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Beyond the bilingual advantage: The potential role of genes and environment on the development of cognitive control

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Abstract

In recent years there has been considerable debate about the presence or absence of a bilingual advantage in tasks that involve cognitive control. Our previous work has established evidence of differences in brain activity between monolinguals and bilinguals in both word learning and in the avoidance of interference during a picture selection task. Recent models of cognitive control have highlighted the importance of a set of neural structures that may show differential tuning due to exposure to two languages. There is also evidence that genetic factors play a role in the availability of dopamine in neural structures involved in cognitive control. Thus, it is important to investigate whether there are interactions effects generating variability in language acquisition when attributed to genetic (e.g., characteristics of dopamine turnover) and environmental (e.g., exposure to two languages) factors. Here preliminary results from genotyping of a sample of bilingual and monolingual individuals are reported. They reveal different distributions in allele frequencies of the DRD2/ANKK1 taq1A polymorphism. These results bring up the possibility that bilinguals may exhibit additional flexibility due to differences in genetic characteristics relative to monolinguals. Future studies should consider genotype as a possible contributing factor to the development of cognitive control across individuals with different language learning histories.

Keywords

Genetic and Environmental Factors; Bilingualism; Cognitive Control

1. Introduction

The claim that bilinguals have an advantage in cognitive control, which includes inhibition, attention, goal maintenance, and task switching has become more and more controversial in recent years (Dunabeitia et al., 2014). The original findings by a number of research studies with different age groups of bilinguals outperforming monolinguals across a variety of

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cognitive control tasks (Bialystok, 2006; Bialystok, Craik, & Luk, 2008; Bialystok, Craik, Klein, & Viswanathan, 2004; Albert Costa, Hernandez, & Sebastian-Galles, 2008) have come into question. For example, Morton and Harper (2007) have argued that the bilingual advantage disappears when groups are equated for socioeconomic status (SES) and non-immigrant status. Similarly, Kousaie and Phillips (2012), testing a group of bilinguals in Montreal, found minimal differences between monolinguals and bilinguals in three separate experiments for both electroencephalographic (EEG) and behavioral measures. However, some studies have failed to find advantages for bilinguals in a variety of cognitive tasks (Anton et al., 2014; Paap, Darrow, Dalibar, & Johnson, 2014; Paap & Greenberg, 2013; Paap & Sawi, 2014). Finally, a recent article by de Bruin, Treccani, and Della Sala (2015) evaluated abstracts from professional conferences. The authors showed that 63% of the abstracts supporting a bilingual advantage were subsequently turned published as journal articles between 1999 and 2012 whereas only 36% that found no difference between the two groups were published in that same time frame. Given the variability in findings across studies, one is left wondering whether the advantage phenomenon is indeed existent or not (for further discussion see Bialystok, Kroll, Green, MacWhinney, & Craik, in press).

1.1 Cognitive control, language control and individual differences

Research considering individual differences has shed light both on the factors that potentially play a role in both cognitive and language control. Festman, Rodriguez-Fornells, and Munte (2010) investigated differences in control by dividing a group of bilinguals into two, based on their performance on a picture-naming task. Bilinguals who made a large number of wrong-language errors constituted the “switcher” group, whereas those with few errors constituted the “non-switcher” group. Participants also completed four non-verbal tasks measuring different aspects of control. Across all four tasks the switcher group performed worse than the non-switcher group—performance on the non-verbal tasks mirrored performance on the verbal task. In a follow-up study, Festman and Munte (2012) administered a picture-naming task to late bilinguals (mean age 24.6 years) who had spent 8–10 years in Germany at the time of testing and showed balanced proficiency profiles in Russian and German. Like the previous study, participants were divided into “switchers” and “non-switchers.” Participants were administered two tasks requiring conflict monitoring and conflict resolution, the Wisconsin Card Sort Task (WCST) and the Flanker Task. Non-switchers performed better than switchers on both tasks. Hence, results across both studies reveal that bilingual language performance, particularly in language switching tasks, is related to performance on cognitive control tasks. Higher cognitive control ability, including conflict monitoring, results in decreased unintentional switching.

Another individual difference that has been found to influence cognitive control is socioeconomic status. Studies investigating the effects of socioeconomic status have found that individuals from lower socioeconomic status also show lower scores on measures of working memory and cognitive control. For example, Ardila and Rosselli (1994) found effects of parental education on measures of working memory and cognitive control. Although reviews of the literature find a larger effect for measures of language, there are still small but reliable effects of SES on cognitive control in both children and adolescents (Hackman, Farah, & Meaney, 2010; Lawson, Duda, Avants, Wu, & Farah, 2013).

Furthermore, recent studies have begun to identify how home environments may influence the gap between individuals from different socioeconomic strata (Hackman, Gallop, Evans, & Farah, 2015).

Taken together studies of control in bilinguals suggest that individual differences in cognitive control correlate with differences in non-verbal control. Work looking at SES also finds an effect on measures of cognitive control, albeit not as large as those seen for language-related measures. The question that emerges when we consider this is how these differences in experience relate to the development of control. In the next sections, we discuss the nature of control in bilinguals before returning to factors that may determine an individual's cognitive control ability.

1.2 The neural basis of cognitive control

The neural bases of cognitive control in bilinguals has been the topic of considerable interest in recent years (Abutalebi, 2013; Buchweitz & Prat, 2013; A. Costa & Sebastian-Galles, 2014; Grady, Luk, Craik, & Bialystok, 2015; Grant, Dennis, & Li, 2014; Hernandez, 2013b; Li, 2013; Onnis, 2013; Stocco, 2013; Tu et al., 2014; Weissberger, Gollan, Bondi, Clark, & Wierenga, 2015). These studies have generally converged on a series of areas that are involved in modulating cognitive control in bilinguals. This network is comprised of a set of cortical and subcortical areas including the dorsolateral prefrontal cortex, the inferior parietal lobule, the anterior cingulate gyrus, and the caudate nucleus. These areas have been generally thought to be involved in executive function and working memory. The caudate nucleus has strong interconnections with the dorsolateral prefrontal cortex and as such plays a role in higher-level control. The anterior cingulate gyrus is involved in conflict monitoring and error detection. The inferior parietal cortex has also been associated with working memory and is seen in a number of bilingual studies of language switching (for further discussion see Abutalebi, 2008).

In the past two years, two separate studies conducted at the laboratory for the neural bases of bilingualism at the University of Houston have found evidence of a difference between monolinguals and Spanish-English bilinguals. Previous studies of language history variables (e.g. language proficiency, age of second language acquisition, etc.) have found that they are related to cognitive control functioning (Iluz-Cohen & Armon-Lotem, 2013; Luk, DeSa, & Bialystok, 2011; Prior & Gollan, 2011). In our case, the bilinguals we test, generally, come from immigrant homes where Spanish is primarily spoken. English is learned through schooling. Previous studies in our laboratory have found that children in this group transition from Spanish dominance in early childhood to English dominance in adulthood (Archila-Suerte, Bunta, & Hernandez, 2014; Kohnert, Hernandez, & Bates, 1998). Thus, the demographics and effects of learning history on language processing in this group of early sequential bilinguals are well documented.

The first study sought to uncover whether Spanish-English bilinguals and monolinguals showed a difference in word learning. A group of adult Spanish-English bilinguals and English monolinguals were taught a set of German written words that were not orthographically related to Spanish (Bradley, King, & Hernandez, 2013). After learning the words to 90% accuracy, participants were placed in an MRI scanner and asked to make a

living/nonliving judgment on the German words that were intermixed with a set of English words. Interestingly, Spanish-English bilinguals were faster and more accurate at making decisions for German words relative to monolinguals. fMRI scanning revealed that bilinguals showed increased activity in the putamen, whereas monolinguals showed increased activity in the dorsolateral prefrontal cortex and the anterior cingulate cortex.

This study is interesting on two different levels. First of all, it replicates other studies that have found improved accuracy in when learning new words in bilinguals relative to monolinguals (Kaushanskaya & Marian, 2009). Secondly, it suggests that the advantage in word learning seen in bilinguals relative to monolinguals may be reflective of reliance on different parts of the striatum which is comprised by the putamen, the caudate nucleus and other structures. The caudate nucleus has been linked to language control in bilinguals (Abutalebi et al., 2008; Crinion et al., 2006; Mohades et al., 2014; Wang, Wang, Jiang, Wang, & Wu, 2013). Studies with bilinguals tend to point to the putamen being involved in language output or articulation (Hervais-Adelman, Moser-Mercer, Michel, & Golestani, 2014; D. Klein, Zatorre, Milner, Meyer, & Evans, 1994). However, some studies have also found a role for the putamen in cognitive control (Ell, Hélie, & Hutchinson, 2012). This distinction between direct motor responses and planning was evident in the brain activity seen when directly comparing monolinguals and bilinguals by Bradley et al. (2013). Increased activity in the putamen in bilinguals suggests that they either engage in cognitive or motor control when making semantic decisions to the newly learned words.

Monolinguals, on the other hand, engage both cortical and subcortical areas of the brain involved in cognitive control, in this case the caudate nucleus and the dorsolateral prefrontal cortex. Thus, for speakers of only one language, learning a new set of words involves increased activity in a more consciously effortful state. Finally, bilinguals and monolinguals showed no statistically significant differences in behavior or brain activity while performing the living/nonliving task in the scanner for English words. Several studies have found that monolinguals tend to perform better than bilinguals when processing words in a single language (Gollan, Montoya, & Bonanni, 2005; Gollan, Montoya, Fennema-Notestine, & Morris, 2005; Palomar-Garcia et al., 2015). Our language proficiency assessment which involved picture naming outside of the scanner revealed that when naming in English, monolinguals scored higher than bilinguals. The fact that bilinguals were not different from monolinguals for semantic decisions to English words when they were intermixed with German words also suggests that bilinguals are better able to tolerate the cost of switching between languages relative to monolinguals. This fits in nicely with the view that bilinguals have some cognitive processing advantages relative to monolinguals.

The ability to resist interference in bilinguals relative to monolinguals was also observed in a second study done in collaboration with Marian and her colleagues (Marian, Chabal, Bartolotti, Bradley, & Hernandez, 2014). In this study, bilinguals and monolinguals were shown a set of four pictures on a computer screen. Participants were asked to name a target picture (e.g. candy) and ignore the other three distractor pictures. On a subset of trials, one of the distractor pictures shared phonology with the target (e.g. candle). In the other trials, the three distractors did not share phonology with the target pictures. The two groups differed in English proficiency but were matched on a number of variables including their

ability to overcome interference as indexed by performance on the Simon task (Simon, Acosta, Mewaldt, & Speidel, 1976). Significant differences in brain activity between bilinguals and monolinguals was observed. Specifically, monolinguals showed increased activity relative to bilinguals in the left middle frontal gyrus (BA 46), the superior frontal gyrus (BA 9), the left and right anterior cingulate gyri and the primary visual cortex. As noted earlier the frontal areas and the cingulate have linked to cognitive control. Like the findings from Bradley et al. (2013), there was increased activity in areas involved in cognitive control for monolinguals relative to bilinguals, suggesting that both groups differ in their need to allocate resources during a task that involves competing information.

Taken together these two studies in our laboratory have found evidence of a difference in the brain systems needed by bilinguals relative to monolinguals in tasks that include resisting interference or having to engage control during a semantic task for newly learned foreign words. These results were obtained with two separate groups of monolinguals and Spanish-English bilinguals from the University of Houston.

1.3 Modeling the effects of bilingualism on cognitive control

Recent attempts have been made to provide theoretical models for cognitive control. These include the adaptive control hypothesis from Green and Abutalebi (2013) as well as the bilingual brain training hypothesis by Stocco, Yamasaki, Natalenko, and Prat (2012).

Stocco, Yamasaki, Natalenko, and Prat (2012) presented a model of the relationship between the striatum and frontal cortex in an attempt to explain the training effect bilingualism has on the brain. They began by outlining evidence for improved executive function in bilinguals in shifting and inhibition, and continued by discussing neuroimaging studies about the bilingual brain. Specifically, Stocco and colleagues emphasize findings of striatal involvement in bilingualism and executive function. The striatum is highly connected to cortical regions and controls signals to the prefrontal cortex, which has been associated with higher order functions. The authors review a number of neuroimaging studies of bilingualism and report that many find activation of the caudate nucleus (a part of the striatum), which receives and transmits information to the prefrontal cortex. The major argument of the paper is that bilingualism trains frontostriatal loops, leading to superior executive function and language control. The authors link recruitment of the basal ganglia which includes the putamen and the caudate nucleus with bilingual language and executive control.

To further understand this link, Stocco and colleagues generated a computational model of the neural circuit in question. They adopt the Conditional Routing Model, which suggests that the basal ganglia serves as a “gating” mechanism to control information flow to the prefrontal cortex. Without basal ganglia intervention, input to the prefrontal cortex, which receives input from a number of other cortical regions, is prioritized by the pre-existing strengths of these various connections. However, in certain situations in which the prefrontal cortex must respond to novel conditions (e.g. task switching), this shifting in behavior is controlled by the basal ganglia. According to Stocco et al., this circuit is “trained” by bilinguals’ constant need to select, apply, and switch between distinct grammatical rules depending on the language context. This continual practice increases the ability of the basal

ganglia to influence and control input to the frontal cortex, resulting in enhanced performance in tasks of executive function. In sum, Stocco et al. suggest that bilinguals' superior executive function results from the strengthening of the basal ganglia's ability to mediate the flow of information to the prefrontal cortex.

Although Stocco et al. do not mention a particular neurotransmitter system in their review, dopamine is a primary neurotransmitter that is involved in both the basal ganglia and the dorsolateral prefrontal cortex and is known to play a role in cognitive flexibility (Colzato, Pratt, & Hommel, 2010; Klanker, Feenstra, & Denys, 2013; Schulz et al., 2012). Thus it makes sense that Stocco and colleagues model is most likely partially related to the release of dopamine in humans in the frontostriatal tract.

The adaptive control hypothesis provides a similar view with regard to the development of control mechanisms in bilinguals (Green & Abutalebi, 2013). Green and Abutalebi argue that control depends on the particular language context encountered. This could involve single language, dual language and heavy code-switching linguistic contexts. This also interacts with the particular type of control processes utilized, including interference suppression, goal maintenance, and task engagement/disengagement among others. Bilinguals, due to the fact that they encounter dual language contexts more often, must work to tune their control processes to the particular context at hand. Empirical support for the adaptive control hypothesis can be found in studies from other research groups. For example, Prior and Gollan (2011) administered a shape-color switching task to groups of Spanish-English bilinguals, Mandarin-English bilinguals, and English monolinguals. 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: Spanish-English bilinguals reported using both languages more evenly and reported more frequent switching between their two languages than the Mandarin-English bilinguals.

The adaptive control hypothesis of Green and Abutalebi (2013) also points to the importance of dopamine and, therefore, related, genetic mechanisms that might play a role in adaptive control. Specifically, the authors posit that the control-oriented mechanisms needed to handle more than one language may require the release of extra dopamine in brain areas involved in control. There is also evidence that control-oriented mechanisms are heritable (Bolger et al., 2014). Finally, the potential importance of dopamine in language learning has also been pointed out in a seminal review by Wong, Morgan-Short, Ettlinger, and Zheng (2012). However, to date no genetic data has been gathered to support this claim.

1.4 Genetics, dopamine and cognitive control

Recent research in imaging genetics has associated a particular allele of a gene involved in the dopamine system in the brain to both differential brain activation patterns, and behavioral performance on non-verbal control tasks (Fossella, Green, & Fan, 2006; Frank & Hutchison, 2009; Jocham et al., 2009; T. A. Klein et al., 2007; McAllister et al., 2008; McAllister et al., 2005; Stelzel, Basten, Montag, Reuter, & Fiebach, 2010). Carriers of the A1 allele (A1+) of the DRD2/ANKK1 taq1A polymorphism present with a 30% reduction of D2 receptor density, primarily in the striatum, compared to non-carriers (A1-) (Noble,

2000). Of particular interest are two studies conducted by Stelzel and colleagues (Stelzel et al., 2010; Stelzel, Fiebach, Cools, Tafazoli, & D'Esposito, 2013).

In the first study, Stelzel et al. (2010), the effects of the A1 allele on cognitive control abilities and the neural correlates of task switching were examined. Carriers and non-carriers of the A1 allele performed a rule-switching task during an fMRI scan. Participants had to decide whether a number presented on the screen was odd or even in one task, and whether it was smaller or greater than five in the other task. Switching costs were calculated as the difference between repetition trials (same task as the previous trial), and switch trials (different task than the previous trial). A1 non-carriers presented with increased switching related activity in the left inferior frontal junction (IFJ) and connectivity between the IFJ and dorsal striatum. Behaviorally, a medium to large effect of genotype on switching costs was also reported, with non-carriers presenting with increased switching costs compared to carriers. This study suggests that differences in task performance and brain activation patterns are influenced by genetic contributions to D2 receptor density.

In the second study, Stelzel et al. (2013) tested the direct effect of dopamine receptor D2 stimulation on task-switching. Participants were administered a low dose of bromocriptine, a DRD2 agonist, or a placebo (in two separate sessions), and their performance on a rule-switching task was examined utilizing fMRI. Switching effects were greater under bromocriptine than under a placebo, characterized by signal increases in the left IFJ during rule-switch trials and signal decreases in the rule-repetition trials. Activation in the left caudate indicated greater switching-related activity under the effects of the drug compared to a placebo. Increased functional connectivity of the caudate nucleus with the IFJ during rule-switching under bromocriptine was also exhibited. The results of this study, that a D2 receptor agonist increases switching related activity, most notably in the IFJ, add to a body of evidence connecting the dopamine system to cognitive flexibility. Behavioral results also revealed differential effects of bromocriptine on reaction time depending on task conditions. Taken together, these studies show that variation in the performance of the D2 receptor, whether genetic or pharmacological, contributes to task-switching performance.

Earlier we discussed results from two studies by Festman and colleagues on the connection between language control and cognitive control. One possible explanation of Festman and colleagues' findings is that they were selecting individuals who might show an underlying difference in the use of cognitive control. Festman and her colleagues allude to the possibility that it might stem from an underlying individual difference in control, which is possibly genetic. A separate line of research has established a connection between A1 carrier status and the ability to switch between tasks. The question is whether this difference in control may have to do with differences in the carrier status of the A1 gene. To date no study has sought to uncover whether or not genetic differences in this gene interact with bilingualism.

2. Sources of genetic variability: Preliminary findings

We have recently begun to collect genetic material from a group of bilinguals and monolingual controls (see Table 1). All monolinguals were Caucasian in order to match our

sample to that collected by Stelzel and colleagues. Bilinguals who learned Spanish at home and English later in life ($M = 6.21$ years; $SD = 3.00$) were chosen from the Hispanic population at the University of Houston. The latter group comes from the same population that was tested in the two studies mentioned earlier. The preliminary findings reported here are part of a project that seeks to address whether the ANKK1 gene (rs1800497) might help to explain some of the variability in findings related to the bilingual advantage. The Institutional Review Board at the University of Houston approved the collection of genetic material through saliva samples, which was analyzed at Yale University.

This future study will seek to test whether genetic status, language history or both contribute to the magnitude of the switching effect using a 2×2 ANOVA design. Our first hypothesis is that we should replicate the finding of reduced switching costs in A1+ carriers across all subjects, if in fact, the findings by Stelzel and colleagues is generalizable to a larger more heterogeneous population. The main question of interest, however, is whether carrier status augments or interacts with language history. For example, if individuals with the A1 allele are indeed better at switching then we might find that the benefits of bilingualism may not apply to them relative to a group of A1+ monolinguals. Alternatively, bilingualism might provide a natural benefit to those without the A1 allele such that only monolinguals without an A1 allele show a disadvantage in switching tasks relative to bilinguals. By testing the effects of bilingualism and gene carrier status, we hope to elucidate the effect of a potential confounding variable.

Because we were splitting our bilingual group into four rather than two subgroups, our initial collection involved a larger bilingual group than monolingual group. However, the preliminary results we have collected suggest that not controlling for gene carrier status might have a possible unintended consequence. The main question here is whether the two populations in our study differ or not in the presence of this particular allele. Genotyping of 58 monolinguals revealed that 18 were A1+ and 40 were A1-. This is in line with previous studies with Caucasians (Noble, 2000). The bilingual college students showed a different frequency of the A1 allele. Eighty-four Spanish-English bilinguals carried the A1 variant and thirty-eight did not. In short, roughly two-thirds of our Hispanics were carriers of the A1 allele relative to one-third of our Caucasians (see Figure 1). A chi-square test comparing the proportion of bilinguals and monolinguals with the A1 allele revealed a significant difference ($\chi^2(1) = 21.38, p < 0.0001$).

Previous studies with Hispanics in the US show the prevalence of the A1 allele to be somewhere between sixty and thirty-three percent. However, none of the previously published studies have reported data on educational attainment or socioeconomic status (SES) in a US sample (see Madrid, MacMurray, Lee, Anderson, & Comings, 2001 for potential effects of SES in a Hispanic sample from Honduras). These preliminary results suggest the possibility that differences in cognitive control between monolinguals and bilinguals may be due to the underlying distribution of the A1 variant in the gene within our population.

3. Discussion and Future Directions

This finding leaves open a very interesting question that should be addressed in future work. What role do genetics and/or bilingualism contribute to cognitive control? It is important to note that this particular gene, *DRD2*, appears to be only one of a subset of genes involved in dopamine and cognitive control. Thus, future work should explore a number of genes and a number of polymorphisms within these genes, the underlying distribution of different alleles at those polymorphisms in different populations, and the potential role that those genes/alleles might play in cognitive control within and between populations. The current results suggest that asking this question may yield a richer and deeper view of what factors might affect cognitive control in general and its role in bilingualism in particular.

Despite these caveats, the preliminary results do lead to an interesting question. Why would a gene the variation in which has been associated with individual differences in cognitive flexibility have double the frequency of a particular allele in the bilingual samples relative to the monolingual samples that we obtained at the University of Houston? As noted above, one possibility might be a difference in allele frequency in different ethnic populations that contribute to these samples. However, another intriguing possibility has to do with the characteristics of the particular population we are testing. In general, the Hispanic population has lower socioeconomic status relative to Caucasian monolinguals in our sample. All of the bilinguals are sequential, meaning that they first learned Spanish and then learned English at school. Studies looking at the development of second language proficiency indicate the need for greater cognitive control across development, particularly when transitioning from Spanish to English dominance in late childhood (Archila-Suerte, Zevin, Ramos, & Hernandez, 2013; Kohnert, Bates, & Hernandez, 1999). Those with the A1 allele, because of the advantages of cognitive flexibility, may be in a prime position to make the transition to English in a more expedient manner. Monolinguals, on the other hand, who gain exposure to English much earlier may be able to overcome a lack of flexibility through increased practice in a single language. In short, it is possible that bilinguals who scale up the educational ladder benefit to a greater extent from added flexibility. Notice that it is not the case that the A1 allele is a necessity. Roughly one-third of our bilinguals did not carry the A1 variant of the gene. These results indicate the need to further understand the potential genetic contributions to cognitive control, both the advantages and limitations of these contributions. Additional studies are needed to indeed show that the proportion of carriers differs in the college and non-college educated segments of the Hispanic population in the United States. Further study with Hispanic monolingual controls would also be of value. The preliminary findings reported here are only a small step in this direction.

For the most part, the literature on cognitive control differences between monolinguals and bilinguals has focused on the nurture side of the nature-nurture debate. The question is to what extent the environment plays a role in the differences observed in an outcome variable. In this specific case, we are discussing language history and cognitive control. Work on the genetics of flexibility looking at the *ANMK1* gene has focused on the how each variant may play a role in cognitive flexibility. The results from simple genotyping of a bilingual and monolingual sample suggest that both factors may play a role. Again, we note that we do not

have the definitive answer to the question, but our data offer the possibility that both environment and genes may interact in highly dynamic ways.

In this sense, the question of the bilingual advantage (or lack thereof) misses the most important point. The real question should be what factors play a role in the development of cognitive flexibility. Some are certainly environmental and others are most likely genetic. Neither are absolutely deterministic in any fashion (Elman, 1996), and both factors are laid out over time in individuals who may come from very different populations. In this respect, our preliminary findings, like a recent study by Yang, Gates, Molenaar, and Li (2015), highlight how individual differences may play a role in bilingualism. Furthermore, the debate on the effects of bilingualism bears a strong resemblance to the debate that has emerged over the effects of online “brain training” games on cognitive processing in older adults. In a similar respect, researchers have suggested that many possible factors (i.e. exercise or non-intelligence boosting video games) may have as big an effect as programs that have been marketed as having beneficial cognitive outcomes. The reality is most definitely complex but in looking at this complex pattern it is our hope that research might turn to understanding more about the process of language and cognitive development in both bilinguals and monolinguals instead of trying to show whether bilinguals have an advantage or not.

Whereas bilingualism has been widely examined as contributing to executive function, other environmental influences (e.g. musical training, video games, SES) have also been found to relate to performance on these tasks (Bialystok, 2006; Moreno et al., 2011). We therefore propose the view that bilingualism is one of many factors (both environmental and genetic) that may affect cognitive control, and the field should evolve and adopt a more holistic view of these various influences (Hernandez, 2013a; Hernandez & Li, 2007).

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- Bilingualism and genetics both previously found to affect cognitive control
- 31% of monolinguals and 69% of bilinguals in college student sample carry allele of interest
- Holistic view of the effects of genes and environment on cognitive control is outlined

Figure 1.
Proportion of A1+ and A1- Alleles in Monolingual and Bilingual Samples

Table 1

Demographic information for bilingual and monolingual sample.

Language Background	Spanish-English Bilingual	English Monolingual
N	122	58
English Age of Acquisition	M = 6.21; SD = 3.00	N/A
English Proficiency ^{*1}	M = 73.96; SD = 5.80	M = 80.36; SD = 5.28
Spanish Proficiency ²	M = 76.58; SD = 7.58	N/A
SES ^{*3}	M = 2.94; SD = 1.46	M = 4.29; SD = 1.03
Fraction with A1 allele	84/122	18/58

¹ English proficiency was measured using the Vocabulary and Passage Comprehension Subtests of the Woodcock-Munoz Language Proficiency Battery-Revised: English Version (Woodcock & Muñoz-Johnson, 2005)

² Spanish proficiency was measured using the Vocabulary and Passage Comprehension Subtests of the Woodcock-Munoz Language Proficiency Battery-Revised: Spanish Version (Woodcock & Muñoz-Johnson, 2005)

³ SES was measured using maternal education rated on a scale from 1–6. 1 = Some elementary school or less than elementary. 2 = Some high school or less than high school. 3 = High school graduate. 4 = Some college. 5 = College Graduate. 6 = Advanced degree.

* significant difference between groups at $p < 0.0001$