimuli were presented using PsychoPy 1.80.0 software (Peirce, 2009) on a computer running the Windows 7 operating system. Audio stimuli were recorded by a bilingual English-Spanish speaker with native speaker proficiency in both languages using Audacity 2.0 software. Audio stimuli were presented and spoken responses were collected using a Sennheiser PC360 gaming headset.

Procedure

All participants gave written informed consent prior to participating in the study. They were then asked to fill out a demographic survey, a handedness inventory, and a vision/audiometry form. Participants were then seated comfortably in front of the presentation computer with a microphone headset. Participants who self-identified as fluent in both Spanish and English then completed the bilingual version of the protocol; those who self-identified as monolingual English speakers (with minimal knowledge of any other language) completed the monolingual version. All participants heard news stories on the same topics (see Appendix C); both the order and, for bilingual participants, language in which news stories were presented were counterbalanced. All versions of the Stroop task were intralingual.

Bilingual Version: The bilingual version of this protocol contained four conditions. Each condition contained a total of 72 randomized trials. Of these, 36 were congruent (matching word name and ink color) and 36 were incongruent (disparate word name and ink color). Each word appeared on screen for 750ms and was followed by a 1250ms blank screen. In condition A, participants heard a short news segment in English. To ensure that they attended to the segment, they were then asked four short questions about it. This was followed by a spoken English Stroop task. Condition B was paralleled condition A, except that both the news segment and Stroop task were conducted in Spanish. These represented the same-language conditions. Conditions C and D represented the cross-language conditions. In condition C, participants heard a news segment in English, but completed the Stroop task in Spanish. In condition D, participants heard a new segment in Spanish, but completed the Stroop task in English (Table 1). Instructions for each condition were presented in the same language as the news segment. The order in which participants were presented the conditions was counterbalanced, and participants were allowed a break after completing each Stroop task. All participants heard news segments on the same four topics, with the order of topics counterbalanced across participants. Each topic had matching stories in English and Spanish, so the language in which each topic was presented was counterbalanced, as well.

Monolingual Version: In the monolingual version of the experiment, participants always heard a new segment in English and completed an English Stroop task. This was repeated four times in order to control for effects of learning and fatigue. The news segments presented to the monolingual participants were the same as the English versions of the news segments presented to the bilingual participants. All other aspects of the procedure were identical to the bilingual version.

English Stroop: For the English version of the Stroop task, participants were asked to verbally name the ink color of the word appearing on the screen as quickly and accurately as possible. They were informed that the word would be a color name (“red”, “blue”, “green”, or “yellow”). The possible ink colors were also red, blue, green, and yellow (Figure 1). Participants were instructed to name the ink color in English.

Spanish Stroop: The Spanish version of the Stroop task only differed from the English version in the language of presentation. That is, while the possible ink colors remained the same, the words themselves were “rojo” (red), “azul” (blue), “verde” (green), and “amarillo” (yellow).

Data Analysis

Responses were coded by trained research assistants. Audacity 2.0 was used to determine both accuracy and speech onset time for each response. Only speech onset times for correct responses were analyzed. Data were trimmed to within 2 standard deviations from the mean for each participant. All statistical analyses were performed using IBM SPSS Statistics software.

Results

Stroop Effect

A significant Stroop effect, measured as difference in speech onset times in response to congruent and incongruent stimuli, was found for both monolingual participants [$F(1,1656) = 186.8$, $p < 0.001$, $MSE = 18151$] and bilingual participants [$F(1,1450) = 140.3$, $p < 0.001$, $MSE = 32775$]. Bilingual participants also showed a significant Stroop effect in each block type [English/English: $F(1,409) = 48.911$, $p < 0.001$, $MSE = 22265.877$; Spanish/Spanish: $F(1,419) = 49.419$, $p < 0.001$, $MSE = 29898.859$; English/Spanish: $F(1,767) = 88.353$, $p < 0.001$, $MSE = 32311.465$; Spanish/English: $F(1,270) = 14.812$, $p < 0.001$, $MSE = 46773.188$].

Comparison of Groups

A 2x2 ANOVA of matched language responses found significant differences between speech onset times for congruent and incongruent trials [$F(3,1) = 83.5$, $p < 0.001$, $MSE = 15415$]. There were significant effects of participant type, with monolinguals responding significantly faster than bilinguals ($p < 0.001$), and trial type, with congruent trials being significantly faster than incongruent trials ($p < 0.001$) (Table 2). The interaction between participant type and trial type was also significant ($p = 0.008$), with a larger Stroop effect for bilinguals than for monolinguals (Figures 2 and 3).

Comparison of Bilingual Conditions

A 4x2 ANOVA of bilingual responses found significant differences between speech onset times for congruent and incongruent trials under the four bilingual conditions [$F(7,3) = 24.6$, $p < 0.001$, $MSE = 22648$]. There were significant effects of block type ($p < 0.001$) and trial type ($p < 0.001$), but no interaction ($p = 0.98$) (Fig. 2). A Bonferroni post-hoc analysis found that speech onset times in the two same-language conditions did not differ ($p = 1.0$), nor did the speech onset times in the two cross-language conditions ($p = 0.21$). However, responses in the same-language conditions were significantly faster than those in the cross-language conditions (English/English vs. English/Spanish: $p = 0.01$; English/English vs. Spanish/English: $p < 0.001$; Spanish/Spanish vs. Spanish/English: $p < 0.001$), with the exception of the Spanish/Spanish and English/Spanish comparison ($p = 0.31$) (Figure 3).

Discussion

Bilingual Advantage

Our data do not show evidence of the bilingual advantage in the Stroop task. Bilingual participants' response times were slower than monolingual response times for all blocks, including the same-language blocks which mimic conditions under which the bilingual advantage is canonically found. Similarly, under the same-language condition, bilingual participants showed a larger Stroop effect than did monolinguals. There are a variety of possible explanations for the lack of continuity between the bilingual advantage found within the Stroop task in the literature and the results of the present study. The most likely explanation has to do with the small sample size of our study: there are many between-subject differences that can affect results when groups are small. However, it is also possible that the lack of bilingual advantage in this study was caused by specific characteristics of the participant population or by the study conditions. Follow-up studies are needed in order to determine which potential explanation is responsible for our outcome (see "Future Directions" section below).

Because language proficiency was self-reported by the participants, we do not have an objective measure of the proficiency of the bilingual participants in either language. All bilingual participants reported being fluent in both English and Spanish; however, their actual degree of fluency/proficiency is unknown. Since lower proficiency bilinguals do not display the bilingual advantage, it is possible that the lack of bilingual advantage in our participants is due to their language proficiency (Bialystok & Feng, 2009). Yet, this explanation is not very likely since the bilingual participants all reported being able to speak both languages without translating, all had been speaking Spanish for at least 6 years, and several reported being fluent in languages besides English and Spanish. Furthermore, the proficiency argument would not explain why monolingual participants had both faster speech onset times and a smaller Stroop effect than bilinguals.

On the other hand, language inhibition due to anticipation of a potential language switch could affected bilingual participants' performance on the Stroop task enough to impede their performance to below monolingual levels. Marian and Spivey note that being in an environment in which bilingual participants know that their bilingualism is being tested can impact performance (2003). Since participants in our study knew that they would be tested in both English and Spanish, but were only informed of the language in which they would be performing the Stroop task directly before being asked to perform it, they may have begun to inhibit the primed language in order to have a head start on overcoming global inhibition should it become necessary (Linck, Kroll & Sunderman, 2010).

The probability of prime language inhibition in response to anticipation further increases when error types are examined. The most common error made by bilingual participants was performing the Stroop task in the incorrect language. This suggests that the bilinguals either did not always read the instruction screen prior to completing the task or had a hard time controlling the language in which they responded. All efforts were made to ensure that participants followed instructions—they were informed of possible block conditions and were reminded to read all instructions that appear on the screen multiple times prior to beginning the computerized portion of the study; however, it is impossible to know whether instructions were actually read. Regardless of the most direct reason for this error type, its frequency relative to other error types is the first piece of evidence that global inhibition of the non-primed language was achieved when bilingual participants were primed by listening to the news articles.

Yet another potential explanation for the lack of bilingual advantage in the Stroop task in this experiment has to do with the version of the task that was utilized. The Stroop task can be completed via button press or verbal color naming. For this experiment, we chose to use the latter version, as many of the early studies on cognitive control in bilingualism measured verbal responses (e.g. Preston & Lambert 1969). These experiments, however, did not look at individual speech onset times, but rather length of time required to name the ink colors on a card of color names. Now that the technology is available, a button-press response may be more apt—it does not require participants to generate words. Since one of the bilingual disadvantages is a longer response time in word naming tasks (see “Bilingual Disadvantages” above), avoiding a voiced response may demonstrate the bilingual advantage in the Stroop effect more clearly. In this case, however, analysis of responses between language conditions would necessarily be different (see “Future Directions” section below).

Bilingual Disadvantage

Evidence of the bilingual disadvantage as caused by global inhibition is clearly represented by the data in this study. Although bilingual participants performed significantly worse than monolingual participants on all blocks of the Stroop task (see “Bilingual Advantage” section above), within-subject comparisons of bilingual response times nonetheless demonstrated deficits caused by language switching in a global context. In fact, our data show significant differences in response times in the four block types, with speech onset times in the same-language conditions being significantly faster than speech onset times to the cross-language conditions for all comparisons but one.

The differences between speech onset times in the different conditions suggest that global inhibition of the non-primed language was achieved by attending to news articles in the primed language. This global inhibition supports a more nuanced model of the cognitive processes of the bilingual brain than the dual activation hypothesis alone would suggest. Although both languages are likely active at all times, the current results suggest that it is possible to inhibit one language over another on a more holistic level than at the generation of each spoken word. This explains why bilinguals make as few code-switching mistakes as they do—if lexical access to the “wrong” language is inhibited at a global level, the probability of selecting a given word in the correct language increases.

It is important to note, however, that not all the same-language vs. cross-language comparisons in our data yielded significant differences between conditions. In particular, the Spanish/Spanish block did not differ from the English/Spanish block. This suggests that global inhibition of Spanish was not achieved by English stories. Most of the bilingual participants reported being less fluent in Spanish than they are in English. It is possible that they were able to access color names in the less-proficient L2 by translating from the more-proficient L1. However, a more objective measure of language fluency would be necessary in order to draw such a conclusion.

Intersection of the Bilingual Advantages and Disadvantages

Although this study set out to examine the intersection of the mechanisms behind bilingual advantages and disadvantages, the lack of evidence of the bilingual advantage in our data neither allows us to support nor reject the hypothesis that the bilingual advantage and disadvantage stem from the same cognitive control mechanisms. Follow-up studies are required in order to find a more conclusive answer.

Future Directions

The next step toward understanding the intersection of the bilingual advantage and disadvantage is to continue data collection under the current experimental conditions. Because the bilingual advantage in the Stroop task is very well documented, it is likely that the fact that our data do not show it is due to our small sample size. If this is true, then simply adding more participants will allow us to examine the relationship between the bilingual advantages and disadvantages more conclusively.

It may also help to add a language proficiency test to the questionnaires that are completed by participants prior to the study. Because it has been shown that higher proficiency bilinguals display more of a bilingual advantage than lower proficiency bilinguals, it is likely that controlling for L2 proficiency will produce more robust results (Bialystok & Feng, 2009). Similarly, this study did not distinguish between English-Spanish bilinguals and Spanish-English bilinguals (although most bilingual participants identified as English as their primary language). While a possible L1/L2 discrepancy ultimately should not impact results given the four conditions of this study, there may nonetheless be differences between participants with different language backgrounds.

If increasing the sample size of the present study and/or including language background in analyses still does not produce a bilingual advantage in the same-language Stroop task, it is likely that the study conditions are responsible for the lack of bilingual advantage (see “Bilingual Advantages” section above). In this case, it is important to explore how the conditions are affecting language processing.

One option would be to look only at bilingual participants and split the experiment into two sessions. During one session, participants would perform only the same-language blocks;

during the other, they would perform only the cross-language blocks. Since participants would be informed of which blocks they would be performing during each session, there would be no anticipation of having to switch languages during the same-language trials, and therefore no anticipatory inhibition. This design could, however, introduce new potential problems many of which were avoided in the initial study by counter balancing.

Another option would be to repeat the current procedure using a button-press Stroop task rather than requiring a verbal response (see “Bilingual Advantage” above). This would prevent the bilingual disadvantage with regard to word naming from playing a role in the Stroop task. However, it would also complicate the analysis of the blocks completed by bilinguals, as interference from written color names in the inhibited language is likely to be less than interference from written color names in the globally activated language. For this reason, the bilingual disadvantage due to global inhibition would likely manifest as faster response times and a smaller Stroop effect in the cross-language conditions than in the same-language conditions. While it is counterintuitive to call improved performance a disadvantage, it would be caused by inhibition that is not due to executive control and would therefore fall under that category.

Conclusions

The present study examined the intersection of the bilingual advantage and the bilingual disadvantage—differences between monolingual and bilingual cognitive function that previous studies have attributed to co-activation of languages in the bilingual brain. In the case of bilingual advantages, researchers have linked inhibition of co-activated words to increased performance of executive control systems; bilingual disadvantages have been attributed to having to inhibit a language during production and/or comprehension. The present study sought to determine whether the same mechanisms are responsible for the two. Although we did not demonstrate a bilingual advantage, we were able to show that language priming affects performance on the Stroop task, a task that has been closely associated with the bilingual advantage. Yet, without evidence of a bilingual advantage, it is difficult to determine how it interacts with the bilingual disadvantage. Follow-up studies will seek to determine why the present study did not find evidence of a bilingual advantage in order to conclusively show the presence or absence of a mechanistic interaction between the consequences of bilingualism.

Resources

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Appendix A: Tables

Table 1: Bilingual Conditions of the Experimental Protocol

Condition Type	**Story Prime**	**Stroop Task**
Matched Language	English	English
	Spanish	Spanish
Cross Language	English	Spanish
	Spanish	English

Table 2: Mean Response Times in Each Condition

Participant Type	**Block Type**	**Trial Type**	**Mean RT in ms (st. dev.)**
Monolingual	English/English	Congruent	659 (116)
		Incongruent	725 (112)
Bilingual	English/English	Congruent	667 (131)
		Incongruent	761 (132)
	Spanish/Spanish	Congruent	678 (152)
		Incongruent	776 (149)
	English/Spanish	Congruent	704 (162)
		Incongruent	799 (164)
	Spanish/English	Congruent	723 (160)
		Incongruent	827 (162)

Appendix B: Figures

a) **red**	**b)** **green**
c) **amarillo**	**d)** **azul**

Figure 1. *Examples of Stroop stimuli. a) Congruent English;b) Incongruent English; c) Congruent Spanish; d) Incongruent Spanish*

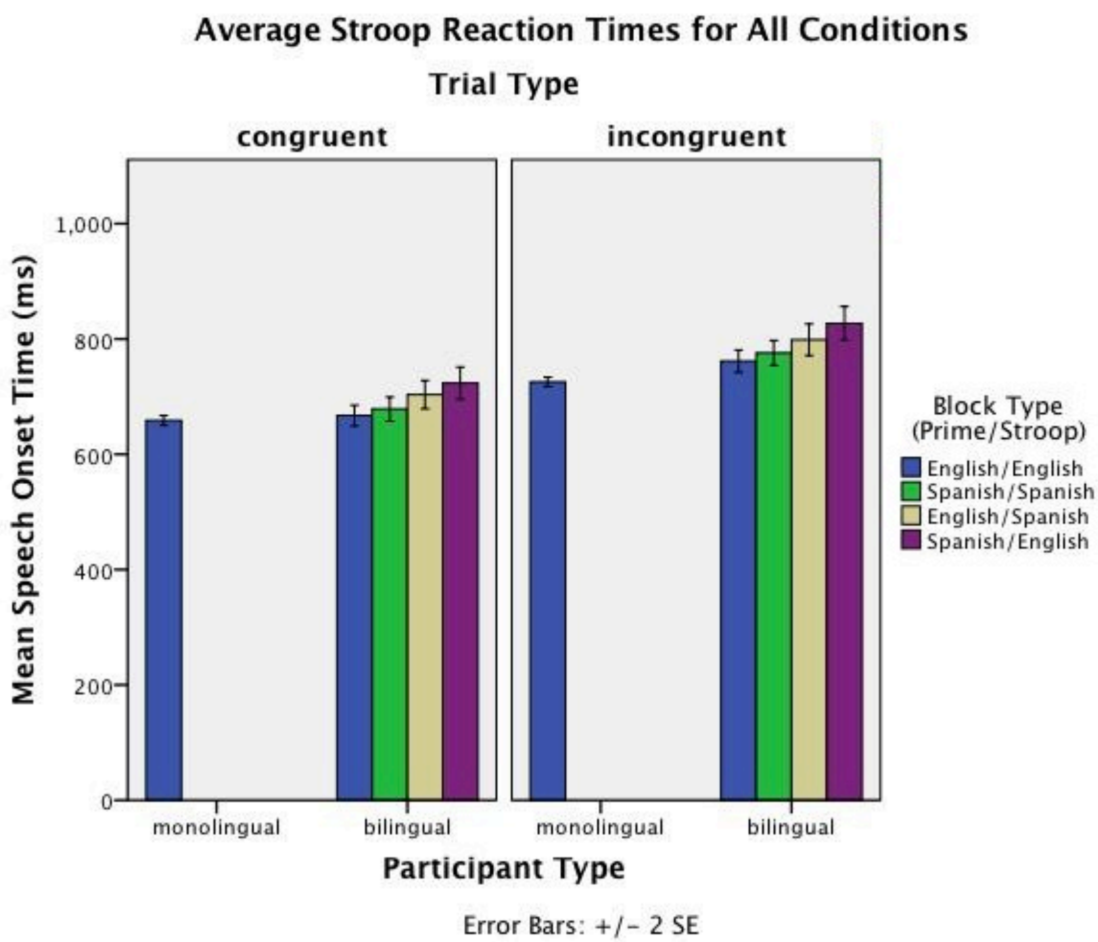

Figure 2. *Response times as a function of participant type, congruence, and block type.*

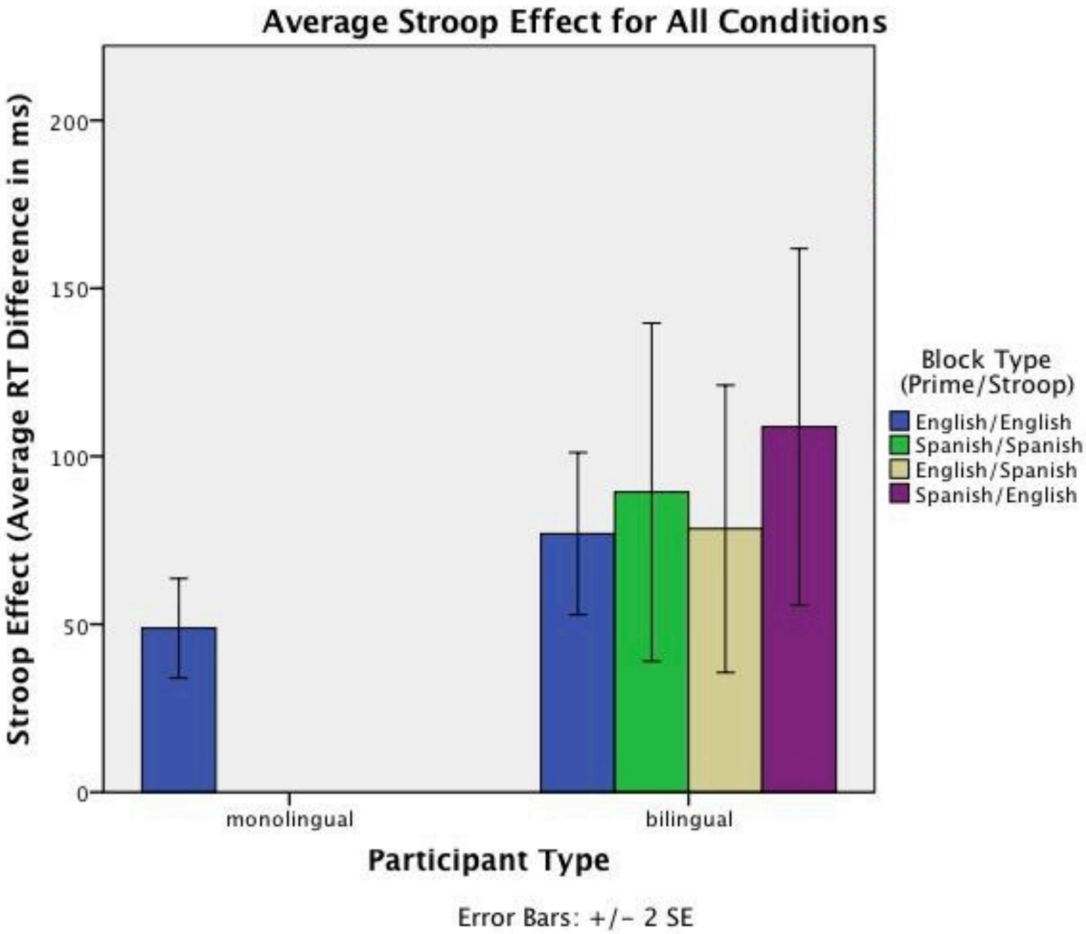

Figure 3. *Stroop effect (response time difference between congruent and incongruent conditions) as a function of participant type and block type.*

Appendix C: News Articles

Topic 1: *Link between paternal age and mental illness*

Carey, B. (2014, Feb. 26). Mental illness risk higher for children of older fathers, study finds. *The New York Times*. Online.

López, Á. (2014, Feb. 27). Ser padre a partir de los 40 se vincula con más problemas psiquiátricos en los hijos. *El Mundo.* Online.

Topic 2: *Altamira cave paintings*

Kassam, A. (2014, Feb. 26). Altamira cave paintings to be opened to the public once again. *The Guardian.* Online.

Corral, M. G. (2014, Feb. 28). La reapertura de altamira desata la polémica científica. *El Mundo.* Online.

Topic 3: EU anti-piracy law

Whittaker, Z. (2013, Apr. 15). EU anti-piracy law overhaul under attack; isps warn against site blocking, censorship. *ZDNet.* Online.

Herraiz, P. (2014, Jan. 03). La UE estrecha el cerco sobre los links piratas. *El Mundo.* Online.

Topic 4: The Second Machine Age

Skidelsky, R. (2014, Feb. 24). The second machine age is upon us: time to reconsider the luddites?. *The Guardian.* Online.

Suarez, E. (2014, Mar. 03). Hacia el mundo feliz de los robots. *El Mundo.* Online.

Acknowledgments

I am somewhat surprised that this project ended up coming together as smoothly as it did, and am all too aware of the many people without whom it would not have been possible. First and foremost, I would like to thank my first reader, Prof. Timothy Justus, for his support, encouragement, guidance, and advice over the course of the last two semesters. If he had not come forward to offer his expertise (and lab space) when it became clear that my original project was not feasible, this thesis would be a lot less original and much more boring.

I would also like to thank my second reader and academic advisor, Prof. Michael Spezio, for supporting every crazy ambition I have had over the past four years. MD/PhD program after graduation? You can do it! Premed neuroscience major with two unrelated minors? Go for it! Modeling thesis after only having taken two computer science courses? Why not! While I am lucky enough to never have crashed and burned, thank you, Prof. Spezio, for always being there when I eventually came down to Earth.

Profs. Justus and Spezio are just two of the many incredible faculty members I have had the good fortune to work with and learn from at the Claremont Colleges. There are far too many of you to mention by name, but thank you all for sharing your knowledge, wisdom, and life experience. This thesis is supposed to tie together my undergraduate career, but it does not do justice to all that you have taught me.

Finally, I would like to thank all those who helped this project come together, especially after I turned into a pirate. Thank you Scripps Associated Students Funding Advisory Committee for funding participant gift certificates. Thank you to Alexandria Gonzales for lending her beautiful voice to the news segment recordings. Thank you to the family and friends who spent hours upon hours coding participant responses and listening to me complain.

Most importantly, thank you to my parents, who have not only put up with everything I have thrown at them over the last 22 years, but have done so with love and minimal eye rolling. Thank you for always being there for me, for encouraging and embedding a love of learning, and for regularly telling me to do my work. I wouldn't be where I am without you guys… in more ways than one.