COGNITIVE CONTROL: GOOD BILINGUALS, BAD BILINGUALS, AND MONOLINGUALS

A Thesis

Presented to

The Faculty of the Department

of Psychology

University of Houston

In Partial Fulfillment

Of the Requirements for the Degree of

Master of Arts

By

Maya Ravid

December, 2013

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ABSTRACT

The purpose of this study was to investigate how differences within the bilingual population affect the discovery of a bilingual advantage. One-hundred and one Spanish-English bilinguals and 53 English monolinguals participated in three different tasks. In a verbal picture-naming task bilinguals were required to switch between English and Spanish while naming pictures in quick succession. Errors of interference (EI), in which bilinguals named a picture in the uncued language, were used to divide the bilingual group into non-switchers (few EI) and switchers (many EI). The two bilingual groups were then compared with monolinguals in two non-verbal tasks of cognitive control, a shape-color switching task and a Simon task. In the shape-color switching task participants were required to respond to either the shape or the color of a stimulus, and the rule for response changed following a number of trials by the presentation of a non-verbal cue. In the Simon task, participants were presented with different colored circles in different locations on the screen and were required to disregard location and respond to the color of the circle. Results revealed that monolinguals responded faster than both bilinguals in the shape-color task. In the Simon task, monolinguals responded faster than switcher bilinguals, with the non-switcher bilinguals not significantly different from the monolinguals or the switcher bilinguals. Non-switcher bilinguals were more accurate on the shape-color task than switcher bilinguals, with the monolinguals not significantly different from either bilingual group. These results suggest that bilinguals and monolinguals approach these tasks differently, with bilinguals focused on response selection and accuracy to the detriment of their reaction time. This may be due to the salience of response selection (i.e. language selection) in the bilinguals' daily lives. Additionally, it was found that some bilinguals (non-switchers) outperformed other

bilinguals (switchers), indicating that better performance on a verbal switching task is related to better performance on a non-verbal switching task, but no bilingual advantage was discovered in comparisons of bilinguals and monolinguals.

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Introduction

There has been considerable debate over the existence of a "bilingual advantage"—increased cognitive abilities in bilinguals. While there is much research supporting this idea, the notion is also being challenged. It is possible that the difference that is sometimes seen in bilinguals' performance on certain cognitive control tasks compared to monolinguals' is not due to bilingualism entirely, but also to pre-existing individual differences. Can the bilingual population be divided into high and low control abilities, and would this division provide a more complete picture of the bilingual advantage? If it can, then current views of the bilingual advantage, the bilingual population, and even the monolingual population, could change dramatically. Instead of a bilingual advantage, it is possible that some individuals present with increased cognitive abilities in general processing domains that may be further affected by experience with language.

The bilingual advantage

In a 2006 paper, Bialystok, Craik, and Ryan summarize the theoretical basis for a bilingual advantage: bilinguals' daily management of multiple languages engages and enhances cognitive control processes, and this enhancement leads to improved performance on non-verbal tasks. Cognitive control is the ability to act according to present goals in spite of interfering information, distractors, and stimuli. The bilingual advantage has been studied extensively and has been found in different age groups (Bialystok, 1999; Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok & Martin, 2004). The bilingual advantage emerges in early childhood and persists well into older adulthood. Different tasks have been used to examine bilingualism's effect on the brain and behavior, such as the Simon task (Bialystok, 2006; Bialystok et al., 2005; Bialystok et al., 2004; Morton & Harper, 2007; Paap &

Greenberg, 2013), switching tasks (Abutalebi et al., 2013; Abutalebi, Rosa, et al., 2012; Costa & Santesteban, 2004; Garbin et al., 2010; Gollan & Ferreira, 2009; Paap & Greenberg, 2013; Prior & Gollan, 2011; Prior & MacWhinney, 2010), and the flanker task (Abutalebi, Della Rosa, et al., 2012; Carlson & Meltzoff, 2008; Emmorey, Luk, Pyers, & Bialystok, 2008; Luk, Anderson, Craik, Grady, & Bialystok, 2010; Paap & Greenberg, 2013).

The Simon task has been studied extensively in relation to bilingualism and cognitive control. In the task, participants respond only to the color of a stimulus, regardless of its position on the screen. For example, participants would be instructed to respond only with their right hand when a blue circle appears. When the stimulus appears on the same side of the screen as the responding hand, the trial is termed congruent. When the stimulus appears on the contralateral side, the trial is called incongruent. The participant must therefore inhibit the natural inclination to respond using the left hand when the blue circle is presented on the left side of the screen. This is the basis of the Simon effect, which is measured as the magnitude of the difference in reaction time between congruent and incongruent trials. Bialystok et al. (2004) compared performance on the Simon task of groups of younger and older adult bilingual and monolingual participants. Bilinguals showed a smaller Simon effect than monolinguals, and younger adults showed a smaller effect than older adults. Bilingualism was also found to mitigate the age-related increase in the Simon effect, indicating that bilingualism serves as a protective factor against age-related decline.

Tasks of language switching and to a lesser extent, non-verbal switching, have also been studied in relation to bilingualism. Garbin et al. (2010) investigated the neural correlates of non-verbal task switching in bilinguals and monolinguals. In that study, monolingual and bilingual participants were presented with blue or red circles or squares and instructed to respond to either the shape or color of the stimulus. Verbal cues indicated which rule they were to follow. Behaviorally, monolinguals presented with greater switching costs (the differences between switch and non-switch trials) than the bilinguals in terms of accuracy, and a similar, almost significant interaction between group and condition was found with reaction time (Figure 1). Thus, monolinguals were less accurate and slower to respond on switch trials than bilinguals. Activation differences were also observed between the groups, with the monolinguals showing activity in the right inferior frontal cortex and anterior cingulate cortex, while the bilinguals presented with activity in the left inferior frontal cortex and the left striatum, suggesting that bilinguals recruit brain regions involved in language control while performing this non-verbal task. The results of this study indicate that experience in managing two languages significantly affects both behavioral performance and neural activation patterns in a non-verbal switching task.

Prior and MacWhinney (2010) administered a similar non-verbal switching task to groups of bilinguals and monolinguals. Participants were required to respond either to the color or shape of a stimulus appearing on the screen. An interaction between trial type and language group was significant for reaction time but not for accuracy. Both monolinguals and bilinguals performed identically on non-switch trials, but bilinguals were much faster on switch trials than monolinguals. These results are consistent with other findings in the literature that identify differences between monolinguals and bilinguals on non-verbal control tasks (e.g. Bialystok et al. 2004; Emmorey et al. 2008).

Challenging the bilingual advantage

While there are many studies that support the notion of a bilingual advantage, some researchers have begun to question the underlying cause of the bilingual advantage, while others question its existence entirely. Morton and Harper (2007) suggest that many studies that show a bilingual advantage lack controls for SES and emotional, ethnic, and psychological factors that may influence performance. Using the Simon task and controlling for SES and ethnicity, Morton and Harper found that bilingual and monolingual children perform identically. When these variables were controlled for, bilinguals failed to show an advantage in the Simon task.

While SES proved to be an important factor in examinations of the bilingual advantage in this single study, a recent meta-analysis of the bilingual advantage literature provides a general overview of the problem. Hilchey and Klein (2011) assert that only a limited number of studies found large bilingual advantages, with many more showing only minor or non-existent bilingual advantages. In young adults, only under very restrictive conditions do bilinguals outperform monolinguals on tasks of interference. These minor differences are very short lived and disappear with practice. These studies, taken together, show that there is still much to be discovered about the bilingual advantage, and that it may not be as clear-cut as it appears.

Another large-scale study of the bilingual advantage attempted to consolidate findings across multiple tasks. Paap and Greenberg (2013) administered the Simon, flanker, and shape-color switching tasks in addition to an antisaccade task to a large number of monolingual and bilingual participants. Paap and Greenberg failed to find a bilingual advantage in these three tasks with large samples and controls for SES. Kousaie and Philips also report similar behavioral findings in two studies of both older and younger adults, using the Simon, flanker, and Stroop tasks (Kousaie & Phillips, 2012a, 2012b). These recent large-scale studies make it clear that the bilingual advantage is an inconsistent finding.

Most previous studies of the bilingual advantage only compared groups of monolinguals and bilinguals; very few investigated individual differences in cognitive control that exist within groups of bilinguals, which could change how the bilingual advantage is interpreted. In one of the first studies of its kind, Festman et al. (2010) examined individual differences in control in a group of Russian-German bilinguals in order to elucidate the extent to which individual differences can be accounted for by different factors affecting bilinguals (age of acquisition, proficiency etc.). The bilinguals were divided into two groups based on their performance on a picture-naming task. In this task, participants were presented with line drawings of common objects and were asked to name each object in the specified language. The language was switched between German and Russian after every two stimuli (GG RR GG and so on). An error of interference occurred when the correct object name was articulated in the non-specified language. Bilinguals who made between 10 and 20 errors of interference constituted the "switcher" group, whereas those who made 5 or less errors of interference constituted the "non-switcher" group. Participants also completed a language history questionnaire, four non-verbal tasks measuring different aspects of control (described below), and intelligence tests.

Festman et al. used four well-known cognitive control tasks to test individual differences in the bilingual group. In the Tower of Hanoi task, participants move several disks from one peg to another peg in as few moves as possible. This task has been used to test problem solving skills, working memory, inhibition and planning (Morris, Miotto, Feigenbaum, Bullock, & Polkey, 1997; Welsh, Satterlee-Cartmell, & Stine, 1999). Switchers needed significantly more moves to solve the task than non-switchers. The Go/noGo task is a measure of inhibition and working memory**.** Participants are presented with five different stimuli and asked to press a button in response to two ("Go") trials. A "false alarm" trial indicates that a participant erroneously pressed a button in response to one of the three "noGo" trials. False alarm and response latencies were greater in the switcher group than in the non-switcher group. Two other tests of cognitive control, a divided attention (dual-task) test and the Ruff Figural Fluency test were administered. The divided attention task required participants to respond to both auditory and visual stimuli using button presses. In the Ruff Figural Fluency test participants produced different visual designs when presented with a large number of identical starting stimuli. These two tasks measure the ability to attend to a particular stimulus and to ignore extraneous information. Similar to results of the other two control tasks, the switcher group performed worse than the non-switcher group on both the divided attention and Ruff Figural Fluency tests. Therefore, across all four non-verbal tasks the switcher group performed worse than the non-switcher group—performance on the non-verbal tasks mirrored performance on the verbal task. Non-switchers also performed better on two verbal subsets (Information and Similarity) of the Wechsler Adult Intelligence Scale. The researchers found no differences between the two groups in age, AOA of L2, and number of years spent in Germany. The groups also did not differ with regard to the educational component of SES. Given these results, Festman et al. determined that the ability to control language is related to general control ability and not simply bilingual language experience.

One factor that was not thoroughly examined by Festman et al. (2010) that may provide further clues about the contribution of individual differences to cognitive control processing is language proficiency. In a subsequent paper, Festman (2011) addressed this issue, and concluded that language proficiency can also be excluded as a difference between the switchers and non-switchers. Therefore, the researchers conclude that that preexisting individual differences in cognitive control abilities influenced language control abilities (measured by the picture-naming paradigm) as well as performance on the four executive function tasks.

In another study highlighting differences between bilinguals, Prior and Gollan (2011) administered a shape-color switching task to groups of Spanish-English bilinguals, Mandarin-English bilinguals, and English monolinguals. Once SES was controlled for, it was discovered that the Spanish-English bilinguals presented with smaller switching costs than the monolinguals while Mandarin-English bilinguals did not. This difference between the bilingual groups was attributed to daily use patterns: the Spanish-English bilinguals reported using both languages more evenly and reported more frequent switching between their two languages than the Mandarin-English bilinguals. These recent studies serve to highlight the importance of considering individual differences within the bilingual population for the ultimate purpose of examining bilingualism's effects on the brain.

These studies accentuate the need to investigate the role of individual differences in the bilingual population, as well as the importance of proper control of variables in order to establish the existence of a bilingual advantage and to determine whether differences in performance might be influenced by factors other than bilingualism alone. It is clear from this review of the literature that previous studies have largely focused on comparisons between bilingual and monolingual groups. Few studies have examined the bilingual advantage across multiple cognitive control tasks with attention paid to individual differences within the bilingual population. Festman was among the first to investigate the influence of individual differences on heightened cognitive performance in bilinguals; however, no study to date has evaluated the contribution of individual differences in control processing in a bilingual advantage context (where monolinguals' performance is examined as well). This study attempted to frame the differences within a bilingual population in a bilingual advantage setting, comparing different groups of bilinguals to a group of monolinguals. This comparison provides context to the individual differences findings within the bilingual population by grounding the findings within the greater realm of the bilingual advantage.

Current study goals

The primary goal of this study was to suggest a new view of the bilingual advantage, by considering not only bilingualism as a defining group feature, but also differences in cognitive control within the bilingual population. This study examined the connection between language control and general cognitive control abilities, and compared monolinguals and bilinguals, while taking into consideration individual differences.

This study revolved around two main hypotheses:

1) Differences in performance between monolinguals and bilinguals (the bilingual advantage) would vary in magnitude depending on the bilingual subgroup used in the comparison—switchers or non-switchers.

2) Performance of bilinguals in the non-verbal control domain would mirror performance in the verbal control domain.

Methods

Participants and screening procedures

One hundred and one healthy Spanish-English bilinguals (mean age = 21.21, SD= 3.13; 87 females) and 53 healthy English monolinguals (mean age =21.94, SD =3.39; 44 females) between the ages of 18 and 33 participated in this study. Participants were recruited from the University of Houston and surrounding community. Participants were questioned about their mental health background, level of parental education, and language use history, and underwent language proficiency assessments in both Spanish and English (the monolingual group participated in the English proficiency assessment only).

Participants gave their informed consent prior to the administration of any screening procedures. The vocabulary and sentence comprehension portions of the Woodcock Language Proficiency Battery-Revised in Spanish and English (Woodcock & Muñoz-Johnson, 2005) were used to assess language proficiency. In the vocabulary assessment, participants were shown pictures of items and asked to name them. In the sentence comprehension assessment, participants were presented sentences with missing words, and asked to fill in the words. A language history questionnaire was administered to the bilingual participants, which assessed age of acquisition (AOA). Spanish was the first language learned by the bilingual participants and the average age of acquisition was 6.14 (SD=2.86) years. Ninety bilinguals learned English at age 9 or less, and the remaining 11 bilinguals learned English between the ages of 10 and 15. The sample is therefore considered to be composed of mostly early bilinguals. During the language history questionnaire, participants also answered questions regarding parental education level as a measure of socioeconomic status (SES). SES is usually considered to be composed of three factors: parental education, occupation, and income. Given that education level is correlated with both income and occupation, SES is reported here as level of parental education alone (American Psychological Association, 2007; Caldas & Bankston, 1997).

Participants were compensated with $15 in gift cards, or 1.5 hours of extra credit for completion of the study.

Stimuli and procedure

One verbal (picture-naming) and two non-verbal (Simon and shape-color) tasks were used in this study. All three tasks were completed during one session in the laboratory using a computer. The tasks were administered using Eprime (Version 2.0, Psychology Software Tools, Inc., http://www.pstnet.com/eprime.cfm) on iMAC computers running windows 7 software.

*Picture-naming***.** The verbal task consisted of naming a total of 80 unique black and white line drawings taken from the UCSD Center for Research in Language International Picture-naming Project database (Bates et al., 2003). Participants saw four blocks of 40 pictures each. One block required participants to name the pictures entirely in English, another block required naming in Spanish, and two blocks required the participant to alternate between naming in English and Spanish each time a picture was presented. The order of the blocks was counterbalanced. The individual pictures in each block were also counterbalanced, with the English and Spanish block pictures adding to the complete 80 pictures set, and the two mixed blocks together comprising the 80 pictures as well. In other words, each participant saw each picture twice in a complete run, once in a single language setting and once in a switching context. Each participant performed two complete (and different) runs, each lasting 5 minutes and 36 seconds**.**

Participants saw a fixation cross lasting 600ms, followed by a blank screen lasting 100ms, then a cue lasting 300ms, and were then presented with the picture for 1000ms (Figure 2). The cue varied depending on the language status of the participant. For bilingual subjects, the cue was either *diga* or *say*, depending on the block and trial, indicating that the participant should name the picture in either Spanish or English. In the monolingual control version, participants were shown slides that contained between one and six images of the same item. The monolinguals were required to either name the item on the slide or the number of items on the slide, depending on the cue ("name" or "number"). Other than these differences in task requirements, the tasks were the same in terms of timing and the pictures used. The participants' responses were recorded using an external recording device.

Simon task. The Simon task is a non-verbal task which requires participants to respond to the color of a circle with either the right or left hand, depending on the color of the stimulus and instructions. Red and green circles were presented, along with a black fixation cross in the center of the screen. Participants were instructed to respond with a particular hand when they saw a particular colored circle (for example, press the button in your right hand when you see a red circle, and the button in your left hand when you see a green circle). The circles could appear on the left or right of the fixation cross, or in the center of the screen. When a colored circle appeared on the same side of the response hand (in the previous example, a red circle appearing to the right of the fixation cross), the trial was termed "congruent." When the circle appeared on the side opposite the response hand, the trial was deemed "incongruent." Finally, when the circle appeared in the center of the screen the trial was termed "neutral." Participants were either asked to respond with the right hand to a red circle and left hand to a green circle, or given the exact opposite instructions. The order in which red and green circles appeared, as well as their location on the screen, was randomized. The circles were presented on the screen for 1000ms. Each stimulus was separated by a 1000ms fixation cross. Each run, composed of 120 stimuli, lasted 4 minutes and 4 seconds. Participants completed two runs.

Shape-color task. In the shape-color task participants were shown a blue circle, a blue square, a red circle, or a red square on the center of the screen. Participants were asked to respond to the stimulus using one of two buttons, depending on the instructions given at the beginning of the task, and the particular rule the participant was following in the specific block. At the beginning of each run participants were given instructions such as "this run begins with color," asking the participant to respond to the color of the stimulus on the screen regardless of the shape, according to a predetermined rule (for example, when you see a red shape, respond with the right button). After a few stimuli in which the participant followed a particular rule, he or she may have been required to switch and respond to the second rule using the predetermined information (for example, when you see a circle press the right button, regardless of the stimulus color). Participants either saw an upright $ sign, indicating they should switch to responding to a different rule than the one they were following, or a horizontal $ sign, indicating they should keep responding using the current rule. Each run consisted of 7 "switch" and 7 "non-switch" signs. Each switch or non-switch symbol was separated from the next by 8-12 shape stimuli. A run consisted of 162 trials (14 $ signs and 148 shapes), and lasted 4 minutes and 5 seconds. Each shape was presented on the screen for 500ms, and separated from the next one by 1000ms. The participants were given 1500ms to respond (Figure 3). Participants performed 5 runs, in a randomized order. Participants completed a number of practice trials before beginning the actual experimental runs.

Power analysis

A power analysis carried out in G-Power 3.1.3 suggested that a total sample size of 154 would be sufficient to detect an effect size (f) of .22 at .80 power (Faul, Erdfelder, Lang, & Buchner, 2007). By convention, effect sizes (f) of .10, .25, and .40 are small, medium, and large, respectively (Cohen, 1992). With this sample size we were therefore confident that we would be able to detect differences with a medium effect size.

Data analysis

All analyses were carried out using SAS version 9.2 (http://www.sas.com/).

Bilingual classification. A Ward's method cluster analysis used to divide the bilingual picture-naming data into clusters by minimizing the variance in each group. The number of errors of interference (EI), in which participants named a picture in the wrong language, was averaged across the four mixed blocks over the two runs. The distribution was normalized using a natural log transformation. A Ward's method cluster analysis was then conducted on the EI data, which divided the bilinguals into 49 non-switchers (an average of 3 or less EI) and 52 switchers (an average of 3.25 or more EI) (Figure 4). This is the same classification method used by Festman et al. 2010.

Shape-color task. Reaction time and accuracy for the switching and non-switching conditions were averaged across the five trials for all participants. Runs with error rates of 40% or more were removed from the final calculation. Reaction time analyses only included trials in which the participant responded correctly; incorrect response reaction times were not included in the calculations. Trials in which the participant failed to respond were removed from accuracy calculations, such that accuracy reflects a percentage of correct responses out of total responses (correct / (incorrect + correct)). Four bilinguals and 4 monolinguals were removed from this analysis due to chance level performance in all five runs. Statistical analyses of this task were conducted with 49 non-switchers, 48 switchers, and 49 monolinguals. Two 3 x 2 (Group x Condition) mixed model ANOVAs were conducted separately for reaction time and accuracy. Group (non-switcher, switcher, monolingual) was the between-subject factor and condition (switch, non-switch) was the repeated measure. Reaction time data was partially normalized using a natural log transformation. Reaction time in the switching condition for the monolingual group remained positively skewed following the transformation. All other reaction time Group x Condition distributions were normal following the transformation. Accuracy rates were normalized using a square root transformation. Since the raw data were negatively skewed, prior to the square root transformation the raw scores were reversed to create an opposite, positive skew, by subtracting the raw score from the highest score plus one.

Given previous evidence of the effects of socioeconomic status and verbal intelligence on non-verbal cognitive control performance, correlational analyses were performed on those variables with regard to behavioral performance in the three groups. English proficiency measures were used as a proxy for verbal intelligence in this analysis (Pray, 2005).

Simon task. Reaction time and accuracy were averaged across the two runs for all participants. Three bilinguals were not included in this analysis due to loss of data, and one monolingual was removed due to poor performance. Statistical analyses of this task proceeded with 46 non-switchers, 52 switchers, and 52 monolinguals. A 3 x 2 mixed model ANOVA (Group: non-switcher, switcher, monolingual x Condition: congruent, incongruent) was conducted with the reaction time data. Accuracy rate was extremely high in all groups (an average of approximately 1.5 errors across both runs), and therefore no further analysis was carried out on accuracy data. Reaction time data was normally distributed; however the homogeneity of variance assumption did not hold true. Multiple attempts at correcting this issue by transforming the data failed. Given the robustness of the ANOVA procedure, the large sample size, and the roughly even groups, analysis using the raw data was conducted. Correlational analyses of socioeconomic status and English proficiency were conducted as well.

Demographics. Differences in demographic variables (Table 1) were investigated using a number of one-way ANOVAS. SES was calculated as a composite score of both parents' education level.

Results

Demographic differences between groups

One-way ANOVAs were conducted to examine demographic differences between groups. No significant differences in age, $F(2,151) = 1.45$, $p = .24$, age of acquisition between the two bilingual groups, $F(1,99) < 1$, or Spanish proficiency between the bilingual groups, $F(1,91) = 1.23$, $p = .27$, were found. Differences among the three groups in English proficiency were significant, $F(2,145) = 18.78$, $p < .0001$. Bonferroni-corrected *post hoc* analyses indicated that all three groups were significantly different from one another, with the monolinguals having the highest proficiency, followed by the non-switcher bilinguals, with switchers having the lowest English proficiency score. SES was also found to be significantly different between groups, $F(2,149) = 20.14$, $p < .0001$. Follow up tests with a Bonferroni correction indicated that all groups were significantly different, with monolinguals having the highest SES, followed by the non-switcher bilinguals, and lastly by the switcher bilinguals. Given that both SES and English proficiency were different between groups, and previous hypotheses about the importance of these variables, correlational analyses between the dependent variables of interest and these two variables were carried out in order to ascertain the effects of both SES and proficiency on the dependent measures.

Shape-color task

Reaction time. Results revealed a significant main effect of group, $F(2,143) = 8.45$, $p = .0003$, suggesting that the groups responded differently in terms of speed of response. There was no significant main effect of condition, $F(1,143) = 3.01$, $p = .085$, indicating that the switch and non-switch conditions did not differ in terms of reaction time, nor was there a significant interaction between group and condition, $F(2,143) = 1.75$, $p = .18$. To determine which groups were different in terms of their reaction time, follow up *post-hoc* tests were performed with a Bonferroni correction for multiple comparisons at $p<.05$. The global reaction time score, the average of both the switching and non-switching reaction times, was used for the follow-up tests given the lack of evidence for an interaction between group and condition. The follow up tests revealed that the monolingual group responded significantly faster than both bilingual groups, which did not differ in terms of their reaction time (Table 2, Figure 5). The effect size $\omega^2=.09$, indicates a moderate effect of group on reaction time (by convention, effect sizes of .01, .06, and .14 represent small, medium, and large effect sizes, respectively (Kirk, 1996)).

Accuracy. Results revealed a significant main effect of group, $F(2,143) = 5.55$, $p = .0048$, suggesting that accuracy was different across groups. A main effect of condition was also significant, $F(1,143) = 10.78$, $p = .0013$, indicating higher accuracy in the non-switching condition compared to the switching condition. The interaction term Group x Condition did not reach significance, $F(2,143) = 2.73$, $p = .069$. Follow up *post-hoc* tests at $p<.05$ were conducted with a Bonferroni correction for multiple comparisons. A global accuracy score was calculated for each individual, since the interaction term was not significant. These follow up comparisons indicated that the non-switcher bilinguals were more accurate in their performance than the switcher bilinguals, and the monolinguals were not different from either bilingual group (Table 3, Figure 6). The effect size ω^2=.06 indicates a moderate effect of group on accuracy level.

Correlation analyses. Spearman correlations between SES, English proficiency, global reaction time, and global accuracy were performed separately in all three groups. The non-parametric Spearman correlation was selected due to the non-normality of the data. SES was not correlated with any dependent variable in any group. English proficiency was moderately correlated with global reaction time (r_s = -.47, p = .001) in the switcher bilingual group, using a Bonferroni corrected p-value. Global reaction time was also significantly correlated with accuracy in the switcher bilingual group (r_s = .47, p = .0008) (Tables 4-6).

Simon task

Reaction time analysis for the Simon task resulted in a significant main effect of group, $F(2,147) = 4.38$, $p = .0142$, indicating a difference in reaction time among groups. A main effect was also found for condition, $F(1,147) = 331.62$, $p < .0001$, with the congruent condition eliciting faster responses than the incongruent condition. The interaction term was not significant, $F(2,147) = 2.12$, $p = .12$. *Post-hoc* follow up tests were conducted with a Bonferroni correction for multiple comparisons at p<.05. A global RT variable was used for the follow up tests. The monolinguals were faster than the switcher bilinguals, and the non-switcher bilinguals were not different from either group. (Table 7, Figure 7). The effect size ω^2=.04 indicates a moderate effect of group on reaction time.

Correlation analysis. Spearman correlation analyses yielded no significant correlations of SES or English proficiency with a Bonferroni corrected p-value in any of the three groups (Tables 8-10).

Discussion

The purpose of this study was to examine the bilingual advantage using a novel approach. Special care and emphasis was given to pre-existing differences within the bilingual sample prior to a direct comparison with a monolingual sample. The first hypothesis, that the magnitude of the bilingual advantage would differ depending on the subgroup of bilinguals used in the comparison was not confirmed: monolinguals actually responded faster than bilinguals, and did not differ in accuracy in the shape-color task. Some findings supported the second hypothesis, that verbal control abilities of bilinguals will mirror performance in non-verbal domains: non-switcher bilinguals were more accurate than switcher bilinguals in the shape-color task, but did not present with decreased reaction times in the Simon or the shape-color task.

Verbal and non-verbal control in the bilingual population

Prior to any comparison with the monolingual sample, the bilingual group was investigated based on their performance in the picture-naming task. In this task, bilinguals were required to switch back and forth between their two languages. Errors of interference (EI), in which the bilingual failed to switch to the cued language and responded in the uncued language, were used to divide the bilingual group into switchers (many EI) and non-switchers (few EI). A large number of EI indicates poor verbal control, since it reflects the bilingual's ability to switch quickly between their two languages. Following the division of the bilingual sample into two groups based on their verbal control abilities, their performance in the non-verbal tasks was examined. In the shape-color task, participants were asked to respond to either the shape or the color of a stimulus, following a particular rule until they were notified to switch by a cue. This task required participants to suppress one rule and follow another for an extended period of time before switching rules and responding in another way. Non-switcher bilinguals were more accurate than switcher bilinguals. These results from the shape-color task indicate that verbal control in a picture-naming task is related to control in a non-verbal switching task as well, in support of hypothesis 2. The Simon task on the other hand, does not support the original hypothesis. Switcher bilinguals and non-switcher bilinguals presented with similar reaction times in both the congruent and incongruent trials. This indicates that reaction time in the Simon task was not necessarily related to verbal control abilities in the picture-naming task. Hypothesis two is therefore partially supported by the findings of this study. Performance on the shape-color switching task was related to performance in the verbal switching task, however reaction time on the Simon task appears to be unrelated. The shape-color task may be more similar to the picture-naming task, in that it requires the suppression of one salient response in order to respond with another. It is therefore possible that the verbal control differences in the picture-naming task only generalize to non-verbal domains when the non-verbal task is similar to the picture-naming task. An advantage in verbal switching may translate into an advantage in non-verbal switching, but it does not necessarily reflect general cognitive control abilities.

Good bilinguals, bad bilinguals, and monolinguals

Previous studies of the bilingual advantage using a rule-switching task emphasize differences in switching costs. Switching costs in a rule-switching task refer to the differences in reaction time and accuracy between switch trials and non-switch trials. A significant interaction between group and condition would indicate a difference in switching costs between the monolinguals and bilinguals. Previous studies found that bilinguals present with decreased switching costs in terms of accuracy (Garbin et al., 2010) and reaction time

(Prior & MacWhinney, 2010), but generally did not find differences in overall reaction time or accuracy rates. In this examination, the interaction terms were not significant between the three groups being compared (bilingual non-switchers, bilingual switchers, and monolinguals), indicating that there was no difference in switching costs between the three groups. The overall reaction time and accuracy levels however, were significantly different and indicate an interesting pattern. Monolinguals presented with decreased reaction times compared to both bilingual groups, and were not different in accuracy from either one. In this task, monolinguals actually outperformed bilinguals, presenting with faster reaction time that did not have a significant tradeoff with accuracy. Reaction time differences may indicate a difference in the way monolinguals and bilinguals approach the task. The bilinguals may spend more time selecting the correct response, due to experience in their daily lives in selecting languages, while the monolinguals, with no such daily selection experience, are focused on responding as quickly as possible. In other words, bilinguals' focus was on selecting the correct response as opposed to responding quickly, due to the importance and salience of correct selection (i.e. selecting the correct language) in their daily lives. The lack of significant accuracy differences between the bilinguals and monolinguals could be due to task difficulty. It is possible that had the task been more difficult, bilinguals' focus on response selection would have translated into superior performance (specifically of the non-switcher bilinguals) in terms of accuracy compared to monolinguals. This interpretation becomes even more interesting when considering the differences in accuracy between the two bilingual groups.

The switcher bilinguals are those with pre-existing poor verbal control skills, evidenced by the larger numbers of errors of interference in the picture-naming task. In the shape-color task, switcher bilinguals responded as slowly as the non-switcher bilinguals, but were less accurate. The switcher bilinguals are likely as concerned as the non-switcher bilinguals with selecting the correct response, and therefore present with similarly increased reaction time, however due to their poor control skills, they are also less accurate in their response selection than the non-switcher bilinguals. An additional notable finding involves the relationship between English proficiency and reaction time in the switcher bilingual group. The switcher bilingual group was the only one to present with a significant and sizeable correlation between English proficiency and global reaction time. In this group, English proficiency was negatively correlated with global reaction time. English proficiency in this study can be thought of as a proxy for verbal intelligence in the bilingual population—it is a direct reflection of bilinguals' abilities to learn another language, usually in a school setting, and also due to the fact that the Woodcock tests used are significantly correlated with verbal intelligence scores (Pray, 2005). A significant correlation in this group may indicate that verbal intelligence plays a role in overall reaction time, but only when an individual already presents with poor cognitive control skills. In other words, higher verbal intelligence is related to faster reaction times only when someone is already at a cognitive disadvantage. When a bilingual already presents with superior cognitive control (the non-switcher bilinguals), English proficiency is not related to variation in speed of response.

The results of this analysis present an interesting conclusion: bilingualism may not actually provide a boost in cognitive control skills, but rather shifts the focus from responding quickly to responding correctly. Bilinguals' daily lives emphasize the importance of correct response selection, and it is possible that the salience of response selection trumps the importance of a quick response in this non-verbal switching task as well. The finding that switcher bilinguals respond as slowly as non-switcher bilinguals, suggests that the two bilingual groups may be equally focused on response accuracy at the cost of an increased reaction time. The switcher bilinguals' poorer accuracy also suggests that pre-existing cognitive control abilities affect accuracy rate. Even though they are as focused on response selection as the non-switcher bilinguals, the switchers lack the cognitive control abilities of the non-switchers that lead to better accuracy.

In examinations of the Simon task, most studies focus on the Simon effect: the difference in reaction time between congruent and incongruent conditions. Studies that find a bilingual advantage on this task often find that bilinguals present with smaller Simon effects than monolinguals. In this study the interaction term of condition x group was not significant, indicating that there was no difference in the Simon effect across the three groups. However the main effects of both condition and group were significant, indicating that the groups responded differently and that the condition had an effect on the reaction time of the participants. Follow up tests revealed that the monolinguals responded quicker than the switcher bilinguals, while the non-switcher bilinguals were not significantly different from either group. These results may be considered an extension of the findings with the shape-color task; monolinguals were less concerned with responding correctly and responded as quickly as possible, while bilinguals, more concerned with responding correctly, responded more slowly. However, since error rates in the Simon task are notoriously low, there was no way to examine differences in accuracy.

There are a number of factors that could be responsible for the fact that a significant interaction, the hallmark of the bilingual advantage, was not discovered in either task. In previous examinations of a shape-color rule-switching task each trial was given a cue of its own, while in the present study switch and non-switch events were presented in blocks of 8-12 stimuli. Differences in the actual task used could account for the differences in the results. Previous research also suggests that the Simon effect and the bilingual advantage in general are most robust in older adults, and therefore any differences in the Simon effect or switching costs may be too small to detect in a sample of young adults. Nevertheless, the findings of overall reaction time and accuracy differences present new insights into how bilingualism affects the brain.

Even though the three groups did not differ in their age, and the two bilingual groups did not differ in their average age of acquisition or Spanish proficiency, all three groups were different with regard to their socioeconomic status and English proficiency. Monolinguals had the highest levels of SES and English proficiency, followed by non-switcher bilinguals, and finally switcher bilinguals presented with the lowest levels of both variables. SES was not directly related to the measures of interest in any of the groups, and English proficiency was only related to global reaction time in the shape-color task in the switcher bilingual group. While there does not seem to be a direct effect of SES or English proficiency on performance (with the exception of the relationship mentioned) it is possible that these two factors affected the formation of the switcher and non-switcher groups indirectly, and therefore contributed to the differences seen in their cognitive control abilities. Future studies should make an attempt to control such variables, in order to examine whether such groups can be formed when these factors are held constant.

In conclusion, the first hypothesis, that the magnitude of the bilingual advantage will depend on the subgroup of bilinguals (switchers or non-switchers) being compared with monolinguals did not hold true. This study did not find a bilingual advantage in either the switchers or non-switchers, but rather indicated that bilinguals in general approach these tasks differently. Bilinguals appear to focus more on response selection and accuracy, which leads to them presenting with increased reaction times. The non-switcher bilinguals, due to their superior cognitive control skills, are able to compensate for the slower speed of response by responding more accurately than the switcher bilinguals. The switcher bilinguals respond as slowly as the non-switcher bilinguals, but lack the control skills necessary to respond more accurately. Therefore, it can be hypothesized that bilinguals may be more focused on accuracy and response selection due to the reinforcement of these principles in the daily management of multiple languages. The present findings do not point to a group bilingual advantage, but rather to a bilingual's advantage, in that certain bilinguals are able to respond more accurately than others and exhibit superior cognitive control skills.

The second hypothesis, that verbal control abilities measured by the picture-naming task would be related to non-verbal cognitive control abilities, was supported by findings from the shape-color task, in which non-switchers were more accurate than switchers, but was not supported by the Simon task, in which both bilingual groups presented with similar reaction times. It is therefore possible that the superior verbal control seen in the picture-naming task only translates to superior control on similar tasks, such as the shape-color rule-switching task, but is not reflective of more general cognitive control abilities. Alternatively, it is possible that on a more difficult task in which error rates were more varied, the non-switcher and switcher bilinguals would have had similar reaction times, but the non-switchers would have outperformed the switchers in terms of accuracy as was seen in the shape-color task. Future studies could expand in this direction and use more difficult tasks that would allow for an examination of both reaction time and accuracy. Through further investigation using these designs, differences between a bilingual group's advantage compared to a bilingual individual's advantage could be explored.

Conclusions

The present study is the first to examine how pre-existing differences in cognitive control within the bilingual population affect the discovery of a bilingual advantage over monolinguals. Bilinguals were divided into two groups, reflecting good and poor cognitive control in a verbal picture-naming task, and compared with monolinguals and with each other in two non-verbal tasks of cognitive control, a shape-color rule-switching task, and the Simon task. Results from this study suggest that bilingualism influences the way in which individuals approach a non-verbal task. Results suggest that bilinguals focus on response selection to the detriment of their response time. This inclination could be attributed to bilinguals' increased daily effort in selecting the correct language in a given situation. In conclusion, the present study did not find a bilingual advantage in the traditional sense, a decrease in switching costs or the Simon effect in bilinguals compared to monolinguals, however, significant implications for the way bilingualism affects the brain have been revealed.

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Table 1. Subject demographics

	n	Age	Age of L2 acquisition	SES	English proficiency	Spanish proficiency
Non-switchers	49	21.55 (2.95)	5.86 (2.90)	3.38 (1.37)	75.19 (5.82)	78.41 (7.29)
Switchers	52	20.89 (3.28)	6.4 (2.82)	2.69 (1.41)	71.98 (4.89)	76.86 (6.18)
Monolinguals	53	21.94 (3.39)	N/A	4.27 (1.05)	78.79 (5.96)	N/A

Table 2. Shape-color reaction times

	n	Raw switch RT	Raw non-switch RT	Raw global RT
Non-switchers	49	421.12 (53.97)	426.33 (50.79)	423.72 (51.09)
Switchers	48	432.62 (51.48)	437.17 (45.02)	434.89 (46.71)
Monolinguals	49	396.85 (56.96)	394.86 (52.75)	395.86 (54.23)

	n	Log switch RT	Log non-switch RT	Log global RT
Non-switchers	49	6.04 (.13)	6.05(.12)	6.04 (.12)
Switchers	48	6.06 (.12)	6.08 (.10)	6.07 (.11)
Monolinguals	49	5.97 (.14)	5.97 (.13)	5.97 (.13)

Both raw reaction time scores and log transformed scores are reported. Note that the analysis of variance was conducted using the transformed scores.

Table 3. Shape-color accuracy

	n	Raw switch ACC	Raw non-switch ACC	Raw global ACC
Non-switchers	49	88.15 (5.55)	88.83 (5.72)	88.49 (5.46)
Switchers	48	84.23 (6.83)	84.91 (7.07)	84.57 (6.63)
Monolinguals	49	85.35 (5.81)	87.29 (5.63)	86.32 (5.51)

	n	Sqrt switch ACC	Sqrt non-switch ACC	Sqrt global ACC
Non-switchers	49	2.80 (.94)	2.73 (.95)	2.78 (.91)
Switchers	48	3.42 (.99)	3.35 (1.03)	3.40 (.97)
Monolinguals	49	3.28 (.88)	3.01 (.92)	3.16 (.88)

Both raw accuracy (in percent correct) and square root transformed means are reported. Note that the analysis of variance was conducted using the transformed scores. Also recall that due to the score reversal prior to the transformation, high accuracy is represented by a lower number and low accuracy is represented by a higher number.

Table 4. Shape-color Spearman correlation matrix

Non-switcher bilinguals

		SES	English Proficiency	Global RT	Global ACC
SES	**Correlation**	1	0.044	-0.193	-0.084
	Significance		0.771	0.19	0.571
	n	48	46	48	48
English Proficiency	**Correlation**		1	-0.131	0.138
	Significance			0.38	0.356
	n		47	47	47
Global RT	**Correlation**			1	0.263
	Significance				0.069
	n			49	49
Global ACC	**Correlation**				1
	Significance				
	n				49

Table 5. Shape-color Spearman correlation matrix

Switcher bilinguals

		SES	English Proficiency	Global RT	Global ACC
SES	**Correlation**	1	0.296	-0.167	-0.161
	Significance		0.052	0.262	0.28
	n	47	44	47	47
English Proficiency	**Correlation**		1	-0.467**	-0.102
	Significance			0.001	0.505
	n		45	45	45
Global RT	**Correlation**			1	0.466**
	Significance				0.0008
	n			48	48
Global ACC	**Correlation**				1
	Significance				
	n				48

Table 6. Shape-color Spearman correlation matrix

Monolinguals

		SES	English Proficiency	Global RT	Global ACC
SES	**Correlation**	1	0.053	-0.103	0.12
	Significance		0.718	0.481	0.412
	n	49	49	49	49
English Proficiency	**Correlation**		1	-0.273	0.156
	Significance			0.058	0.285
	n		49	49	49
Global RT	**Correlation**			1	0.243
	Significance				0.093
	n			49	49
Global ACC	**Correlation**				1
	Significance				
	n				49

Table 7. Simon reaction time

	n	Congruent RT	Incongruent RT	Global RT
Non-switchers	46	465.88 (48)	496.52 (46.36)	481.20 (45.76)
Switchers	52	479.88 (61.58)	519.35 (62.43)	499.62 (61.15)
Monolinguals	52	449.26 (65.60)	481.48 (70.39)	465.37 (66.88)

Table 8. Simon Spearman correlation matrix

Non-switcher bilinguals

		SES	English Proficiency	Global RT
SES	**Correlation**	1	-0.004	-0.068
	Significance		0.982	0.655
	n	45	43	45
English Proficiency	**Correlation**		1	-0.13
	Significance			0.401
	n		44	44
Global RT	**Correlation**			1
	Significance			
	n			46

Table 9. Simon Spearman correlation matrix

		Switcher bilinguals		
		SES	**English Proficiency**	**Global RT**
SES	**Correlation**	1	0.287	-0.243
	Significance		0.05	0.085
	n	51	47	51
English Proficiency	**Correlation**		1	-0.246
	Significance			0.093
	n		48	48
Global RT	**Correlation**			1
	Significance			
	n			52

Table 10. Simon Spearman correlation matrix

Monolinguals

		SES	English Proficiency	Global RT
SES	**Correlation**	1	0.097	-0.129
	Significance		0.495	0.363
	n	52	52	52
English Proficiency	**Correlation**		1	-0.227
	Significance			0.105
	n		52	52
Global RT	**Correlation**			1
	Significance			
	n			52

Figure 1. Garbin et al. (2010). Results of behavioral task switching analyses. Switching costs in the monolingual group were significantly bigger than the bilingual group's in terms of accuracy, and a similar pattern approaching significance was also apparent in the reaction time analysis.

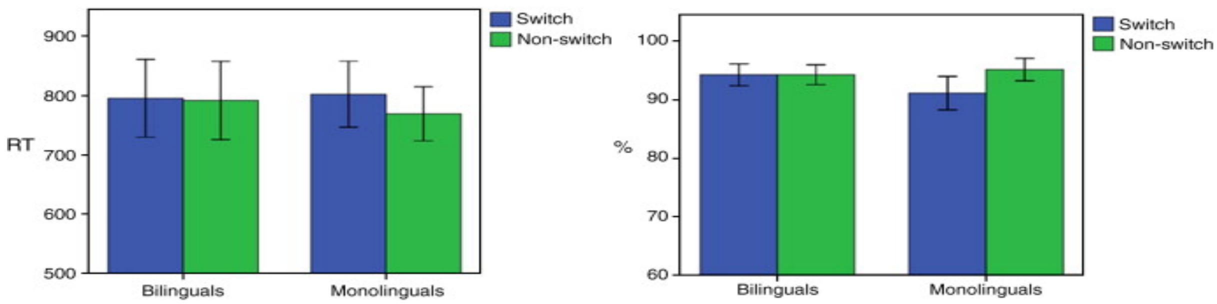


Figure 2. Sample picture-naming trials. Participants had to switch between naming the pictures in English and Spanish, depending on the cue preceding the picture

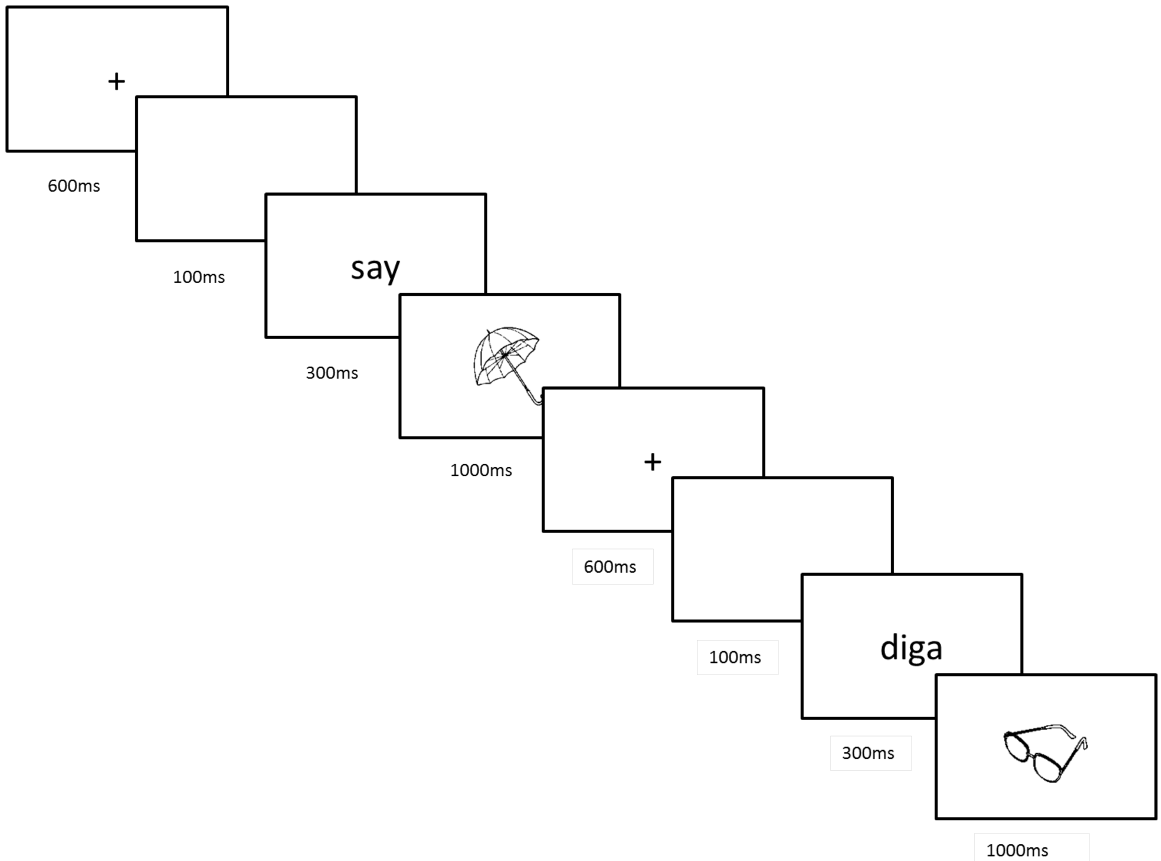


Figure 3. Sample shape-color trials. The participant needed to respond to either the color or the shape of the stimulus presented. The last slide indicates a non-switch event, and the participant will need to continue to follow the same rule in upcoming slides

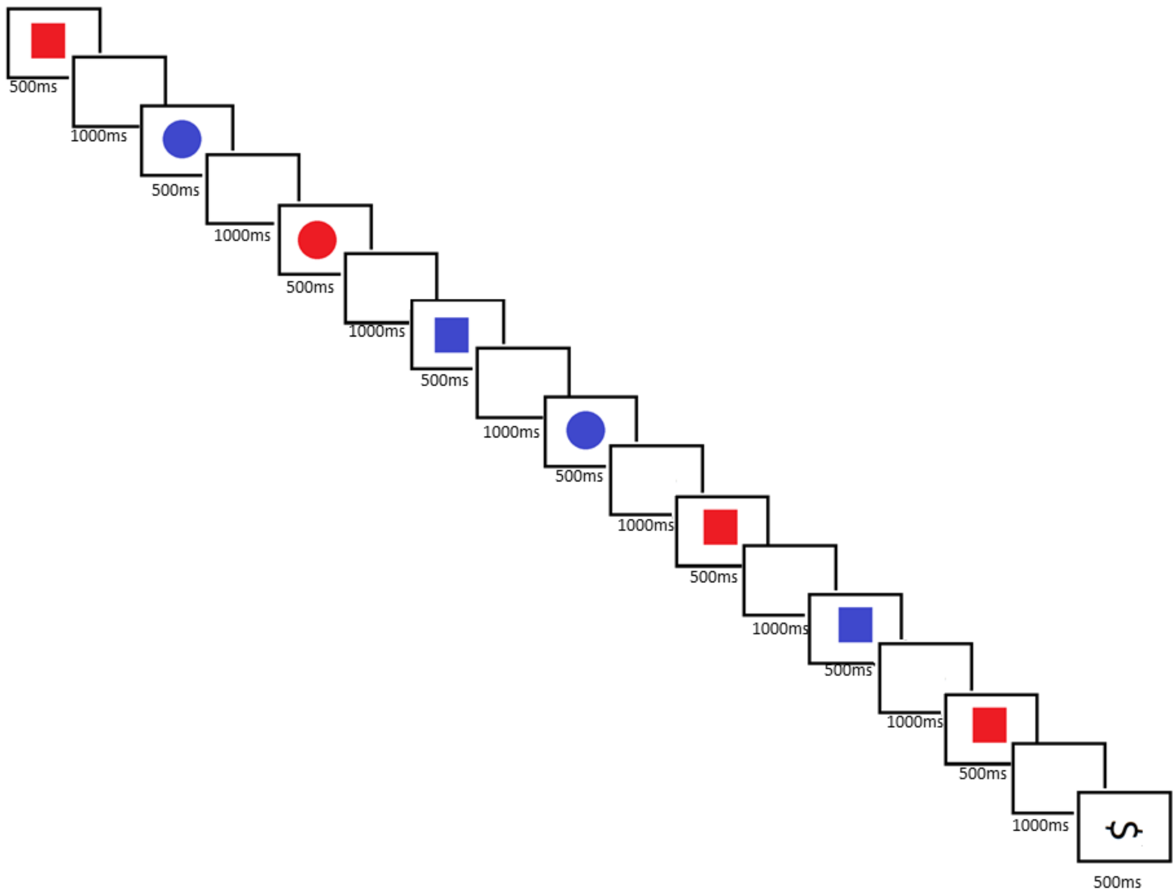


Figure 4. Dendogram created by cluster analysis of the EI of the bilingual picture-naming data.

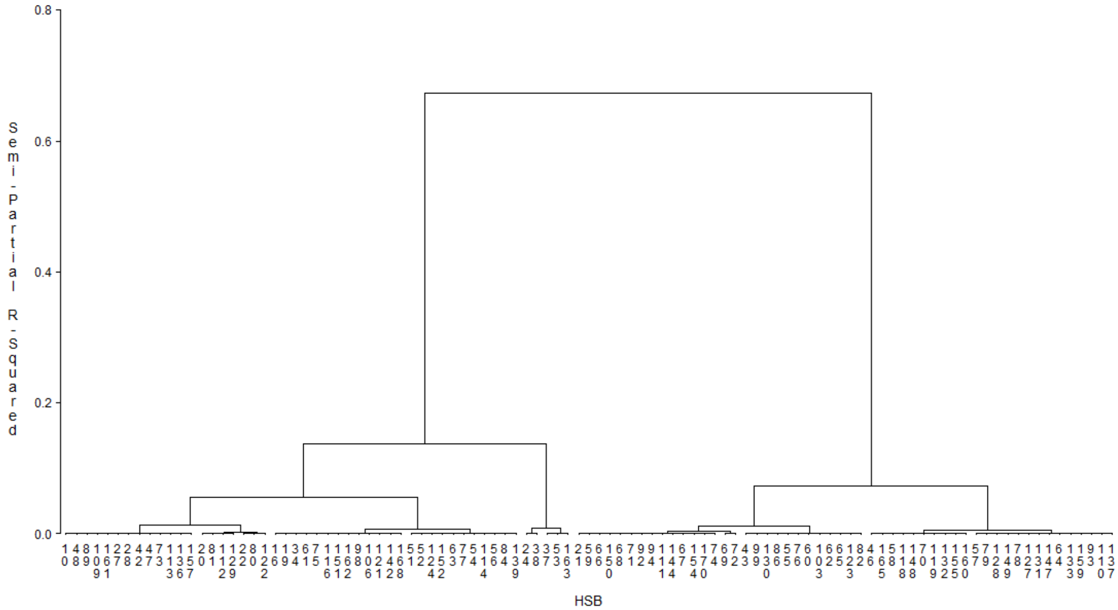


Figure 5. Shape-color reaction time. The log transformed global reaction time for all three groups. The monolinguals were significantly faster than both bilingual groups who were not significantly different from each another.

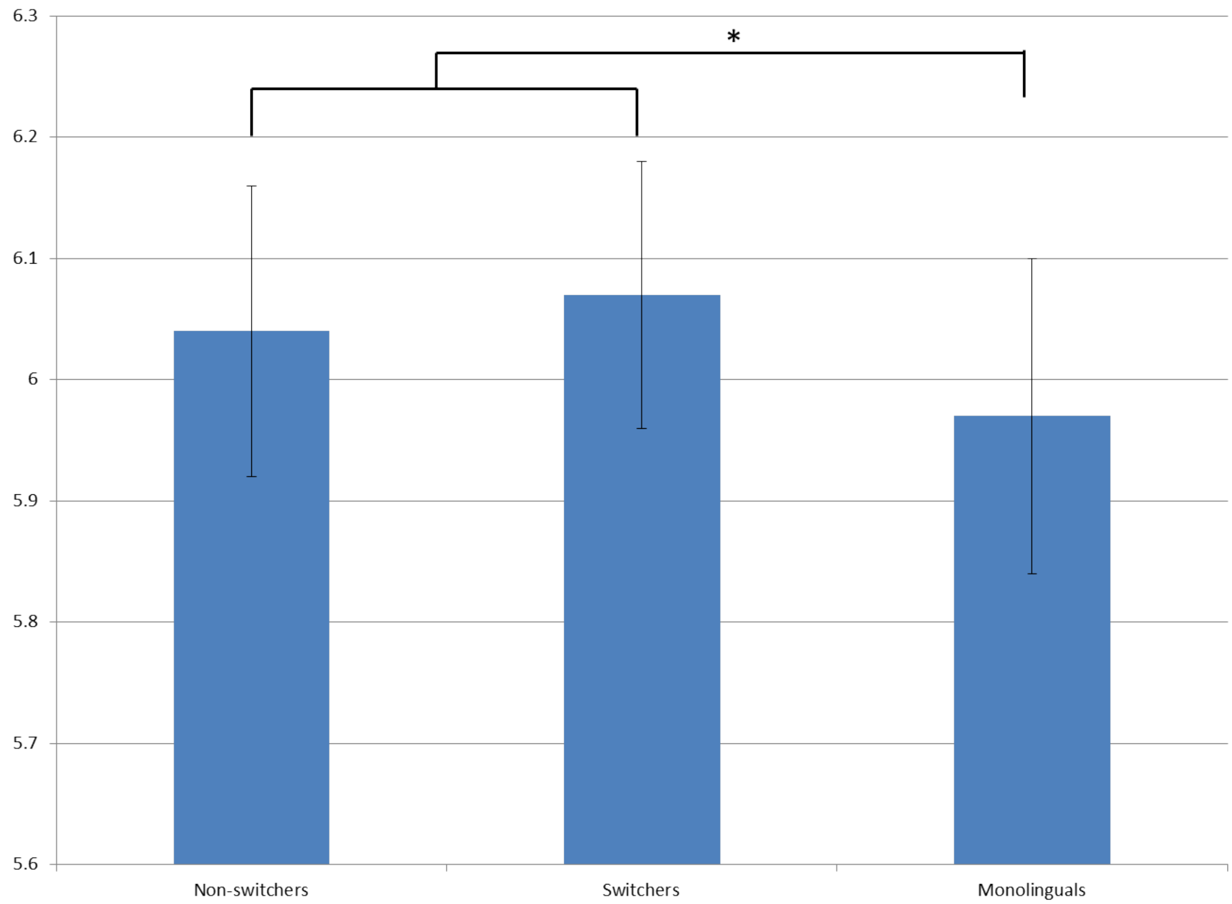


Figure 6. Shape-color accuracy. The square root accuracy of each of the three groups. Note that due to the reverse transformation, high scores represent lower accuracy. Non-switchers were more accurate than switchers, and the monolinguals were not significantly different from either one.

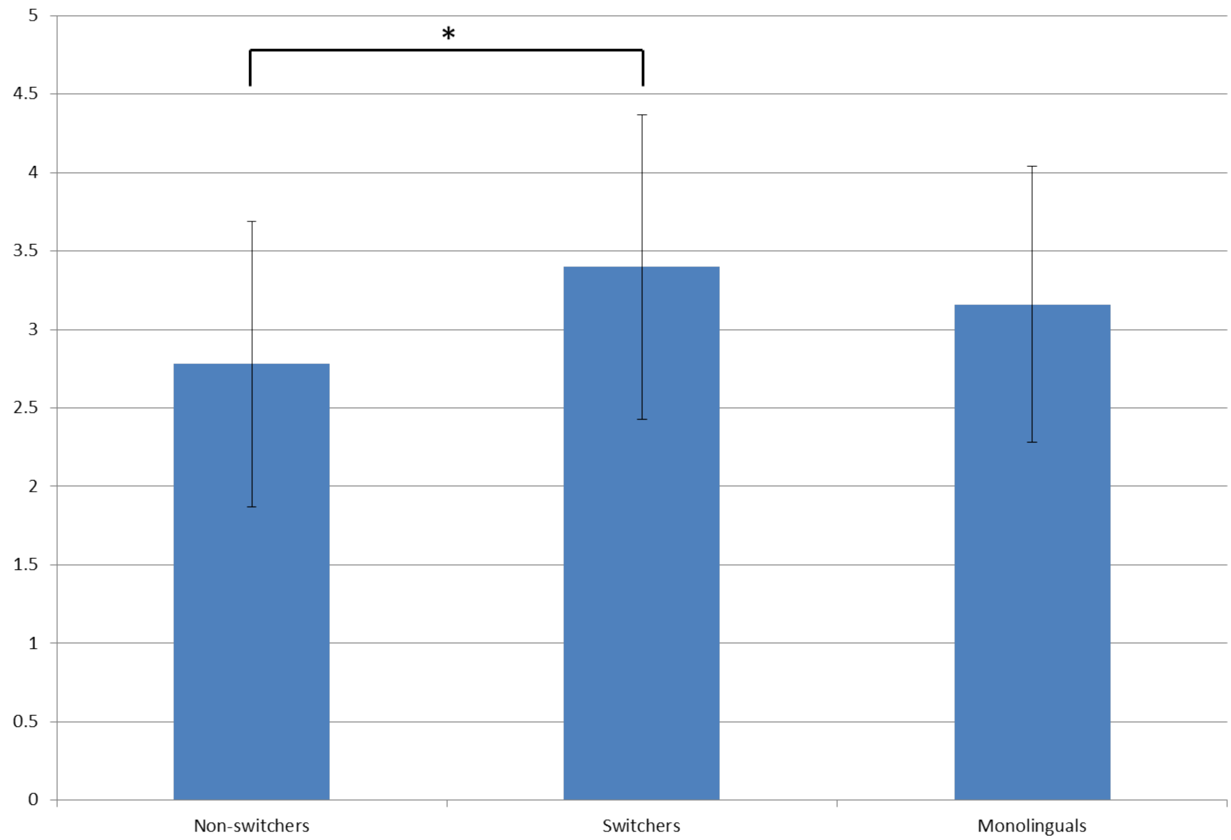
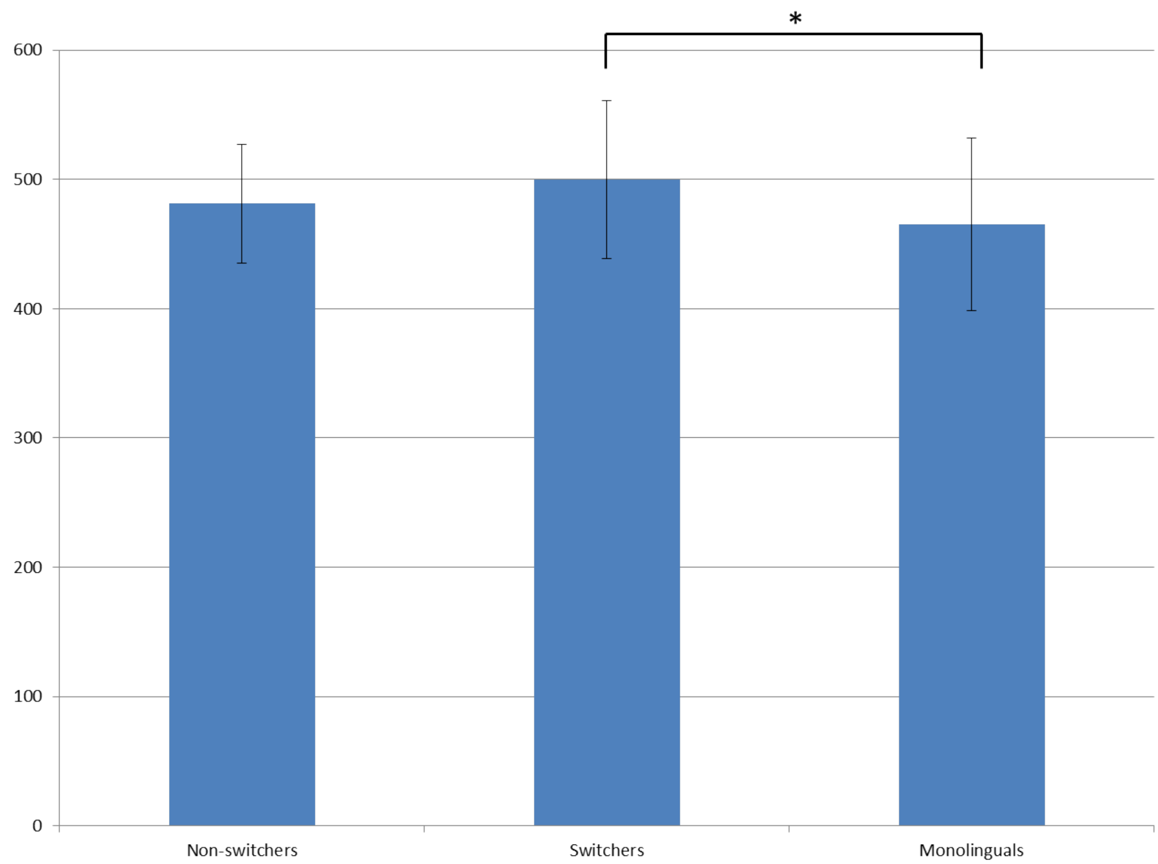


Figure 7. Simon reaction time. Monolinguals were faster than switcher bilinguals, and non-switcher bilinguals did not differ from either group.



Appendix A: Picture-naming items

English	Spanish
basket	canasta
swan	cisne
hammer	martio
watch	reloj
cactus	nopal
dog	perro
stool	vanco
pot	olla
handcuffs	esposas
umbrella	paraguas
bed	cama
log	madera
letter	carta
cake	pastel
apple	manzana
lightbulb	foco
glove	juante
flashlight	lampara
lips	labios
popcorn	palomitas
rabbit	conejo
moon	luna
table	mesa
nest	nido
ax	hacha
donkey	burro
boy	niño
finger	dedo
tire	llanta
lizard	lagartija
waiter	mesero
pan	sarten
horse	caballo
parrot	perrico
man	hombre
shell	choncha
bucket	cubeta
pumpkin	calabaza
scissors	tijeras
envelope	sobre

English	Spanish
goat	chivo
bread	pan
grape	uvas
duck	pato
backpack	mochila
airplane	avion
knife	cuchillo
hand	mano
glass	vaso
glasses	lentes
bag	bolsa
drawer	cajon
bow	moño
butterfly	mariposa
book	libro
wing	ala
house	casa
eye	ojo
tree	arbol
fly	mosca
owl	buho
chair	silla
mushroom	ongo
sun	sol
bear	oso
frog	rana
stoplight	semafolo
pencil	lapiz
piggybank	alcancia
bathtub	tina
arm	brazo
cow	vaca
spiderweb	telaraña
whistle	pito/silvato
fire	fuego
heart	corazon
suitcase	maleta
balloon	globo
candle	vela/veladora
key	llave