Does Language Translate to Executive Functions?
Investigating the Bilingual Advantage in Executive Control

Melina L. Knabe

Washington and Lee University

Lexington, Virginia

Author Note

Melina L. Knabe, Neuroscience Program - Department of Biology,
Washington & Lee University

The author wishes to thank Dr. Sarah Blythe, Dr. Wythe Whiting, and Dr. Daniel Johnson for their continued guidance, revision, and support. This work would not have been possible without their mentorship.

This work was supported in part by the Virginia Academy of Science Undergraduate Research Grant

Contacts: knabem17@mail.wlu.edu

Abstract

Given that twenty-percent of the U.S. population speaks a language other than English at home, it is imperative to assess the effect of a second language on brain structure and function. The *bilingual advantage hypothesis* claims that command over two languages leads to enhanced non-linguistic cognition. The need of a bilingual to maintain both languages active simultaneously, inhibit one, and flexibly switch between both may transfer to executive control (EC) functions. The present study investigates the effect of mono- and bilingualism on inhibitory control and cognitive flexibility across age groups. Implementing an online format, mono- and bilinguals (ages 18-89, n = 334) of diverse language parities completed a language background and demographic questionnaire. EC performance was assessed using a Simon task, task-switching paradigm, and directed forgetting (DF) paradigm. In addition, Shipley-II vocabulary and block patterns tests served to assess crystallized and fluid intelligence. It was hypothesized that bilinguals would outperform monolinguals on all tasks and that this difference would be most pronounced in older ages. Further, it was hypothesized that amongst bilinguals, age of active onset, language proficiency, and amount of language switching would be most predictive of outcomes. A moderated regression showed that after controlling for various lifestyle factors, middle-aged bilinguals showed faster reaction times than their monolingual counterparts, suggestive of a Bilingual Executive Processing Advantage (BEPA) rather than a Bilingual Inhibitory Control Advantage (BICA). Results also revealed that this trend disappeared in the task-switching paradigm, a more demanding task. Finally, young bilinguals showed greater item recall on the DF paradigm, suggesting improved maintenance of information in the presence of interfering information. Multiple hierarchical regressions revealed no significant predictive value of various bilingual experiences on task outcomes, except for a putative role of age of active onset on Simon effect outcomes.

Keywords: bilingualism, bilingual advantage, executive control, language control, aging

Does Language Translate to Executive Functions?
Investigating the Bilingual Advantage in Executive Control

Introduction

Bilingualism as a Source of Neuroplasticity

Various experiences fundamentally change brain structure and function through practice and repetition, including excessive computer use (Green & Bavelier, 2003), musical ability (Moreno et al. 2011), juggling (Draganski et al. 2004), careers in architecture (Salthouse & Mitchell, 1990), and taxi-driving (Maguire et al. 2000). Therefore, the notion that life experiences can substantially reorganize the brain is not novel. However, one underappreciated experience with putative effects on cognition is bi- or multilingualism (i.e. the ability to speak more than one language fluently).

Considering that twenty percent of the U.S. population (2007 American Community Survey) speaks a language other than English at home, it has become increasingly important to address the effect of multilingualism on cognition. The literature has produced mixed results, demonstrating that the exact direction and manner by which language affects cognition remains unclear (Bialystok, 2009). Regardless, prolonged experience with a cognitively stimulating activity may contribute to cognitive reserve (Stern, 2002). In fact, when investigating the impact of bilingualism on the development of Alzheimer’s disease, studies demonstrate that onset of cognitive decline is delayed by 5 years in bilingual patients in comparison to matched monolinguals (Craik, Bialystok, & Freedman, 2010). Unlike other experiences, language is active at all times and speakers become “language experts” who are neither selected for interest nor talent. This begs the question of how being an expert in more than one language impacts the brain.

Beyond differing in daily language use, differences between mono- and bilinguals have been shown in structural and functional imaging studies. When comparing healthy monolinguals to bilinguals with early language exposure and high proficiency, bilinguals demonstrated a distinct “neural signature” (Kovelman, Baker, Petitto, 2008). Specifically, early-exposed, very proficient bilinguals showed similar activation in their two languages. Abutalebi and Green (2008) claim that this bilingual language control (bLC) system utilizes processes from the domain-general executive control (EC) system. In controlling both language systems and preventing conflict from the second language, bilinguals recruit the anterior cingulate cortex (ACC), prefrontal cortex (PFC), and caudate nuclei, implicated in non-linguistic cognitive control (Abutalebi et al. 2011). Taken together, these studies suggests that the distinction between a mono- and a bilingual is not merely sociolinguistic, but also functional.

While joint activation of both languages may enhance EC function, it also contributes to poorer lexical retrieval. Indeed, bilingual children develop their vocabulary more slowly than their monolingual peers, and often demonstrate diminished vocabularies in both languages (Oller & Eilers, 2002). Studies have also shown differences in receptive and expressive vocabulary (Bialystok, Luk, Peets, & Yang, 2010) as well as verbal fluency, which continue into adulthood (Gollan & Kroll, 2011; Portocarreroro, Burright, & Donovick, 2007). The aforementioned deficits in lexical retrieval may stem from a bilingual learning two languages in the same timespan as a monolingual learns one language, resulting in larger combined vocabularies (Bialystok, Luk, Peets, & Yang, 2010). Finally, these linguistic deficits arise primarily when individuals must rapidly retrieve words (Young, 2016).

Language Control Transfers to Executive Control

Ironically, while conflict between both languages compromises lexical access, activation of both languages may enhance cognitive control processes that mitigate interference effects and allow for switching between languages (Bialystok, 2009; Costa et al. 2008; Hernández et al. 2000). Thus, bilinguals become experts at eliminating interfering information, representing and maintaining "rules" when conversing, and switching between languages. Given that the EC system entails inhibition, mental set-shifting (i.e. task-switching or cognitive flexibility), and updating information in working memory (WM) (Miyake et al. 2000), it is plausible that a bilingual's language experiences confer general advantages in non-linguistic domains. The hypothesis purporting that language status results in enhanced non-linguistic cognition has been coined the *bilingual advantage*. In fact, researchers have observed measurable differences in reaction times (RT) between mono- and bilinguals on a variety of EC tasks. Specifically, studies have indicated that bilinguals demonstrate better inhibitory control and cognitive flexibility in comparison to their monolingual peers. I would like to emphasize that despite observed differences in behavioral and imaging studies, it remains to be determined whether the effect of bilingualism on various EC functions is advantageous, disadvantageous, or negligible (Bialystok, 2009).

Inhibitory Control and the Bilingual Advantage

Differences between mono- and bilinguals have been studied extensively in the domain of inhibitory control (Kroll & Bialystok, 2013). The *inhibitory control model* developed by Green (1998) claims that due to joint language activation, bilinguals must employ the EC system to resolve conflicts between languages, contributing to greater inhibitory control. In effect, based on cues in the environment, one language is preferentially selected over the other, while the irrelevant language is suppressed (Fabbro, Skrap, & Aglioti, 2000). These cues rely on the language spoken or heard, the location, and the partner of interaction (Heidlmayer et al., 2014).

The Simon task (Simon & Ruddell, 1967) is one of the most widely used tasks employed in bilingualism research. Here, based on a color cue, participants must respond with a corresponding key press while suppressing information about cue position. Trials in which the position and key press correspond are known as congruent trials, while trials where these responses do not converge are known as incongruent trials (Bialystok, 2009). Efficient at inhibiting conflicting information through selective attention, bilingual children (Martin-Rhee & Bialysotk, 2008), young adults (Bialystok, 2006) and middle-aged and older adults (Bialystok, Craik, Klein, & Viswanathan, 2004) have been shown to outperform monolinguals on the Simon task. With age, older adults exhibit slower overall RTs on the Simon task. However, faster RTs in older bilinguals suggest that bilingualism may hamper the rate of slowing observed on EC tasks with age (Daniels, Toth, & Jacoby, 2006; Bialystok, Craik, & Ryan, 2006). Thus, apart from interacting with age, longer experiences with bilingualism may result in greater practice of certain EC functions. It is important to note that some studies fail to replicate the bilingual advantage in the Simon task (Morton & Harper, 2007), challenging its robustness.

Task-Switching and the Bilingual Advantage

Apart from inhibiting the non-target language, bilinguals must also maintain both languages active and switch between languages in a controlled manner. This is captured by another domain of EC: mental set-shifting (i.e. cognitive flexibility and task-switching) (Diamond, 2013). Task-switching requires the maintenance of several sets of instructions that are executed based on a cue (Bialystok, Craik, & Ryan, 2006). Based on functional imaging and behavioral studies, investigators have claimed bilinguals are “set-shifting experts” (Wisehart, Viswanathan, & Bialystok, 2016). Having to focus attention on one task in a context where two conflicting options are presented simulates a bilingual's daily experience of controlling and selecting between two language options. Because cognitive flexibility is considered an integral part of EC function (Sylvester et al., 2003), practicing task-switching actually improves performance on EC tasks (Karbach & Kray, 2009). As such, a bilingual's practice in switching between languages could generalize to non-linguistic control functions. These observations are met with contradictory evidence that bilingualism affects task-switching performance (Garbin et al. 2010; Costa et al. 2008, 2009). Understanding the role bilingualism plays in task-switching is important, especially considering that cognitive control decreases markedly with age (Kramer, 1999). This is due in part to decreased neural efficiency, (Gold et al. 2013). Using a color-shape task-switching paradigm, Gold et al. (2013) showed that lifelong bilingualism resulted in lower switch costs and activation of the dorsolateral prefrontal cortex (DLPFC), ventrolateral prefrontal cortex (VLPFC), and ACC. This suggests that by switching languages daily, bilinguals increase the efficiency of brain regions implicated in shifting, meaning that cognitive control processing becomes more automatic. Whether this observation extends to behavior across a wide age range has yet to be determined.

Proactive Interference and the Bilingual Advantage

I will now turn to the third component of EC: updating WM. According to Bialystok (2009), it remains unclear whether bilingualism affects WM. It is possible that domain-general enhancements in EC transfer to WM. However, based on free recall tests, bilinguals do not seem to exhibit greater recall on verbal (Fernandes, Craik, Bialystok, & Kreuger, 2007) or non-verbal tasks (Bialystok et al. 2008). However, it has been established that WM processing capacity is improved when interfering information is eliminated (Jonides & Nee, 2006). For example, the inability to effectively suppress goal-irrelevant information may underlie the WM deficits seen in aging individuals (Conway & Engle, 1994). Considering that the demand to inhibit one language and selectively attend to another language is high in bilinguals, it is plausible that they are better at eliminating interfering information.

Never before utilized in bilingualism research, DF tasks make use of *controlled forgetting strategies*, in which interfering information is suppressed (Reitman, Malin, Bjork, & Higman, 1973). After studying a word list, subjects assigned to a Forget group are offered a cue to forget the previously learned list, while a Remember group is administered a cue to remember the list. Both groups are then asked to remember a second word list before completing a final recall test on both lists. Results reveal that for subjects in the Forget group, elimination of interfering information leads to improved recall on the latter material. While DF studies employ two separate lists, these two sets of materials interact with one another (Sahakyan & Goodmon, 2007). Studies have indicated that the first material studied will adversely affect retention of the second material studied, particularly if the two lists are related in content (Underwood, 1969). This observation is known as *proactive interference* (PI), where previously learned material disables retention of novel information (Underwood, 1969).

Researchers have not extensively studied differences in elimination of PI between mono- and bilingual populations. Bialystok & Feng (2009) provide the only study investigating language proficiency and PI using mono- and bilingual children. Considering that bilinguals experience intrusions from the non-target language, or a cross-language speech error (Abutalebi et al. 2011), DF tasks employing PI may help develop a better understanding of differences in inhibition between mono- and bilinguals.

Inconsistencies in Bilingualism Research

While research suggests that certain bilingual populations will demonstrate improved performance on tasks commonly used to assess EC function, findings have been inconsistent. Hilchey and Klein (2011) reviewed empirical literature and challenged the bilingual advantage in inhibitory control. In reviewing the data, the authors observed that bilingual advantages vanished with more practice of the task, suggesting that factors apart from language may influence task performance. The authors concluded that a bilingual advantage in conflict resolution, or nonlinguistic inhibitory control, was only rarely observed. Similarly, Paap, Johnson, & Sawi (2014) claim that since 2011, more than 80% of the studies examining a bilingual advantage demonstrated inconclusive results and small sample sizes. A further explanation for the lack of observed differences is that various factors (e.g. education, socio-economic status, exercise, IQ etc.) affect general EC functioning.

Inconsistencies in research results may also be due to differences in language profiles of the populations studied, disparities in criteria used to determine bilingualism, and different experimental tasks and demands. Disparate task difficulties, memory loads, and task types (i.e. verbal or nonverbal) affect the reported benefits of bilingualism on higher order functions (Bialystok, 2015). According to Bialystok (2015), this variation in methodology reflects the different linguistic experiences amongst bilinguals, who vary in the two languages spoken, verbal and written abilities, age of acquisition, amount of daily use, and age of active second language use. For that reason, much of the recent literature has focused on finding reliable and valid measurements of the degree of bilingualism. In fact, recent evidence suggests that age of active onset of language use is most predictive of performance on EC tasks (Luk, De Sa, & Bialystok, 2011).

Additional confounding factors in bilingualism research include that EC function is affected by genetics (Friedman et al., 2008), as well as specialized skills (i.e. video game playing, musical training, education, exercise) (Bialystok, 2006; Valian, 2014). Secondly, results depend on the linguistic similarity between the two languages, socio-economic status (SES), and immigrant status (Valian, 2014). Additional factors include a parents' level of education and income, as well as childhood intelligence (Paap & Greenberg, 2013; Bak, Nissan, Allerhand, & Deary, 2014). Similarly, resources provided by parents (e.g. educational and enriching opportunities) can also affect cognitive development (Dickinson & Adelson, 2014). Finally, the age of the sample may also influence obtained results.

Despite these inconsistencies, the impact of bilingualism on cognition has been observed in all age groups: infancy (Kovács & Mehler, 2008), toddler-hood (Poulin-Dubois, Blaye, Coutya, & Bialystok, 2011), young childhood (Carlson & Meltzoff, 2008), middle childhood (Bialystok, 2011), young adulthood (Costa, Hernández, & Sebastian-Gallés, 2008), and older age (Bialystok, Craik, Klein, & Viswanathan, 2004). In fact, the majority of literature focuses on the effect of bilingualism in children, possibly due to concerns that the command of more than on language adversely impacts development (Bialystok, Martin & Viswanathan, 2005). Thus, one aim of this study is to determine whether the advantages of multilingualism extend into adulthood.

The Current Study

The current study serves to investigate the following questions: (1) What type of bilingual experience contributes advantageously to EC? (2) At what age, if at all, is the bilingual advantage robust? (3) Could a DF paradigm be implemented in bilingualism research? (4) How do inhibitory control and cognitive flexibility interact across the lifespan of a mono- and bilingual? While various studies have demonstrated a bilingual advantage in the Simon task and task-switching paradigms, investigators have not used a classic DF paradigm in comparing mono- and bilingual populations across a wide range of ages. Relying on inhibition of interfering information, and thus attentional control, DF tasks would be an appropriate task to investigate in a bilingual sample. Therefore, the aim of the current study is to assess the effect of mono- or bilingualism on Simon, task-switching, and DF task performance across young, middle-aged, and older adults using an online survey platform. In light of the discussion by Johnson, Paap, & Sawi (2015), attaining a large sample size and identifying what type of bilingual experience contributes advantageously to executive function is crucial for further research on bilingualism. This research may not only have policy implications, but may substantially affect the popular conception of multilingualism's role in cognitive development. Extending these implications, bilingualism may serve a protective and preventative role in age-related cognitive decline.

Method

Participants

The present study was approved by the Institutional Review Board at Washington and Lee University (IRB.201617.008). Three-hundred and thirty-two subjects were recruited (18-89 years) with the chance of earning a $20 gift card or receiving course credit. The sample was recruited through flyers, message boards, and email notifications on campus, and through email messages to known foreign language speakers, faculty, and international schools. Additionally, the survey was posted on various online platforms and portals.

Of the 332 participants, 27 older adults (60+ years) were excluded from ANOVA analyses due to a small sample size. The remaining subjects were divided into young (18-29 years, $n = 210$) and middle-aged (30-59 years, $n = 94$) adults. While the literature provides inconsistent age ranges, the following age groups were adopted from Bialystok et al. (2004). Age groups were further divided into young monolingual ($n = 109$, $M = 20.0$ years) and bilingual ($n = 101$, $M = 21.3$ years) adults, and middle-aged monolingual ($n = 54$, $M = 44.8$ years) and bilingual ($n = 41$, $M = 43.2$ years) adults.

Utilizing self-report measures, 152 bilingual subjects were identified. Of the bilinguals, 39% indicated English as their first language (L1) and 57% indicated English as their second language (L2). Additional languages (in order of largest representation) included German, Spanish, French, Chinese, Russian, Urdu, Hindi, Korean, Tagalog, Finnish, Italian, Portuguese, Marathi, Nepali, Mandarin, Thai, Arabic, Dutch, Romanian, Slovenian, and Swedish. Further, 83 subjects indicated speaking at least an additional language (L3).

Given the importance of proficiency in the outcomes of bilingualism on cognitive control tasks, proficiency in speaking and writing the L2 was assessed. Over 97% of bilinguals agreed (i.e. “Strongly agree”, “Agree”, “Somewhat agree”) they were proficient speakers and 90% agreed they were proficient writers. Similarly, a majority (92%) had received a formal education in their L2, suggesting the population was composed of relatively highly proficient bilinguals. Finally, 64% acquired their L2 early (0-11 years) and 37% actively started using their L2 early (0-11 years), suggesting the importance of differentiating between early and late bilinguals in subsequent analyses.

A limitation of online studies is that the survey was completed in an uncontrolled environment. To account for this limitation, all participants were asked to self-report their level of distraction and alertness. Of all 332 participants, 4% felt very distracted and 5% felt very tired. However, 46% reported feeling somewhat distracted, while 42% reported feeling a bit tired. Therefore, results should be treated with some caution.

Tasks and Procedure

Survey Platform. Participants completed an online survey using PsyToolkit, an online platform for coding and running psychological experiments. Developed by Gijsbert Stoet at Leeds Beckett University, PsyToolkit can be effectively used for browser-based online reaction time experiments and has demonstrated accurate and precise millisecond timing within the limitations of the browser (Stoet, 2010). The platform is open-source and includes a scripting language. This is the first study to implement an online format in the bilingualism literature, which allowed for a large sample size, a wide age range, and a diversity of linguistic experiences.

Shipley-II Vocabulary and Block Patterns Test. To account for fluid and crystallized intelligence, the study began with a Shipley-II vocabulary test and ended with a Shipley-II block patterns test (Appendix A; Appendix B). The vocabulary test consisted of 40 items and participants were asked to choose a synonymous word amongst five options. The block patterns test consisted of 12 items, each of which contained a missing square. The participants were asked to complete the picture with one of the six available items. For both tests, the level of difficulty increased incrementally with every question and responses were scored using an answer sheet. Raw scores for both tests by age and language group are reported in Table 1.

Language and Social Background Questionnaire (LSBQ). To investigate how linguistic experiences relate to cognitive outcomes, a language acquisition and demographic questionnaire was presented (Appendix F). This questionnaire was adopted from the LSBQ developed by Luk & Bialystok (2013), which determines the percentage each language is used at work, at home, and in daily life, and assesses further demographic factors. The responses were used to determine the degree to which the participant was functionally bilingual, and the questionnaire was extended to account for verbal and written proficiencies in both languages. To control for a variety of factors that affect executive function, the questionnaire also captured level of education, income, and music and computer abilities. The questionnaire was placed at the end of the study to avoid demand effects.

Simon Task. The Simon task (Appendix D) was chosen because it employs cognitive processes implicated in the bilingual advantage and has been used across a wide age-range (Bialystok, Craik, Klein, & Viswanathan, 2004). Each trial began with a fixation cross for 250-ms, followed by an immediate stimulus onset. The stimuli consisted of a blue or red square appearing on the right ($x = 355$, $y = 0$) or left ($x = -355$, $y = 0$) side of the screen. Participants were asked to respond to a blue square with a right arrow key press regardless of its position on the right (congruent) or left (incongruent) side of the screen. When a red square was presented, participants responded with a left arrow key press regardless of its position on the left (congruent) or right (incongruent) side of the screen. The stimulus was terminated after a response was given or after 1,000-ms if no response was given, and another blank interval followed before starting the next trial. Stimulus presentation was randomized and each subject was provided instructions and eight practice trials with feedback before beginning the test block. Decision accuracies and latencies were recorded for all 60 trials of the test block, and the Simon effect (i.e. incongruent-congruent trials) was calculated.

Task-Switching Paradigm. The task-switching paradigm was based on Rogers and Monsell (1995) and resembles the bilingual experience of inhibiting one language and rapidly switching between both (Appendix E). Each trial began with a four-quadrant grid located at the center of the screen. During each trial, a letter and number pair (e.g. G6) appeared in one of the quadrants in random order. If the letter and number pair appeared in the top two quadrants, the participant was asked to attend to the letter only. The subjected pressed the “N” key if the letter was a vowel and the “B” key if the letter was a consonant. Similarly, if the letter and number pair appeared in the bottom two quadrants, the participant was asked to attend to the number only. The subject then pressed the “N” key if the number was even and the “B” key if the number was odd. Based on the presentation sequence, the trial was either considered a switch (i.e. change from top quadrants to bottom quadrants) or a non-switch trial (i.e. change within top or bottom quadrants). Stimulus presentation was randomized and each subject was provided instructions and eight practice trials for each of the three blocks. The first block was a single condition block and contained 20 trials in which the participant solely focused on the letter in the pair. The second block was a single condition block and contained 20 trials in which the participant solely focused on the number in the pair. The final block was a mixed condition block and consisted of 80 trials in which the participant responded to both letters and numbers by maintaining the outlined rules. Response accuracies and latencies were captured, and local (i.e. mixed block non-switch trial RT – mixed block switch trial RT) and global switch costs (i.e. mixed block non-switch trial RT – single block non-switch trial RT) were computed.

Directed Forgetting Paradigm. Following the vocabulary test, subjects began the first component of the DF task. In DF tasks, participants are asked to study a list of words that is either cued to be remembered or forgotten, before studying a second word list cued to be remembered. Participants who are asked to forget the first word list and then asked to remember the subsequent list demonstrate improved recall on the latter list. This is largely due to the elimination of interfering information through the forget cue. Both mono- and bilingual subjects were randomly assigned to a Forget (F) and a Remember (R) group, and were blind to their assigned group. All groups received the first 12-item word list (Appendix C) and had two minutes to study these words before receiving their respective cue (F Group: “FORGET”; R Group: “REMEMBER”). Following presentation of the cue, the participants began the Simon task, which served as a distractor task.

After completing the Simon task, the subjects were given two minutes to study the second 12-item word list. After the study period ended, both DF groups received a “REMEMBER” cue. As a second distractor test, the participants completed the task-switching paradigm. Thereafter, subjects were given unlimited time to recall as many words as possible from both lists, regardless of the provided cue. The proportion of recalled items for both lists was calculated.

Design and Data Analysis

A 2 (language group; monolingual, bilingual) x 2 (age group; young, middle) x 2 (trial type) mixed ANOVA was conducted for the Simon task and task-switching paradigm. Trial type varied by task: Incongruent and congruent trials for the Simon task, and mixed block non-switch trials and mixed block switch trials, as well as single block non-switch trials for the task-switching paradigm. RTs on these various trials served as the dependent variables. In addition, a 2 (language group) x 2 (age group) between-subjects ANOVA was conducted, where the Simon effect, and global and local switch costs served as the dependent variables.

For the DF paradigm, a 2 (DF group: Forget, Remember) x 2 (language group: monolingual, bilingual) x 2 (list type: list 1, list 2) mixed ANOVA was conducted by age group. The dependent measures were recall performance on the two word lists, and were measured as the proportion of correct answers of the total possible correct answers.

To incorporate the entire age sample, moderated regression analyses were conducted using Andrew Hayes' PROCESS dialog for SPSS. Finally, to investigate when the bilingual advantage emerges, multiple hierarchical regressions were conducted.

Results

A correlation matrix of primary study variables is displayed in Table 3.

Demographic Characteristics of Total Sample

The demographic and lifestyle measures are displayed in Table 1. Independent samples *t*-tests comparing mono- and bilingual participants for each age group revealed a significant difference in mean age ($p < .001$), education ($p < .001$), and amount of video game playing ($p = .001$) between language groups amongst younger adults. Specifically, monolingual subjects were younger, demonstrated some University credit, and indicated playing video games less than their bilingual peers. There were no significant differences between mono- and bilingual participants in the middle-aged group.

2 (age group; young, middle) x 2 (language group; monolingual, bilingual) between-subjects ANOVAs on Shipley-II block-patterns scores found no difference for either age or language group (results not shown). A similar analysis on Shipley-II vocabulary scores showed that middle-aged adults had higher vocabulary scores than young adults, and there was an interaction between age and language, $F(1, 301) = 138.5$, $p = .02$, $\eta^2 = .82$. Monolingual young-adults had lower vocabulary scores than their middle-aged counterparts, $t(161) = 5.91$, $p = .000$, $d = 1.01$; bilingual young-adults also had lower vocabulary scores than their middle-aged counterparts, $t(140) = 3.34$, $p = .001$, $d = .68$. These results are consistent with studies showing lower vocabulary scores in bilinguals (Bialystok, Craik, & Luk, 2008).

A two-way ANOVA on handedness revealed an interaction between age and language, $F(1, 301) = 4.99$, $p = .03$, $\eta^2 = .02$. Bilingual middle-aged adults showed lower handedness scores than young middle-aged adults, while monolingual young adults showed lower handedness scores than bilingual young adults. Here, higher scores refer to full use of the right-hand in a variety of daily activities (e.g. brushing teeth, eating).

Language Background of Bilingual Population

Table 2 captures the language background of the bilingual population. On average, both age groups used English around 70% of the day. This result may stem from sampling primarily in the United States, where bilinguals are embedded in English-speaking contexts. Specifically, English use at the work place could be driving this result, as percent English use at home was generally lower for both age groups.

Given that cognitive and linguistic advantages for bilinguals are most pronounced in those with balanced proficiency, it is important to consider language proficiency. Most young (84%) and middle-aged (85%) bilinguals reported being highly proficient in speaking their L2. Similarly, 75% of young and 78% of middle-aged bilinguals reported being highly proficient in writing their L2. However, young adults reported lower proficiency in writing their L1 than middle-aged adults ($p = .03$). This difference is negligible, considering that the Likert scale responses of “Strongly Agree” and “Agree” are similar. Further, young bilinguals indicated earlier age of acquisition (AoA), $p = .003$, and age of active onset (AoAO), $p = .02$, in comparison to middle-aged bilinguals.

Simon Task Accuracy

Mean accuracy scores and RTs for the Simon task trials are displayed as a function of age and language group in Table 4. First, the presence of speed-accuracy trade-offs was assessed. After excluding subjects with accuracy scores below .80 for any of the Simon task parameters, no significant speed-accuracy trade-offs for congruent and incongruent trials were observed. In fact, accuracy decreased as congruent trial RTs increased (r = -.40, p < .001), nonindicative of a speed-accuracy trade-off.

A three-way ANOVA for age group (younger, middle), language group (monolingual, bilingual), and trial type (congruent, incongruent) was conducted, revealing greater errors made on incongruent (M = .96, SD = .05, n = 296) versus congruent trials (M = .98, SD = .03, n = 296), $F(1, 296) = 47.36$, $p < .001$, $\eta^2 = .14$. Middle-aged adults (M = .98, SD = .00, n = 94) also demonstrated fewer errors than young adults (M = .96, SD = .00, n = 202), $F(1, 292) = 34.99$, $p < .001$, $\eta^2 = .11$. There was no main effect of language, and no interactions between language and age or language, age, and congruency. However, there was a significant interaction between congruency and age, $F(1, 296) = 4.31$, $p = .04$, $\eta^2 = .02$. Follow-up Bonferroni-corrected paired samples t-tests ($\alpha = .025$) were conducted to assess pairwise differences amongst the subjects' accuracy scores in each age group. Post-hoc comparisons revealed a significant difference between congruent and incongruent trial accuracies in young adults, $t(201) = 7.27$, $p = .000$, $d = .49$, and middle-aged adults, $t(93) = 4.16$, $p = .000$, $d = .55$.

Task-Switching Paradigm Accuracy

Mean accuracy scores and RTs for the task-switching trials and switch costs are shown as a function of age and language group in Table 5 and Table 6. After excluding subjects with accuracy scores below .80 for any of the task-switching trials, no speed-accuracy trade-offs were observed. In fact, for mixed block switch trials (r = -.16, p = .007) and local switch costs (r = -.16, p = .009), accuracy decreased as RTs increased. For all other trial types, no significant correlations were observed.

A three-way ANOVA for age group (younger, middle), language group (monolingual, bilingual), and trial type (mixed non-switch, mixed switch) was conducted for local switch costs (i.e. mixed non-switch, mixed switch). Results revealed greater errors on switch trials (M = .94, *SD* = .05, *n* = 257) versus non-switch trials (*M* = .97, *SD* = .03, *n* = 257), $F(1, 257) = 99.32$, $p < .001$, $\eta^2 = .28$. Middle-aged adults (*M* = .97, *SD* = .06, *n* = 83) also demonstrated fewer errors than young adults (*M* = .95, *SD* = .05, *n* = 174), $F(1, 253) = 10.88$, $p = .001$, $\eta^2 = .04$. There were no further main effects or interactions.

A similar analysis was conducted for global switch costs (i.e. mixed non-switch, single non-switch). Results revealed that middle-aged adults (*M* = .97, *SD* = .06, *n* = 83) demonstrated fewer errors than young adults (*M* = .95, *SD* = .05, *n* = 174), $F(1, 253) = 10.88$, $p = .001$, $\eta^2 = .04$. No further main effects or interactions were observed.

Simon Task Performance

RTs were examined using a three-way ANOVA for language group, age group, and congruency. Congruent trials (*M* = 516.7, *SD* = 104.1) were significantly faster than incongruent trials (*M* = 544.3, *SD* = 100.6), $F(1, 292) = 74.90$, $p < .001$, $\eta^2 = 0.20$ (Figure 1A, B), and middle-aged adults (*M* = 583.7, *SD* = 162.8, *n* = 94) had significantly slower RTs than their younger counterparts (*M* = 505.8, *SD* = 110.3, *n* = 2 02), $F(1, 292) = 46.46$, $p < .001$, $\eta^2 = 0.14$.

There was a also significant two-way interaction between age and language, $F(1, 292) = 4.07$, $p = .045$, $\eta^2 = .01$. Follow-up Bonferroni-corrected independent samples *t*-tests were conducted ($\alpha = .0125$). For young-adults, post-hoc comparisons revealed no significant difference between monolinguals and bilinguals on congruent trials, $t(200) = 2.22$, $p = .03$, $d = .31$, and incongruent trials, $t(200) = 2.09$, $p = .04$, $d = .73$. Similarly, there was no significant difference between middle-aged monolinguals and bilinguals on congruent trials, $t(92) = .57$, $p = .57$, $d = .12$, and incongruent trials, $t(92) = 1.17$, $p = .24$, $d = .02$. Finally, results revealed a marginally significant interaction between trial type and age group, $F(1,292) = 3.21$, $p = .074$, $\eta^2 = .01$. No further interactions were observed.

A two-way ANOVA for language group and age group was conducted to assess difference in the Simon effect scores, revealing a marginally significant main effect of age group, $F(1, 292) = 3.21$, $p = .07$, $\eta^2 = .01$. Specifically, middle-aged adults (*M* = 35.61, *SD* = 96.5, *n* = 94) showed larger Simon effects than their younger counterparts (*M* = 23.39, *SD* = 65.31, *n* = 202) (Figure 2). No further main effect or interaction was observed.

Task-Switching Paradigm: Global Switch Cost

A three-way ANOVA for language group, age group, and trial type (i.e. mixed non-switch, single non-switch) was conducted. Single block non-switch trials (*M* = 796.1, *SD* = 142.8) were significantly faster than mixed block non-switch trials (*M* = 1084.3, *SD* = 209.8, *n* = 257), $F(1, 257) = 803.9$, $p < .001$, $\eta^2 = .76$, and young adults were significantly faster (*M* = 891.1, *SD* = 175.2, *n* = 174) than middle-aged adults (*M* = 1044.3, *SD* = 255.1, *n* = 83), $F(1, 257) = 62.97$, $p < .001$, $\eta^2 = .20$.

There was also a significant two-way interaction between trial type and age group, $F(1, 257) = 7.77$, $p = .006$, $\eta^2 = .03$. Follow-up Bonferroni-corrected paired samples *t*-tests were conducted to assess pairwise differences in mixed and single block non-switch trials within age groups ($\alpha = .025$). Post-hoc comparisons revealed faster single block non-switch trials than mixed block non-switch trials in young adults, $t(177) = 24.3$, $p = .000$, $d = 1.96$, and middle-aged adults, $t(83) = 16.7$, $p = .000$, $d = 1.94$. No further main effects or interactions were observed.

A two-way ANOVA for language group and age group was conducted to assess difference in global switch costs, revealing that young-adults (*M* = 270.1, *SD* = 147.7, *n* = 174) had smaller switch costs than middle-aged adults (*M* = 326.2, *SD* = 177.6), $F(1, 253) = 7.77$, $p = .006$, $\eta^2 = .03$. No further main effects or interactions were observed.

Task-Switching Paradigm: Local Switch Cost

Similarly, a three-way ANOVA for language group, age group, and trial type (i.e. mixed non-switch, mixed block switch) was conducted (Figure 3). Given the presence of a higher order interaction between language, age, and trial type, $F(1, 257) = 1.04$, $p = .31$, $\eta^2 = .00$, lower order interactions will not be interpreted. A two-way ANOVA for language group and trial type was conducted separately for young and middle-aged adults to isolate the source of this interaction. For young adults, results revealed that non-switch trials (*M* = 1024.5, *SD* = 179.8) were significantly faster than switch trials (*M* = 1512.9, *SD* = 301.3), $F(1, 178) = 802.9$, $p = .000$, $\eta^2 = .82$ (Figure 3A). Monolinguals (*M* = 1236.6, *SD* = 217.6) were also significantly faster than bilinguals (*M* = 1303.1, *SD* = 217.6), $F(1, 257) = 4.15$, $p = .04$, $\eta^2 = .02$ (Figure 3A). There were no further significant main effects or interactions.

For middle-aged adults, results revealed non-switch trials (*M* = 1206.9, *SD* = 214.7) were significantly faster than switch trial RTs (*M* = 1729.0, *SD* = 313.4), $F(1, 81) = 333.5$, $p = .000$, $\eta^2 = .81$ (Figure 3B). There were no further significant main effects or interactions.

A two-way ANOVA for language group and age group was conducted to assess differences in local switch costs. Results revealed no significant main effect of language group or age group on local switch costs. However, there was a marginally significant interaction between language and age groups, $F(1, 253) = 3.61$, $p = .06$, $\eta^2 = .01$.

Directed Forgetting Paradigm

Mean recall scores as a function of DF group, age, and language are displayed in Table 7.

A three-way ANOVA for language group, DF group (i.e. Forget group, Remember group), and list type (i.e. list 1, list 2) was conducted separately for age groups because four-way interactions are difficult to detect (Figure 4). For young adults, mean recall was greater for the second list (*M* = .58, *SD* = .35) than the first list (*M* = .49, *SD* = .34), $F(1, 206) = 10.71$, $p = .001$, $\eta^2 = .05$. Also, bilinguals (*M* = .61, *SD* = .28) exhibited greater recall than monolinguals (*M* = .47, *SD* = .27) across both DF groups and lists, $F(1, 206) = 12.94$, $p < .001$, $\eta^2 = .06$ (Figure A, B)

There was also a significant two-way interaction between list type and DF group, $F(1, 206) = 30.45$, $p < .001$, $\eta^2 = .13$. Follow-up Bonferroni-corrected ($\alpha = .025$) paired samples *t*-tests were conducted to assess differences amongst the subjects' recall performance on both lists within DF groups. Post-hoc comparisons revealed that for the F group, recall was significantly higher for list 2 (*M* = .64, *SD* = .33) than list 1 (*M* = .42, *SD* = .33), $t(112) = 6.41$, $p = .000$, $d = .60$ (Figure 4A). For the R group, recall did not differ significantly between list 1 (*M* = .57, *SD* = .33) and list 2 (*M* = .51, *SD* = .37), $t(97) = 1.56$, $p = .11$, $d = .16$ (Figure 4B). There was also a two-way interaction between list type and language identity, $F(1, 206) = 3.98$, $p = .047$, $\eta^2 = .02$. Follow-up Bonferroni-corrected ($\alpha = .025$) paired samples *t*-tests were conducted to decompose the interaction, demonstrating that young monolinguals had significantly greater recall on list 2 than list 1, $t(108) = 3.85$, $p = .000$, $d = .37$. This difference between lists was not observed for young bilinguals, $t(100) = 1.02$, $p = .31$, $d = .10$.

For middle-aged adults, a three-way ANOVA revealed greater recall on list 2 (*M* = .67, *SD* = .33) than list 1 (*M* = .48, *SD* = .33), $F(1, 90) = 24.48$, $p < .001$, $\eta^2 = .21$. There were no further significant main effects or interactions. However, there was a significant two-way interaction between list and DF group, $F(1, 90) = 3.93$, $p = .05$, $\eta^2 = .04$. Follow-up Bonferroni-corrected ($\alpha = .025$) paired samples *t*-tests were conducted to decompose the interaction. Results revealed that for the F-group, list 2 recall (*M* = .65, *SD* = .31) was significantly higher than list 1 recall (*M* = .39, *SD* = .32), $t(46) = 5.02$, $p = .000$, $d = .73$ (Figure 4C). For the R group, list 2 recall (*M* = .69, *SD* = .35) was also significantly higher than list 1 recall (*M* = .58, *SD* = .31), $t(46) = 2.13$, $p = .04$, $d = .31$ (Figure 4D).

Moderated Regression

The PROCESS custom dialogue for SPSS was used to test whether the effect of language on task performance differed at various ages. Developed by Hayes (2012), PROCESS uses the “pick-a-point” method to decompose interactions with simple slope analyses. Using Model 1, a simple moderation model, language group (i.e. bi- or monolingual) was entered as a predictor variable for each analysis, while age (on a continuous scale) served as the moderator. Sex, high level of education, and video game use were entered as covariates. These covariates were dichotomized: For sex, individuals received a 1 if they were female and 0 if they were male. For education, individuals received a 1 if they had received a Bachelor’s, Master’s, or doctorate degree, and a 0 if otherwise. Finally, for video game use, individuals received a 1 if they played video games more than once a week, and 0 if they never played video games. In total, eight moderated regressions were conducted to assess the interaction between language and age on Simon task and task-switching parameters.

Simon Task. Age and language were significantly related to incongruent RT and age significantly moderated this relationship (Table 8). To decompose any moderator effects, simple slope analyses were conducted at the minimum (one standard deviation below the mean was outside the range of the data), at the mean, and one standard deviation above the mean age (Table 9). Language was significantly related to incongruent trial RT on the Simon Task when age was at its minimum ($B = 37.73$, $p = .004$) and one standard deviation above the mean ($B = -38.16$, $p = .04$) (Figure 5A). Age and language were also significantly related to congruent RT and age significantly moderated this relationship (Table 8). Simple slope analyses revealed that language was significantly related to congruent trial RT on the Simon Task only when age was one standard deviation below the mean ($B = 33.6$, $p = .02$) (Table 9; Figure 5B). Age did not significantly moderate the relationship between language and Simon effect RTs, as no interaction between language group and age was observed (*B* = -0.59, *p* = .14) (results not shown).

Task-Switching Paradigm Switch and Non-Switch Trials. After controlling for the same covariates described above (*n* = 279), age did not significantly moderate the relationship between language group and non-switch trial RT for the task-switching paradigm mixed block, as no interaction between language and age was observed (*B* = -1.72, *p* = .31). Similarly, age only marginally significantly moderated the relationship between language group and switch trial RT of the task-switching paradigm mixed block (*B* = -4.43, *p* = .06). Given the absence of an interaction in both cases, the moderated regression does not provide more insight than an ANOVA. Nonetheless, this is an interesting observation, considering that significant interactions were observed on Simon task incongruent trials, which also require inhibition of a response in favor of another. However, the task-switching paradigm also requires rapid switching and maintaining of more complex rules. Finally, age also did not significantly moderate the relationship between language group and single block trial RT, as there was no interaction between age and language group (*B* = -0.49, *p* = .64). Results also revealed that age did not significantly moderate the relationship between language group and global switch costs as indicated by the absence of a significant interaction between age and language group (*B* = -1.22, *p* = .38). Similarly, age did not significantly moderate the relationship between language group and local switch costs (*B* = -2.71, *p* = .15).

Multiple Hierarchical Regression

I conducted a series of multiple hierarchical regressions to estimate the effect of various measures of language ability on the Simon effect, and global and local switch costs amongst the bilingual sample. This is important considering that self-report measures revealed both early and late bilinguals amongst the sample. To do so, I estimated several variations of the following OLS regression:

$$Y_i = \alpha + \beta_1(Age_i) + \beta_2(Language_i) + \beta_3(Age_i \times Language_i) + \boldsymbol{X}_i'\delta + \varepsilon_i, \qquad (1)$$

where *Y* was the outcome variable (i.e. Simon effect, local switch cost, global switch cost) for individual *i*; *Age* was a continuous variable representing an individual's age; *Language,* was the variable of interest indicating a particular measure of language ability; and ***X*** was a vector of control variables, including an individual's sex, educational attainment, and frequency of playing video games. Here, sex, high education, and video game use were entered in Step 1. *Age* was entered in Step 2, *Language* was entered in Step 3, and the *Age* × *Language* interaction term was entered in Step 3. All bilinguals were assigned a value of 0 or 1 for each of the language measures, with 1 indicating early age of language acquisition and onset (0-11 years for L2) and 0 otherwise. Individuals also received a value of 1 if they reported high proficiency in speaking and writing ("Strongly Agree" or "Agree" that they are highly proficient in speaking and writing their L2; assigned 0 otherwise). Similarly, subjects received a value of 1 if they switched frequently between their L1 and L2 (0-74% total English use in a day; assigned 0 otherwise). These analyses were conducted based on literature suggesting high proficiency, and early acquisition and onset of the second language are crucial for inhibitory control, while high language switching is crucial for task-switching.

Results revealed that beyond age and the specified control variables, high language proficiency and early age of acquisition did not significantly predict the Simon effect (results not shown). However, early active onset of L2 seemed to be important for the Simon effect (Table 10). While the control variables did not account for significant variance in Simon effect scores, age emerged as a significant predictor in the second step, accounting for an additional 2.9% of the variance, $B = .75$, $p = .04$. In the third step, early active onset did not account for significant variance in Simon effect scores. However, in the final step of the model, the interaction of age and the language measure was significant, accounting for an additional 3.4% variance in predicting Simon effect scores, $B = 1.62$, $p = .02$. It is interesting to note that the coefficient of early onset of language use was negative and significant, $B = -52.85$, $p = .02$, suggesting that actively using a language earlier produces a smaller Simon effect. The coefficient for the interaction term, on the other hand, suggests that with age, having had an active early onset of L2 actually produces a larger Simon effect. High daily language switching did not significantly predict performance on global and local switch costs in the task-switching paradigm (results not shown).

Discussion

The current study explored the presence of a bilingual advantage in three tasks. Additionally, the effect of various linguistic and demographic factors on task performance was assessed. The study was motivated by increasing evidence that bilinguals' enhanced language control generalizes to EC, an ability crucial for goal maintenance and interference resistance (Gray, Chabris, & Braver, 2003). Specifically, the study explored performance between mono- and bilinguals across a wide age range (18-89 years) to determine when, if at all, the bilingual advantage emerges. This study is the first to implement a directed forgetting paradigm and an online format in studying the effects of bilingualism on cognitive function, providing promising avenues for future research. Finally, by being one of very few studies to provide a comprehensive investigation of the association between bilingualism and cognitive control, this study aids in understanding the interaction between inhibitory control, cognitive flexibility, and language experience across the lifespan.

It was postulated that a marked bilingual advantage would emerge in all tasks, especially with increasing age, when EC function begins to decline. This hypothesis was also driven by studies suggesting improved EC function with longer exposure to two languages. However, the results only partially supported these hypotheses. In the following sections, I will first describe the bilingual population examined in this study. Next, I will discuss the results and place them in context of the current literature. Finally, I will conclude with a discussion of the strengths and limitations of the present study and provide implications for future research.

Bilingual Sample

Before discussing the results, it is important to examine the bilingual sample. Recent literature has emphasized the heterogeneity of bilingualism, which may contribute to discrepancies in results between studies. Firstly, the present sample represented diverse language experiences. While the majority acquired and actively started using their second language between ages 0-6, a substantial number did so at a later age. Apart from acquiring the language later in life, not all bilingual speakers indicated English as their first language. More importantly, the sample consisted of a variety of language combinations. Thus, a promising line of research would be to identify the role of greater lexical distance between L1 and L2, also known as 'stronger bilingualism' (Ardila, 2007), on the bilingual advantage. Given that most bilinguals in the current study reported command over English and a Germanic or Romance language, this effect could not be explored.

Another distinctive characteristic of the current sample is that percent English use at home and at work exceeded 50% on average. If 50% English use serves as a proxy of frequent language switching, then one can infer that the population did not actively switch daily. This may be a product of sampling primarily in the United States, leading to an overrepresentation of reported daily English use. Additionally, language switching and proficiency was not assessed directly, but relied on self-reported measures. One limitation, therefore, is the lack of objective measures of the individuals' bilingual status. However, strong correlations exist between self-reported and actual proficiency (Hakuta, Bialystok, & Wiley, 2003).

To explore the role of different bilingual experiences on task outcomes, I conducted a series of multiple hierarchical regressions. Here, the bilingual population was assigned a value of 0 or 1 on four indicator variables. Individuals received a value 1 if they learned their second language early (0-11 years; 0 otherwise). In alternative specifications, I examined other measures of bilingualism, assigning a value of 1 if the participant started to actively use the second language early (0-11 years; 0 otherwise), reported high proficiency in speaking and writing (assigned 1 and 0 otherwise), and switched frequently between their first and second language (assigned 1 and 0 otherwise). Results revealed that only age of active language onset significantly predicted Simon effect RTs.

Given the restricted age sample, this study cannot make definitive claims regarding the interaction between bilingualism and cognitive aging. Instead, age served as a proxy for number of years of experience with a second language.

Simon Task

Adopted from Bialystok, Craik, Klein, & Viswanathan (2004), the Simon task (Simon & Ruddell, 1967) is the most common task utilized in exploring differences between mono- and bilinguals. Thus, it was used to determine whether the bilingual advantage could be replicated in the present sample. While RTs on incongruent trials were significantly slower than congruent trials for all groups, young and middle-aged bilinguals did not show reduced RTs on incongruent trials, failing to support my hypothesis. In fact, bilingual young-adults showed significantly slower reaction times for both trial types in comparison to their monolingual counterparts. This is a surprising result and does not find support in the literature.

It was also hypothesized that bilinguals would exhibit diminished Simon effect RTs, suggesting effective suppression of competing responses. While no significant differences were observed between mono- and bilinguals of both age groups, the Simon effects were somewhat diminished in bilingual subjects. Additionally, the magnitude of the observed Simon effects coincided with van der Lubbe and Verleger (2002), who observed 20-35 ms in young adults and 48-96 ms in older adults. Bialystok et al. (2004), on the other hand, reported ranges between 123-500 ms. The discrepancy in the two studies may stem from van der Lubbe and Verleger (2002) having a very small sample size, a high number of trials (i.e. 600), and using a visual Simon task with two letters (i.e. A, B) rather than shapes.

The results of the current study corroborate studies providing no evidence for differences in inhibitory control between mono- and bilinguals (Dunabeitia et al. 2014, von Bastian et al. 2015, de Bruin, Bak, & Della Sala 2015; Paap & Greenberg, 2013; Paap et al. 2015). While this research was motivated by a believed association between the bilingual language control (bLC) system and domain-general EC system (Abutalebi & Green, 2008), neuroimaging studies have challenged whether these systems truly employ similar mechanisms, which would account for the difficulty in replicating the bilingual advantage in inhibitory control (Paap & Greenberg, 2013).

An indication of the sensitivity of the task was the presence of slower RTs with age, such that middle-aged adults showed significantly slower RTs than young adults. Nonetheless, the mean RTs for the middle-aged adults were faster than previous studies (Bialystok et al. 2004). This difference may stem from the middle-aged group including individuals between 30 and 60 years, while other studies demonstrated mean ages well above 60 (Salvatierra & Rosselli, 2010; Bialystok, 2004). Due to a limited sample size for the older age groups, 27 (60+) elderly adults were not included in the ANOVA analyses. However, in the moderated and multiple hierarchical regressions, these subjects were included given that age was a continuous variable. Here, age significantly moderated the association between language and Simon task performance on congruent and incongruent trials. Interestingly, although bilinguals performed more slowly at younger ages (i.e. 18), older bilinguals (i.e. one standard deviation above the mean, or 47 years and above) were faster than their monolingual counterparts on incongruent trials. While this result could be an artifact of fewer subjects above the age of 60, it may suggest that a bilingual advantage in inhibitory control emerges at older ages. Future investigations are necessary to substantiate this claim.

Assessing the relationship between age and cognitive control is especially interesting considering evidence suggesting that bilingualism is protective against cognitive decline and dementia (Abutalebi et al. 2015; Schweizer et al. 2012; Craik, Bialystok, & Freedman. 2010). With fewer opportunities for cognitive enrichment in older adults, Valian (2015) suggests bilingualism may pose an advantage for the aging brain. Because this study was not an aging study in that it did not compare young, middle-aged, and older adults in the ANOVA analyses, age served as a proxy for greater exposure to two languages.

Goral, Campanelli, and Spiro (2015) suggest that frequency of language use and proficiency are important in older bilinguals' performance on the Simon Task. Therefore, multiple hierarchical regression analyses were conducted to assess the contribution of these factors on performance. In comparison to other studies, language use and proficiency did not significantly predict outcomes in this study. The disparity in results may stem from relying on self-report rather than objective measures. However, early active onset of the language did appear to reduce overall Simon effect RTs amongst the bilingual population.

In summary, these results support literature suggesting that the bilingual advantage only emerges under unique conditions, including increased task demands (e.g. four colored objects in the Simon task) and greater number of incongruent trials (Costa et al. 2009).

A puzzling result remains that older bilinguals show somewhat faster RTs on congruent trials, which is inconsistent with the theory of inhibitory control (Morton & Harper, 2007). This theory would expect differences solely in trials where a response must be inhibited. It is possible, however, that not all experiences with two languages must necessarily lead to greater inhibitory control. In fact, investigators suggest that different bilingual experiences may have different cognitive ramifications (Grant & Dennis, 2016). Specifically, bilingualism may result in general neuroplasticity instead of a distinct 'advantage' (Baum & Titone, 2014). This general neuroplasticity could mean that rather than a bilingual inhibitory control advantage (BICA), bilinguals may have a bilingual executive processing advantage (BEPA) (Hilchey, Saint-Aubin, & Klein, 2015; Bonifacci et al. 2011). While evidence for BEPA remains sparse, it is important to consider alternative explanations.

Similarly, Grant and Dennis (2016) argue that that the lack of replicability in the literature may be a result of the focus on inhibition and EC, rather than processing speed and domain-general processes. This focus on inhibition has led to models that claim language processing in bilinguals relies on inhibition of the non-target language. A construct motivating much of this research is Green's (1998) model of inhibitory control. Consequently, investigators fail to attend to models that claim bilinguals not only suppress the non-target language, but also activate the target language (Dijkstra & Van Heuven, 2002). Thus, it is plausible that to select an action, information must accumulate rapidly, requiring greater processing speed (Verbruggen, McClaren, & Chambers, 2014; Grant & Dennis, 2016). Bialystok, Martin, and Viswanathan (2004) explored the possibility of better processing speed in bilinguals by introducing a neutral condition in their Simon task. While no differences were observed on the neutral conditions, bilinguals were nonetheless faster on congruent and incongruent trials. Given that bilingualism may not only enhance inhibitory control, it is important to consider other components of EC.

Task-Switching Paradigm

Requiring mental set-shifting, task-switching paradigms are useful in studying the bilingual advantage. Task-switching paradigms are considered challenging, resulting in large switch costs for high-performing young adults (Monsell 2003; Prior & MacWhinney, 2010; Prior & Gollan, 2011; Wiseheart, 2016). Therefore, it is an appropriate task to utilize in young adults at their cognitive peak to account for ceiling effects that may plague simple tasks (Prior & MacWhinney, 2010).

The present task-switching paradigm was adopted from Rogers and Monsell (1995) and was effective in that RTs on mixed block switch trials were significantly slower than non-switch trails across all groups. Contrary to the hypothesis that frequent language switching in bilinguals leads to smaller switch costs, both language groups performed similarly.

According to Garbin et al. 2010, there is both indirect and contradictory evidence that bilingualism affects task-switching performance. This is due in part to the disparate ways task-switching paradigms can be implemented, including using predictable or unpredictable switches, longer or shorter intervals between trials, and bivalent or univalent stimuli (Prior & MacWhinney, 2010). Unlike univalent stimuli, which reflect response inhibition, bivalent stimuli contain distracting information that needs to be inhibited (i.e. suppression of interfering information)

(Esposito, Baker-Ward, & Mueller, 2014). Thus, the bilingual advantage has been mainly observed in tasks requiring control over competing cues rather than competing responses (Martin-Rhee & Bialystok, 2008). For example, while Simon tasks and task-switching paradigms require the subject to override a habitual response by suppressing irrelevant perceptual information (e.g. presence of the letter when focusing on the number), tasks that require response inhibition do not exhibit the same conflict. In children, Day/Night tasks measure response inhibition. Here, children respond “Day” to the image of a moon and “Night” to an image of a sun. While this task requires inhibition of a dominant response, it does not contain any irrelevant distractions (Esposito, Bake-Ward, & Mueller, 2014).

An additional measure of interest was the global switch cost, which represents the ability to maintain task sets and follows a U-shape curve across the lifetime (Bialystok & Barac, 2012). While previous studies have demonstrated smaller global switch costs in bilinguals (Costa, Hernández, & Sebastian-Gallés, 2008; Bialystok & Barac, 2002), there was no significant difference between mono- and bilinguals in both age groups. However, as expected, young adults had smaller global switch costs than middle-aged adults.

Local switch costs, on the other hand, remain relatively preserved across age and reflect changes in stimulus-response associations (Kray & Lindenberger, 2000; Reimers & Maylor, 2005). This was reflected in the present results, in which no difference was observed between young and middle-aged adults. Interestingly, bilingual young and middle-aged adults appeared to have somewhat smaller, albeit nonsignificant, local switch costs.

An explanation for the lack of difference in switch costs between mono- and bilinguals is that the effect of bilingualism is dependent on high linguistic proficiency and daily language switching (Bialystok & Barac, 2002; Soveri et al. 2011). In the present study, multiple hierarchical regression amongst bilinguals did not suggest a predictive effect of high language switching on any task-switching paradigm outcomes. This may be due to a lacking direct measure of language switching. Instead, percent daily English use served as a proxy for frequent language switch, which may not be reflective of switching amount. For example, one bilingual may speak wholly one language at work and one language at home, while another may attend school where language mixing occurs, requiring rapid code-switching.

Another explanation for the lack of difference between mono- and bilinguals is that the present study did not assess asymmetrical switch costs, or the differential switch costs incurred by switching from a difficult to an easier task and from an easier to a more difficult task (Yeung & Monsell, 2003). Asymmetrical switch costs have been shown to be smaller in bilinguals and result from the build-up of proactive interference (PI), which is larger when switching from a difficult to an easier task (Prior & MacWhinney, 2010). In fact, a correlation between shifting and inhibition has been suggested, possibly because both require a form of controlled attention (Miyake et al. 2000). I will now turn to the directed forgetting (DF) paradigm that relies on PI, a subtype of inhibitory function (Miyake et al. 2000).

Directed-Forgetting Paradigm

This is the first study to implement a DF paradigm in research on bilingualism. DF paradigms demand EC in two ways: (1) Elimination of interference from previously learned information and (2) retrieval of encoded information. Suppression of interfering information is important, because the build-up of PI decreases the amount of information that can be retrieved from WM (Jonides & Nee, 2006). By eliminating PI, greater WM processing capacity is enabled (Bjorklund & Harnishfeger, 1993). Considering that bilinguals are proficient in eliminating interference, it is plausible that DF paradigms could be utilized in the realm of studies on bilingualism.

The DF paradigm can be implemented in several different ways, including using an item- or list-method (Bjork, 1970). In the present study, I employed a list-method in which the forget or remember cue is provided after studying the whole list. Retrieval-inhibition is especially important in list-methods, where to-be-forgotten words are inhibited from being retrieved following encoding (Brainerd & Reyna, 1993; Wilson & Kipp, 1998). By inhibiting goal-irrelevant information, this information is less likely to interfere with WM (Zachs, Hasher, & Radvansky, 1996).

WM benefits are gained from both inhibition of unnecessary information and the active maintenance of important information (Baddeley, 1986). It follows that WM deficits in older adults partially stem from the inability to use attentional control to inhibit interfering information (Conway & Engle, 1994). Therefore, if being bilingual improves attentional control, one would expect to see diminished recall on to-be-forgotten items and greater recall on to-be-remembered items with increased experience with a second language (i.e. with age). This trend was not observed amongst the present participants. Instead, both mono- and bilinguals in the Forget groups showed diminished recall on the first list and greater recall on the second list. One could argue that because recall was tested shortly after the second list was presented, recall would be greater for the more recent list. That is true, but for the Remember group, there was no difference in recall between both lists for young and middle-aged adults. Additionally, amongst the young adults, the Forget group performed significantly better on the to-be-remembered list than the Remember group. This suggests that receiving a forget cue on the first list does in fact increase recall for the second list.

Interestingly, amongst the young adults, bilinguals showed greater recall across both lists and DF groups. This difference was not observed in middle-aged adults. Despite higher recall on the interfering to-be-forgotten list, young bilinguals still showed higher recall on the to-be-remembered list. This suggests that apart from practice in eliminating interference from another item, bilinguals must also constantly maintain more than one item active. Therefore, it is plausible that bilinguals have more efficient retrieval and active maintenance of information, and are not as disrupted by interfering information.

Bialystok and Feng (2009) are the only authors that have investigated the ability of bilinguals – albeit children - to eliminate PI. They argue that PI effects are a unique research area in bilingualism, because bilinguals typically demonstrate poor recall of word lists as a function of smaller vocabularies. Their results revealed that after controlling for vocabulary, bilinguals demonstrated fewer intrusions, higher recall, and no significant decline in recall between list 1 and 2, suggesting less build-up of interference. While the investigators did not test adults, it is important to note that the words on both lists were from the same category (e.g. fruit, clothing, colors), increasing interference effects. In the present study, the items on both lists did not stem from the same categories. However, some words were related categorically, including categories such as weather, nature, and war. A next step in data analysis will be to compare the number of intrusions from list 1 between mono- and bilinguals in both age groups.

Strengths and Limitations

By representing different language combinations, ages of acquisition, age of active onset, and other linguistic backgrounds, this study was more reflective of the diversity in bilinguals world-wide. Rather than deductively selecting bilinguals with certain characteristics, this sampling allowed for an inductive approach in which unexpected patterns could emerge. Further, while tasks were selected for replication purposes, they triangulated similar constructs: The Simon task investigated inhibitory control, while the task-switching paradigm demanded greater WM load, and explored inhibition and set-shifting, two moderately correlated constructs in EF (Miyake et al. 2000). Finally, the DF paradigm assessed elimination of interfering information, which is a subtype of inhibitory control.

Considering the mixed results observed in the literature, Baum and Titone (2014) suggest that rather than asking whether the bilingual advantage exists or not, it is more important to ask under what conditions it may emerge. Using a wide age range and moderated regression analysis enabled an investigation of "when" the bilingual advantage might emerge. However, a limitation of the study was the small sample size of elderly adults, which did not allow for a more restricted division into young, middle-aged, and older adults. Additionally, the online format may have been more inaccessible to elderly individuals.

One of the greatest limitations of this study was the heterogeneity of bilingual experiences in the sample, as well as the many factors that impact EC functions. While the LSBQ captured some of these factors, it is difficult to rigorously control for SES, immigrant status, education, and other lifestyle factors in an online questionnaire format. Nonetheless, potential confounds were explored and controlled for in the regression analyses. Thus, rather than relying on self-reported characteristics, future studies should utilize objective measures of language ability and ensure the inclusion of bilingualism-associated confounding variables.

Conclusion

In conclusion, there was no substantive evidence of a bilingual advantage in inhibitory control or set-shifting. However, with increasing age, bilinguals demonstrated better performance on Simon task trials, suggesting the possibility of a BEPA rather than a BICA as age-related decision speed declines. To further investigate BEPA, investigators should combine behavioral work with investigations of white matter integrity between mono-and bilinguals, which has been implicated in processing speed (Luk et al. 2011). After all, inconsistencies in the literature exist at both the behavioral and structural level. While behavioral differences may not be observed, bilingualism appears to alter key structures implicated in language and EC systems (Gold et al. 2013; Abutalebi & Green, 2011; Bialystok et al. 2005).

Additionally, the trend in the Simon task was not observed in the task-switching paradigm, which imposes greater demands on attention and WM, suggesting that bilingualism may primarily contribute to domain-general processes. However, young bilinguals did demonstrate higher recall of both lists in the DF paradigm, suggesting a potential difference in the active maintenance of information in the face of interfering information.

While the results were unexpected, they provide interesting avenues for future research. These include investigating the role of practice effects, asymmetrical switch costs, and varying tasks demands on EC performance. Further, these results suggest the importance of utilizing regression analyses rather than ANOVAs to assess which bilingual experiences are most advantageous. Specifically, Baum and Titone (2014) recommend the use of linear mixed effects regression models, which have shown promise (Whitford & Titone, 2012 for linear mixed effects models used in visual word recognition in bilinguals).

Finally, further investigations into the interaction between aging and language experience could provide useful insight into the possible protective role of bilingualism in cognitive aging. While the results did not confirm the presence of a consistent bilingual advantage, they highlight the importance of developing accurate models that may explain the role language plays in cognition across the lifespan. In fact, viewing bilingualism as a source of neuroplasticity rather than a particular advantage could aid in improving research design, analysis, interpretation, and reproducibility (Baum & Titone, 2014). Why seek simple answers to complex questions?

References

Abutalebi, J., & Green, D. W. (2008). Control mechanisms in bilingual language production: neural evidence form language switching studies. *Lang Cogn Process, 23,* 557-582.

Abutalebi, J., Della Rosa, P. A., Green, D. W., Hernández, M., Scifo, P., Keim, R., Cappa, S. F., & Costa, A. (2011). Bilingualism tunes the anterior cingulate cortex for conflict monitoring. *Cerebral Cortex, 22,* 2076-2086.

Ardila, A. (2007). Bilingualism in the contemporary world. In A. Ardila & E. Ramos (Eds.), *Speech and language disorders in bilinguals* (pp. 1-19). New York: Nova Science Publishers.

Bak, T. H., Nissan, J. J., Allerhand, M. M., & Deary, I. J. (2014). Does bilingualism influence cognitive aging? *Ann Neurol, 75,* 959-963.

Baum, S., & Titone, D. (2014). Moving toward a neuroplasticity view of bilingualism, executive control, and aging. *Applied Psycholinguistics, 35,* 857-894. doi: 10.1017/SO142716414000174.

Bialystok, E., Craik, F. I. M., Klein, R., & Viswanathan, M. (2004). Bilingualism, aging, and cognitive control: Evidence from the Simon task. *Psychology and Aging, 19,* 290-303.

Bialystok, E., & Martin, M. M. (2004). Attention and inhibition in bilingual children: evidence from the dimension change card sort task. *Dev Sci, 7,* 325-339.

Bialystok, E., Craik, F. I. M., Grady, C., Chau, W., Ishii, R., Gunji, A., & Pantev, C. (2005). Effect of bilingualism on cognitive control in the Simon task: evidence from MEG. *Neuroimage, 24,* 40-49.

Bialystok, E. (2006). Effect of Bilingualism and Computer Video Game Experience on the Simon Task. *Canadian Journal of Experimental Psychology, 60,* 66-79. doi: 10.1057/cjep2006008.

Bialystok, E., Craik, F. I. M., & Ryan, J. (2006). Executive control in a modified antisaccade task: effects of aging and bilingualism. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32,* 1341-1354. doi: 10.1037/02787393.32.6.1341.

Bialystok, E., Craik, F. I. M., & Luk, G. (2008). Lexical access in bilinguals: effects of vocabulary size and executive control. *Journal of Neurolinguistics, 21,* 522-538. doi: 10.1016/j.jneuroling.2007.07.001.

Bialystok, E., & Martin-Rhee, M. M. (2008). The development of two types of inhibitory control in monolingual and bilingual children. *Language and Cognition, 21,* 81-93. doi: 10.1017/S1366728907003227.

Bialystok, E. (2009). Bilingualism: the good, the bad, and the indifferent. *Bilingualism: Language and Cognition, 12,* 3-11. doi: 10.1017/S1366728908003477.

Bialystok, E., & Feng, X. (2009). Language proficiency and executive control in proactive interference: evidence form monolingual and bilingual children and adults. *Brain Lang, 109,* 93-100. doi: 10.1016/j.bandl.2008.09.001.

Bialystok, E., Luk, G., Peets, K. F., & Yang, S. (2010). Receptive vocabulary differences in monolingual and bilingual children. *Biling (Camb Engl), 13,* 535-531. doi: 10.1017/S13667289990423.

Bialystok, E. (2011). Reshaping the mind: the benefits of bilingualism. *Can J Exp Psychol, 65,* 229-235. doi: 10.1037/a0025406.

Bialystok, E., & Barac, R. (2012). Emerging bilingualism: dissociating advantages for metalinguistic awareness and executive control. *Cognition, 122,* 67-73. doi: 10.1016/j.cognition.2011.08.003.

Bialystok, E. (2015). Bilingualism and the development of executive function: the role of attention. *Child Development Perspectives, 9,* 117-121. doi: 10.1111/cdep.12116.

Bjork, R. A. (1970). Positive forgetting: The noninterference of items intentionally forgotten. *Journal of Verbal Learning and Verbal Behavior, 9,* 255-268.

Bjorklund, D. F., & Harnishfeger, K. K. (1990). The resources construct in cognitive development: Diverse sources of evidence and a theory of inefficient inhibition. *Developmental Review, 1,* 48-71.

Bonifacci, P., Giombini, L., Bellocchi, S., & Contento, S. (2011). Speed of processing, anticipation, inhibition and working memory in bilinguals. *Developmental Science, 14,* 256-269. doi: 10.1111/j.1467-7687.2010.00974.x.

Carlson, S. M., & Meltzoff, A. N. (2008). Bilingual experience and executive functioning in young children. *Developmental Science, 11,* 282-298. doi: 10.1111/j.1467-7687.2008.00675.x.

Conway, A. R. A., & Engle, R. W. (1994). Working memory and retrieval: a resource-dependent inhibition model. *Journal of Experimental Psychology: General, 123,* 354-373.

Costa, A., Hernández, M., & Sebastián-Gallés, N. (2008). Bilingualism aids in conflict resolution: Evidence form the ANT task. *Cognition, 106,* 308-325.

Costa, A., Hernández, M., Costa-Faidella, J., & Sebastián-Gallés, N. (2009). On the bilingual advantage in conflict processing: Now you see it, now you don't. *Cognition, 113,* 135-149. doi: 10.1016/j.cognition.2009.09.00

Craik, F. I., Bialystok, E., & Freedman, M. (2010). Delaying the onset of Alzheimer's disease: bilingualism as a form of cognitive reserve. *Neurology, 75,* 1726-1729. doi: 10.1212/WNL.0b013e3181fc2a1c.

Daniels, K., Toth, J., & Jacoby, L. (2006). The aging of executive functions. In E. Bialystok & F. I. M. (Eds.), *Lifelong cognition: Mechanisms of change* (pp. 96-111). New York: Oxford University Press.

De Bruin, A., Treccani, B., & Della Sala, S. (2015). Cognitive advantage in bilingualism: an example of publication bias? *Psychological Science, 26*, 99-107. doi: 10.1177/0956797814557866.

Diamond, A. (2013). Executive functions. *Annu Rev Psychol, 64,* 135-168. doi: 10.1146/annurev-psych-113011-143750.

Dickinson, E. R., & Adelson, J. L. (2014). Exploring the limitations of measures of student's socioeconomic status (SES). *Practical Assessment, Research & Evaluation, 19,* 1-14.

Dijkstra, T., & van Heuven, W. J. B. (2002). The architecture of the bilingual word recognition system: from identification to decision. *Bilingualism: Language and Cognition, 5,* 175-179. doi: 10.1017/S1366728902003012.

Duñabeitia, J. A., Hernández, J. A., Antón, E., Macizo, P., Estévez, A., Fuentes, L. J., & Carreiras, M. (2014). The inhibitory advantage in bilingual children revisited. Myth or reality? *Experimental Psychology, 61,* 234-251. doi: 10.1027/1618-3169/a000243.

Draganski, B., Gaser, C., Busch, V., Schuierer, G., Bogdahn, U., & May, A. (2004). Neuroplasticity: changes in grey matter induced by training. *Nature, 427, 11-312.*

Esposito, A. G., Baker-Ward, L., & Mueller, S. (2014). Interference suppression vs. response inhibition: an explanation for the absence of a bilingual advantage in preschoolers' stroop task performance. *Cogn Dev, 28,* 354-363. doi: 10.1016/j.cogdev.2013.09.002.

Fabbro, F., Skrap, M., & Aglioti, S. (2000). Pathological switching between languages following frontal lesion in a bilingual patient. *Journal of Neurology, Neurosurgery, and Psychiatry*, 68, 650–652. doi: 10.1136/jnnp.68.5.650.

Fernandes, M. A., Craik, F. I. M., Bialystok, E. & Kreuger, S. (2007). Effects of bilingualism, aging, and semantic relatedness on memory under divided attention. *Canadian Journal of Experimental Psychology, 61,* 128-141.

Friedman, N. P, Miyake, A., Young, S. E., DeFries, J. C., Corley, R. P., & Hewitt, J. K. (2008). Individual differences in executive functions are almost entirely genetic in origin. *Journal of Experimental Psychology General, 137,* 201-225.

Garbin, G., Sanjuan, A., Forn, C., Bustamante, J. C., Rodriguez-Pujadas, A., Belloch, V., Hernández, M., Costa, A., & Ávila, C. (2010). Bridging language and attention: brain basis of the impact of bilingualism on cognitive control.

Gold, B. T., Kim, C., Johnson, N. F., Kryscio, R. J., & Smith, C. D. (2013). Lifelong bilingualism maintains neural efficiency for cognitive control in aging. *The Journal of Neuroscience, 33,* 387-396.

Gollan T. H., Kroll, J. F. (2011). Bilingual lexical access. In: Rapp B, editor. The handbook of cognitive neuropsychology: What deficits reveal about the human mind. Philadelphia: Psychology Press; 2001. pp. 321–345.

Goral, M., Campanelli, L., & Spiro, A. (2015). Language dominance and inhibition abilities in bilingual older adults. *Bilingualism: Language and Cognition, 18,* 79-89.

Grant, A., & Dennis, N. (2016). Increased processing speed in young adult bilinguals: evidence from source memory judgments. *Bilingualism: Language and Cognition*, 1-10. doi: 10.1017/S1366728916000729.

Gray, J. R., Chabris, C. F., & Braver, T. S. (2003). Neural mechanisms of general fluid intelligence. *Nature Neuroscience, 6*, 316-322. doi: 10.1038/nn1014.

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and Cognition, 1,* 67-81.

Green, C. S., & Bavelier, D. (2003). Acton video game modifies visual selective attention. *Nature, 423,* 534-537.

Green, D. W., & Abutalebi, J. (2013). Language control in bilinguals: the adaptive control hypothesis. *Journal of Cognitive Psychology, 25,* 515-530. doi: 10.1080/20445911.2013.796377.

Hakuta, K., Bialystok, E., & Wiley, E. (2003). Critical evidence: a test of the critical-period hypothesis for second language acquisition. *Psychological Science, 14,* 31-38.

Heidlmayr, K., Moutier, S., Hemforth, B., Courtin, C., Tanzmeister, R., & Isel, F. (2014). Successive bilingualism and executive functions: The effect of second language use on inhibitory control in a behavioral Stroop Colour Word task. *Bilingualism: Language and Cognition, 17,* 630-645. doi: 10.1017/S1366728913000539.

Hernández, M. (2000). In search of the language switch: an fMRI study of picture naming in Spanish-English bilinguals. *Brain Lang, 73,* 421-431

Hernández, M., Martin, C. D., Barceló, F., Costa, A. (2013). Where is the bilingual advantage in task-switching? *Journal of Memory and Language, 69,* 257-276. doi: 10.1016/j.jmL2013.06.004.

Hilchey, M. D., & Klein, R. M. (2011). Are there bilingual advantages in nonlinguistic interference tasks? Implications for the plasticity of executive control processes. *Psychon Bull Rev, 18,* 625-658. doi: 10.3758/s13423-011-0116-7.

Hilchey, M. D., & Saint-Aubin, J., & Klein, R. M. (2015). Does bilingual exercise enhance cognitive fitness in traditional non-linguistic executive processing tasks? In J. Schwieter (Eds.) *The Cambridge Handbook of Bilingual Processing.* Pp. 586-613. Cambridge: Cambridge University Press. doi: 10.1007/s00221-015-4439-x.

Jonides, J., & Nee, D. E. (2006). Brain mechanisms of proactive interference in working memory. *Neuroscience, 139,* 181-193.

Karbach, J. & Kray, J. (2009). How useful is executive control training? Age differences in near and far transfer of task-switching training. *Dev Sci, 12,* 978-990. doi: 10.1111/j.1467-7687.2009.00846.x.

Kovács, Á. M., & Mehler, J. (2008). Cognitive gains in 7-month-old bilingual infants. *PNAS, 106,* 6556-6560.

Kovelman, I., Baker, S. A., & Petitto, L. (2008). Bilingual and monolingual brains compared: a functional magnetic resonance imaging investigation of syntactic processing and a possible “neural signature” of bilingualism. *J Cogn Neurosci, 20,* 153-169. doi: 10.1162/jocn.2008.20011.

Kramer, A. F., Hahn, S., & Gopher, D. (1999). Task coordination and aging: Exploration of executive control processes in the task switching paradigm. *Acta Psychologica, 101,* 339-378.

Kray, J., & Lindenberger, U. (2000). Adult age differences in task switching. *Psychology and Aging, 15,* 126-147.

Kroll, J. F., & Bialystok. E. (2013). Understanding the consequences of bilingualism for language processing and cognition. *J Cogn Psychol, 25,* 1-22. doi: 10.1080/20445911.2013.799170.

Luk, G., Bialystok, E., Craik, F. I. M., & Grady, C. L. (2011). Lifelong bilingualism maintains white matter integrity in older adults. *J Neurosci, 31,* 16808-16813. doi: 10.1523/JNEUROSSCI.4563-11.2011.

Luk, G., De Sa, E., & Bialystok, E. (2011). Is there a relation between onset age of bilingualism and enhancement of cognitive control? *Bilingualism: Language and Cognition, 4,* 588-595. doi: 10.1017/S1366728911000010.

Luk, G., & Bialystok, E. (2014). Bilingualism in not a categorical variable: interaction between language proficiency and usage. *J Cogn Psychol, 25,* 605-621. doi: 10.1080/20445911.2013.795574.

Maguire, E. A., Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S., & Frith, C. D. (2000). Navigation-related structural change in the hippocampi of taxi drivers. *Proc Natl Acad Sci USA, 97,* 4398-4403.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (2000). The unity and diversity of executive functions and their contribution to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology, 41,* 49-100.

Monsell, S. (2003). Task switching. *Trends in Cognitive Science, 7,* 134-140. doi: 10.1016/S1364-6613(03)00028-7.

Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Capeda, N. J., & Chau, T. (2011). Music training enhances verbal and executive function. *Psychological Science, 22,* 1425-1433. doi: 10.1177/0956797611.

Morton, J. B., & Harper, S. N. (2007). What did Simon say? Revisiting the bilingual advantage. *Developmental Science, 10,* 719-726. doi: 10.1111/j.1467-7687.2007.00623.x.

Oller, D. K., & Eilers, R. E. (2002). Language and literacy in bilingual children. *Multilingual Matters*; Clevedon.

Paap, K. R., & Greenberg, Z. I. (2013). There is no coherent evidence for a bilingual advantage in executive processing. *Cogn Psychol, 66,* 232-258. doi: 10.1016/j.cogpsych.2012.12.002

Paap, K. R., Johnson, H. A., & Sawi, O. (2015). Bilingual advantages in executive functioning either do not exist or are restricted to very specific and undetermined circumstances. *Cortex, 69,* 265-278. doi: 10.1016/j.cortex.2015.04.014.

Portocarrero, J. S., Burright, R. G., & Donovick, P. J. (2007). Vocabulary and verbal fluency of bilingual and monolingual college students. *Arch Clin Neuropsychol, 22,* 415-422. doi: 10.1016/j.acn.2007.01.015.

Poulin-Dubois, D., Blaye, A., Coutya, J., & Bialystok, E. (2011). The effects of bilingualism on toddlers’ executive functioning. *J Exp Child Psychol, 108,* 567-579. doi: 10.1016/j.jecp.2010.10.009.

Prior, A., & MacWhinney, B. (2010). The bilingual advantage in task switching. *Bilingualism: Language and Cognition, 13,* 253-262. doi: 10.1017/S1366728909990526.

Prior, A., & Gollan, T. H. (2011). Good language-switchers are good task-switchers: evidence from Spanish-English and Mandarin-English bilinguals. *J Int Neuropsychol Soc, 17,* 682-691. doi: 10.1017/S1355617711000580.

Reimers, S., & Maylor, E. A. (2005). Task switching across the life span: Effects of age on general and specific switch costs. *Developmental Psychology, 41*, 661-671.

Reitman, W., Malin, J. T., Bjork, R. A., & Higman, B. (1973). Strategy control and directed forgetting. *Journal of Verbal Learning and Verbal Behavior, 12*, 140-149.

Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General*, *124*, 207-231.

Sahakyan, L., & Goodmon, L. B. (2007). The influence of directional associations on directed forgetting and interference. *Journal of Experimental Psychology, 33,* 1035-1049. doi: 10.1037/0278-7393.33.6.1035.

Salthouse, T. A., & Mitchell, D. R. D. (1990). Effects of age and naturally occurring experience on spatial visualization performance. *Developmental Psychology, 26,* 845-854. doi: 10.1037/0012-1649.26.5.845

Salvatierra, J. L., & Rosseli, M. (2010). The effect of bilingualism and age on inhibitory control. *International Journal of Bilingualism*, *15*, 26-37. doi: 10.1177/1367006910371021.

Schweizer, T. A., Ware, J., Fischer, C. E., Craik, F. I. M, & Bialystok, E. (2012). Bilingualism as a contributor to cognitive reserve: Evidence from brain atrophy in Alzheimer's disease. *Cortex, 48*, 991-996. doi: 10.1016/j.cortex.2011.04.009

Simon, J., & Ruddell, A. P. (1967). Auditory S-R compatibility: The effect of an irrelevant cue on information processing. *Journal of Applied Psychology, 51,* 300-304.

Soveri, A., Rodriguez-Fornells, A., & Laine, M. (2011). Is there a relationship between language switching and executive functions in bilingualism? Introducing a within-group analysis approach. *Bilingualism and cognitive control, 138.*

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *J Int Neuropsychol Soc, 8,* 448-460.

Stoet, G. (2010). PsyToolkit: a software package for programming psychological experiments using Linux. *Behav Res Methods, 4,* 1096-1194. doi: 10.3758/BRM.42.4.1096.

Sylvester, C. Y. C., Wager, T. D., Lacey, S. C., Hernández, L., Nichols, T. E., . . ., Smith, E. E. (2003). Switching attention and resolving interference: fMRI measures of executive functions. *Neuropsychologia, 41,* 357-370.

Underwood, Benton J. (1957). Interference and forgetting. *Psychological Review, 64,* 49–60. doi: 10.1037/h0044616

U.S. Department of Commerce Economics and Statistics Administration Census Bureau. (2010). Language Use in the United States 2007 – American Community Survey Reports. Retrieved March 9, 2015, from http://www.census.gov/hhes/socdemo/language/data/acs/ACS-12.pdf

Valian, V. (2014). Bilingualism and cognition. *Bilingualism: Language and Cognition, 18,* 3-24.

Verbruggen, f., McLaren, I. P. L., & Chambers, C. D. (2014). Banishing the control homunculi in studies of action control and behaviour change. *Perspectives on Psychological Science, 9,* 497-524. doi: 10.1177/1745691614526414.

Whitford, V., & Titone, D. (2012). Second-language experience modulates first- and second-language word frequency effects: evidence from eye movement measures of natural paragraph reading. *Psychon Bull Rev, 19,* 73-80. doi: 10.3758/s13423-011-0179-5.

Wilson, S. P., & Kipp, K. (1998). The development of efficient inhibition: evidence from directed-forgetting tasks. *Developmental Review, 18,* 86-123.

Wiseheart, M., Viswanathan, M., & Bialystok, E. (2016). Flexibility in task switching by monolinguals and bilinguals. *Bilingualism: Language and Cognition, 19,* 141-146.

Yang, H., & Yang, S. (2015). Are all interferences bad? Bilingual advantages in working memory are modulated by varying demands for controlled processing. *Bilingualism: Language and Cognition,* 1-13. doi: 10.107/S1366728915000632.

Yang, H., Yang, S., Ceci, S. J., & Wang, Q. (2005). Effects of bilinguals' controlled-attention on working memory and recognition. *Research Collection School of Social Sciences, 433,* 1-6.

Yeung, N., & Monsell, S. (2003). The effects of recent practice on task switching. *Journal of Experimental Psychology: Human Perception and Performance, 29,* 919-936.

Young, S. E. (2016). The effects of bilingualism and multilingualism on lexical retrieval. *Linguistics Senior Research Projects.* Paper 6.

Van der Lubbe, R. H. J., & Verleger, R. (2002). Effects of frontal lobe damage on interference effects in working memory. *Journal of Cognitive, Affective, and Behavioral Neuroscience, 2,* 109-120.

Von Bastian, C. C., Souza, A. S., & Miriam, G. (2016). No evidence for bilingual cognitive advantages: a test of four hypotheses. *Journal of Experimental Psychology, 145,* 246-258. doi: 10.137/xge0000120.

Zacks, R. T., Hasher, L., & Radvansky, G. (1996). Studies of directed forgetting in older adults. *Journal of Experimental Psychology: Learning, Memory and Cognition, 22,* 143-156.

Table 1

Mean (SD) Demographic and Lifestyle Measures by Age and Language Group

	Young Adults		Middle Adults	
Variable	Monolingual	Bilingual	Monolingual	Bilingual
Age	20.0 (1.87)**	21.3 (2.75)	44.8 (8.30)	43.2 (8.91)
Sex (Male:Female)	31:77	34:66	16:38	17:24
Education	3.09 (1.05)**	4.07 (2.34)	6.93 (1.80)	7.12 (1.47)
Shipley-II Vocabulary	33.6 (3.07)	33.9 (4.20)	36.4 (2.30)	36.4 (3.20)
Shipley-II Block Patterns	31.8 (7.23)	32.1 (7.35)	30.6 (6.85)	31.1 (7.07)
Colorblind (Yes:No)	1:107	2:98	2:51	0:41
Video Game	4.64 (0.69)**	4.17(1.26)	4.54 (1.02)	4.71 (0.72)
Computer	1.13 (0.55)	1.09 (0.40)	1.07 (0.33)	1.10 (0.49)
Handedness	62.2 (62.7)	75.6 (42.7)	82.6 (39.8)	67.1 (56.9)
Musical Instrument (Yes:No)	19:90	34:67	14:40	17:24

Note. Demographic and lifestyle measures of mono- (n = 109) and bilingual (n = 101) young adults and mono- (n = 54) and bilingual (n = 41) middle adults. Mean level of education based on 1-10 scale (1 = "No schooling", 2 = "High School", 3 = "Some university credit, no degree", 4 = "Trade/technical/vocational training", 5 = "Associate's degree", 6 = "Bachelor's degree", 7 = "Master's degree", 8 = "Professional degree", 9 = "Doctorate degree", 10 = "Some high school, no diploma"). Mean weekly video game and computer use based on 1-5 scale (1 = "Daily", 2 = "4-6 times a week", 3 = "2-3 times a week", 4 = "Once a week", 5 = "Never")
** denotes significant difference between mono- and bilinguals within an age group at the $p < .001$ level

Table 2

Language Proficiency and Use of Bilinguals

	Young (*n* = 101)	Middle (*n* = 41)
AoA		
L1	1.04 (0.25)	1.03 (0.16)
L2	1.90 (0.93)*	2.45 (0.87)*
AoAO		
L1	1.42 (0.90)	1.38 (0.87)
L2	2.78 (1.23)*	3.30 (1.14)*
Proficiency in L1		
Speaking	1.43 (0.93)	1.23 (0.87)
Writing	2.04 (1.84)*	1.36 (1.10)*
Proficiency in L2		
Speaking	1.64 (0.86)	1.63 (0.90)
Writing	1.99 (1.36)	1.90 (1.36)
% English Use (Home)		
Speaking	52.9 (38.2)	65.5 (37.1)
Listening	55.4 (36.2)	67.6 (34.0)
Reading	73.1 (28.2)	73.1 (29.6)
Writing	66.6 (34.8)	66.8 (37.6)
Watching TV	69.6 (31.4)	75.2 (32.2)
Listening to Radio	55.8 (41.4)	65.1 (40.8)
% Total Use	63.0 (27.5)	69.6 (30.5)
% English Use (Work)		
Speaking	71.6 (34.7)	70.3 (37.5)
Listening	72.6 (34.2)	69.0 (38.7)
Reading	74.4 (32.8)	73.4 (35.2)
Writing	72.8 (35.7)	72.9 (37.7)
% Total Use	73.4 (32.2)	72.1 (35.9)
% Total Daily English Use	67.3 (25.3)	70.6 (30.9)

Note. Mean Age of Acquisition (AoA) and Age of Active Onset (AoAO) on 1-4 scale (1 = "0-5 years", 2 = "6-11 years", 3 = "12-17 years", 4 = "18+ years"). Mean perceived high language proficiency on 1-7 scale (1 = "Strongly Agree" to 7 = "Strongly Disagree").
Percent English use with 100 meaning activity carried out solely in English.
* denotes significant difference between young and middle-aged adults at the .05 level.

Table 3

Correlations Among Primary Study Variables (N = 305)

Variable	1	2	3	4	5
1. Simon Effect	___	.11	-.18**	.00	-.10
2. Local Switch Cost (TS)		___	-.17**	-.08	-.06
3. Global Switch Cost (TS)			___	.14*	-.18**
4. Vocabulary Score				___	.17*
5. Block Patterns Score					___

Note. Correlations between primary study variables.
* $p < .05$, ** $p < .01$

Table 4

Mean (SD) Simon Task Accuracy and Reaction Time (RT in ms) by Age and Language Group

Group (*N* = 296)	Incongruent	Accuracy	Congruent	Accuracy	Simon Effect
Young Adults					
Monolinguals	504.8 (78.4)	.97 (.04)	479.4 (85.7)	.97 (.06)	25.4 (47.8)
Bilinguals	530.1 (94.1)	.97 (.04)	508.7 (102)	.97 (.04)	21.4 (57.9)
Middle Adults					
Monolinguals	614.0 (101)	.98 (.02)	572.2 (107)	.97 (.10)	.94 (.05)
Bilinguals	588.9 (104)	.98 (.02)	559.6 (106)	.99 (.02)	.94 (.05)

Note. Nine subjects were excluded for accuracy scores lower than .80. Subjects include young monolinguals (*n* = 92) and bilinguals (*n* = 86), and middle-aged monolinguals (*n* = 46) and bilinguals (*n* = 37).

Table 5

Mean (SD) Task-Switching Paradigm Accuracy and RT (in ms) by Age and Language Group

Group (*N* = 261)	Young Adults		Middle Adults	
Variable	Monolingual	Bilingual	Monolingual	Bilingual
Single Block				
Non-Switch	744.1 (113.8)	770.1 (124.1)	888.8 (154.3)	870.6 (148.5)
Accuracy	.97 (.04)	.96 (.04)	.98 (.02)	.99 (.02)
Mixed Block				
Non-Switch	1006.0 (174.8)	1044.3 (183.9)	1191.3 (206.3)	1226.3 (226.2)
Accuracy	.97 (.04)	.97 (.03)	.98 (.02)	.98 (.03)
Switch	1467.2 (269.4)	1561.8 (326.6)	1740.2 (369.6)	1715.2 (229.4)
Accuracy	.93 (.05)	.94 (.04)	.96 (.05)	.95 (.05)

Note. Forty-four subjects were excluded due to accuracy scores below .80 on switch or non-switch trials. Subjects include young monolinguals (*n* = 92) and bilinguals (*n* = 86), and middle-aged monolinguals (*n* = 46) and bilinguals (*n* = 37).

Table 6

Local and Global Switch Costs in Task-Switching Paradigm

Group (*N* = 261)	Global Switch Cost	Accuracy	Local Switch Cost	Accuracy
Young Adults				
Monolinguals	265.1 (141)	.97 (.03)	456.4 (212)	.95 (.04)
Bilinguals	275.2 (173)	.96 (.03)	518.2 (248)	.96 (.03)
Middle Adults				
Monolinguals	302.5 (173)	.98 (.02)	548.9 (282)	.97 (.03)
Bilinguals	355.7 (181)	.98 (.02)	488.9 (224)	.96 (.03)

Note. Forty-four subjects were excluded due to accuracy scores below .80 on switch or non-switch trials. Subjects include young monolinguals (*n* = 92) and bilinguals (*n* = 86), and middle-aged monolinguals (*n* = 46) and bilinguals (*n* = 37).

Table 7

Mean Item Recall on Directed-Forgetting Paradigm by Age, Language, and DF Group

Group (*N* = 304)	Young Adults (*n* = 210)		Middle Adults (*n* = 94)	
Variable	Monolingual	Bilingual	Monolingual	Bilingual
Forget Group (*n* = 113)				
List 1	.29 (.28)	.55 (.34)	.39 (.33)	.39 (.32)
List 2	.59 (.34)	.69 (.30)	.64 (.32)	.67 (.39)
Remember Group (*n* = 97)				
List 1	.51 (.34)	.63 (.31)	.67 (.39)	.61 (.33)
List 2	.47 (.36)	.55 (.39)	.98 (.02)	.72 (.30)

Note. Remember Group: young bilinguals (*n* = 49) and monolinguals (*n* = 48), middle-aged bilinguals (*n* = 21) and monolinguals (*n* = 27). Forget Group: young bilinguals (*n* = 48) and monolinguals (*n* = 53), middle-aged bilinguals (*n* = 20) and monolinguals (*n* = 26).

Table 8

Conditional Effects of Language on Simon Task at Mean, +/-1 SD of Age (N = 296)

					95% Confidence Interval	
Age	*B*	SE	t	*p*	Lower Bound	Upper Bound
Simon Task Incongruent Trials						
-1 SD Below Mean	37.73	13.09	2.88	.004*	11.97	63.48
Mean	31.14	3.47	10.6	.74	-17.36	24.30
+1 SD Above Mean	-38.16	18.62	-2.05	.04*	-74.79	-1.53
Simon Task Congruent Trials						
-1 SD Below Mean	33.58	14.53	2.31	.02*	4.99	62.17
Mean	13.49	11.13	1.21	.23	-8.40	35.39
+1 SD Above Mean	-10.82	15.68	-0.69	.49	-41.67	20.04

Note. One SD below the mean of the moderator (18.00 years), mean of the moderator (31.14 years), and one SD above the mean of the moderator (47.12 years).
*p < .05

Table 9

Moderated Regression Results for Simon Task (N = 296)

					95% Confidence Interval	
Variable	*B*	SE	t	*p*	Lower Bound	Upper Bound
Simon Task Incongruent Trials						
Sex	24.35	10.99	2.22	.03*	2.73	45.97
High Education	-10.9	10.83	-0.93	.35	-31.38	11.21
Video Games	-23.03	11.66	-1.97	.05*	-45.96	-0.08
Age	5.71	0.77	7.37	.000**	4.19	7.23
Language	84.64	24.94	3.39	.001**	35.58	133.70
Age x Language	-2.61	0.81	-3.21	.002*	-4.20	-1.01
Simon Task Congruent Trials						
Sex	6.16	12.58	0.49	0.63	-18.59	30.92
High Education	3.49	9.92	0.35	0.72	-16.02	23.01
Video Games	-24.65	13.37	-1.84	0.07	-50.95	1.65
Age	3.72	0.58	6.92	.00**	2.66	4.78
Language	61.15	24.66	2.48	.01*	12.64	109.7
Age x Language	-1.53	0.70	-2.18	.03*	-2.92	-0.15

Note. Sex, High Education, and Video Games are dummy variables.
*p < .05, **p < .001

Table 10

Hierarchical Regression Analysis Predicting Simon Effect (N = 147)

Variable	R^2	ΔR^2	*B*	*SE B*	β
Step 1	.02	.02			
Sex			8.93	9.89	.07
High Education			-5.47	6.32	-.07
Video Games			-10.71	10.28	-.09
Step 2	.05*	.03*			
Sex			13.61	10.04	.12
High Education			-13.01	7.24	-.17
Video Games			-5.47	10.47	-.05
Age			0.75*	0.36	.21*
Step 3	.05	.00			
Sex			13.50	10.06	.12
High Education			-13.76	7.32	-.18
Video Games			-5.12	10.50	-.04
Age			0.71	0.37	.20
AoAO			-7.12	9.94	-.06
Step 4	.09*	.03*			
Sex			15.56	9.95	.13
High Education			-13.63	7.21	-.18
Video Games			-4.56	10.35	-.04
Age			0.32	0.40	.09
AoAO			-52.85*	22.16	-.46*
Age × AoAO			1.62*	0.70	.43*

* $p < .05$.

Figures

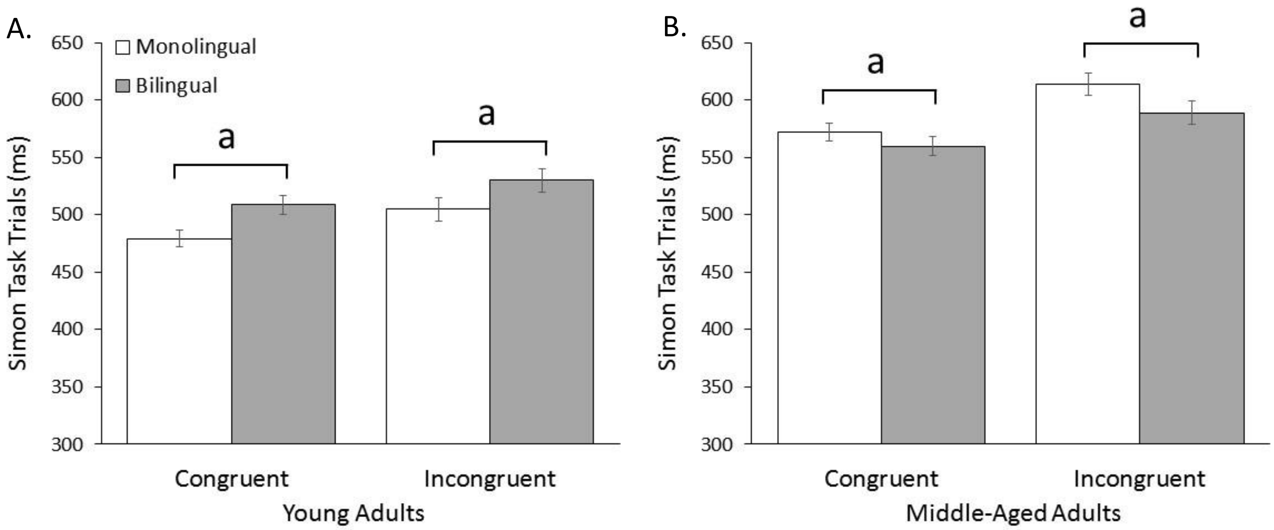


Figure 1. Simon Task incongruent and congruent RTs (ms) for (A) young and (B) middle-aged monolinguals and bilinguals.
a, denotes significant difference between congruent and incongruent trial RTs.

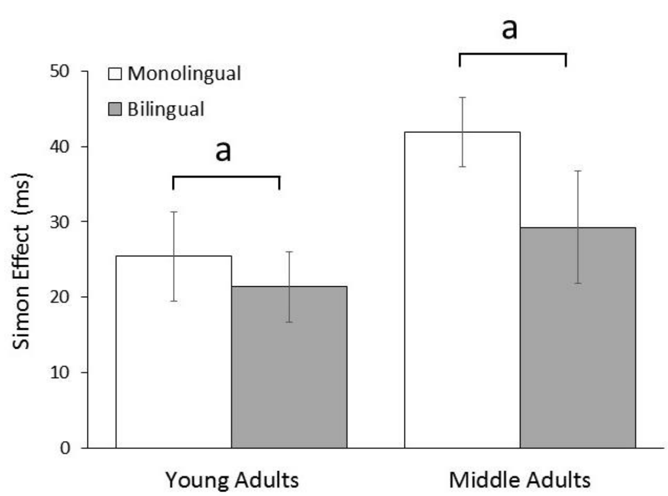


Figure 2. Simon Effect (ms) for young and middle-aged monolinguals and bilinguals.
a, denotes significant difference between young adults and middle-aged adults.

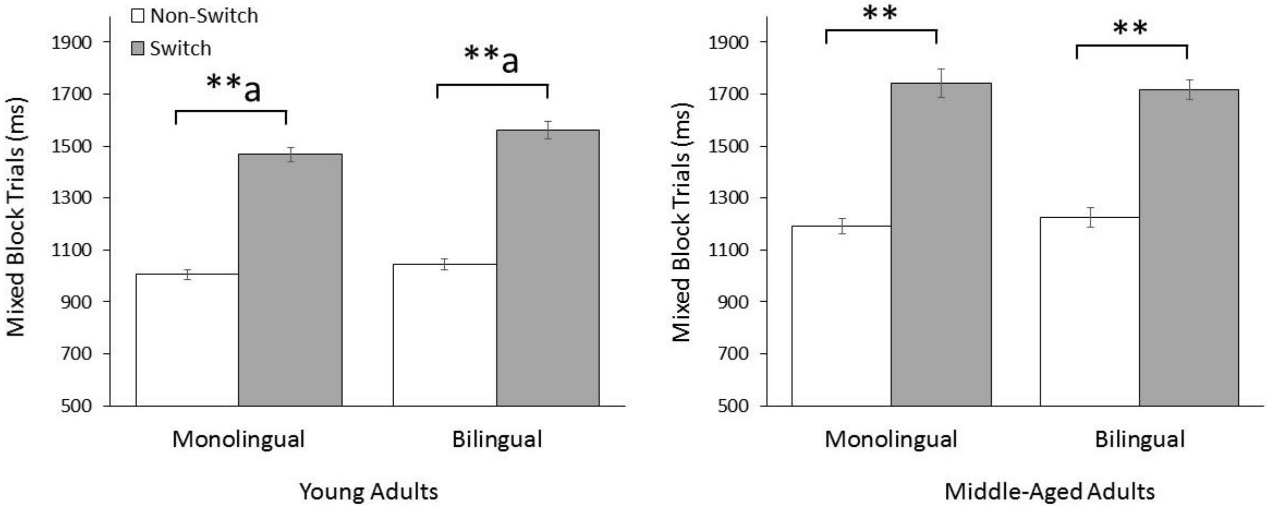


Figure 3. Task-switching paradigm mixed block switch and non-switch trials for (A) young and (B) middle-aged monolinguals and bilinguals.
a, denotes significant difference between mono- and bilinguals.
**, denotes significant difference at $p < .001$ level between switch and non-switch trials

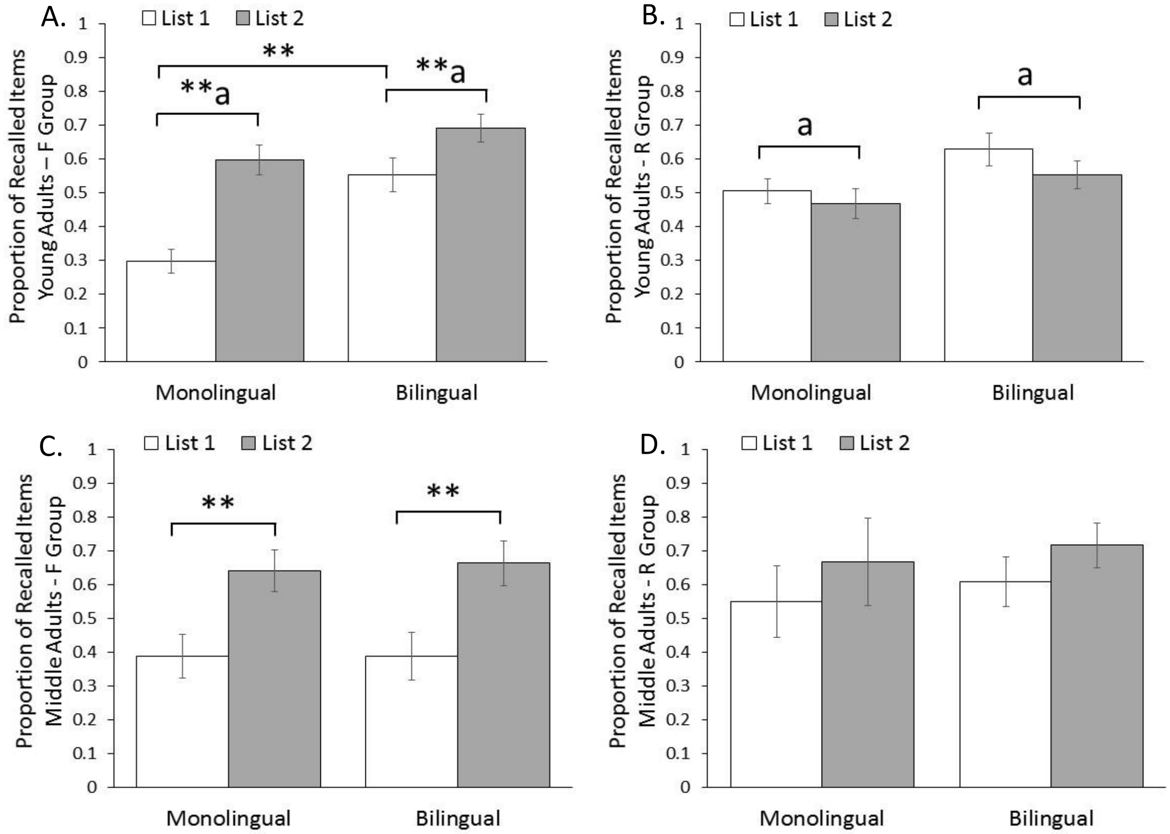


Figure 4. Directed forgetting paradigm proportion of recalled items for mono- and bilingual young adults in (A) F group and (B) R group, and mono- and bilingual middle-aged adults in (C) F group and (D) R group.

a, denotes significant difference between mono- and bilinguals.

**, denotes significant difference at $p < .001$ level between list 1 and list 2, or list 1 for both language groups.

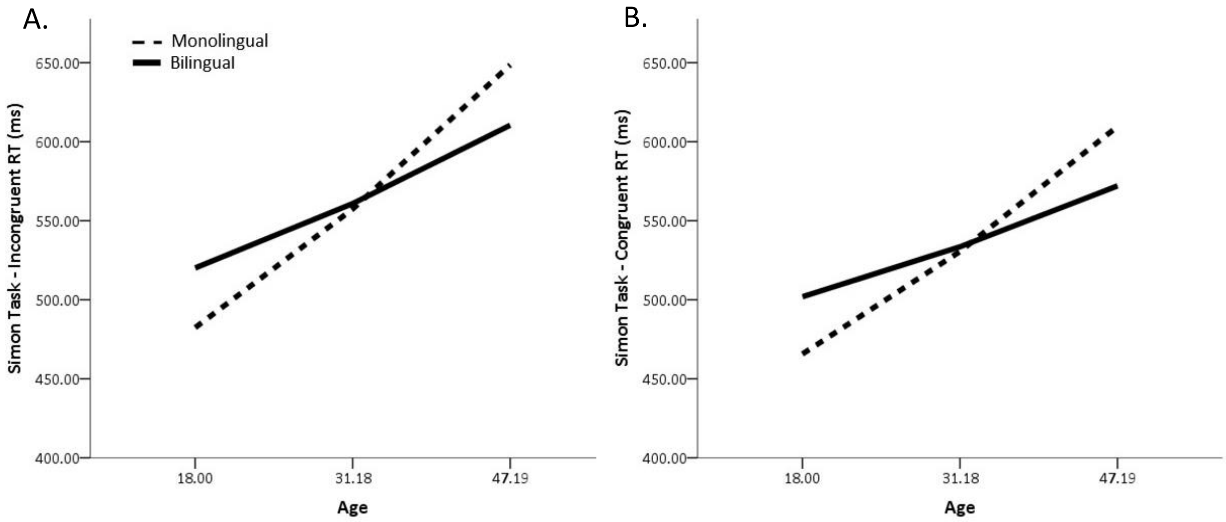


Figure 5. Simple slopes showing moderating effect of age on association between language and Simon task performance.

APPENDIX A: Shipley-II Vocabulary Test

1. Select the word that has the same meaning as the one written in capital letters. TALK
    a. Draw
    b. Eat
    c. Speak
    d. Sleep
2. COUCH
    a. Pin
    b. Eraser
    c. Sofa
    d. Glass
3. REMEMBER
    a. Swim
    b. Recall
    c. Number
    d. Plan
4. PARDON
    a. Forgive
    b. Pound
    c. Divide
    d. Crash
5. HIDEOUS
    a. Silvery
    b. Tilted
    c. Young
    d. Dreadful
6. MASSIVE
    a. Bright
    b. Large
    c. Speedy
    d. Low
7. PROBABLE
    a. Likely
    b. Portable
    c. Friendly
    d. Comprehensive
8. IMPOSTOR
    a. Conductor
    b. Officer
    c. Book
    d. Pretender
9. FASCINATE
    a. Welcome
    b. Fix
    c. Stir

   d. Enchant
10. EVIDENT
   a. Green
   b. Obvious
   c. Skeptical
   d. Afraid
11. NARRATE
   a. Yield
   b. Buy
   c. Associate
   d. Tell
12. HAUL
   a. Respond
   b. Twist
   c. Pull
   d. Realize
13. HILARITY
   a. Laughter
   b. Speed
   c. Grace
   d. Malice
14. IGNORANT
   a. Red
   b. Sharp
   c. Uninformed
   d. Precise
15. CAPTION
   a. Drum
   b. Ballast
   c. Heading
   d. Ape
16. INDICATE
   a. Defy
   b. Excite
   c. Signify
   d. Bicker
17. SOLEMN
   a. Serious
   b. Satisfying
   c. Rough
   d. Tremendous
18. FORTIFY
   a. Submerge
   b. Strengthen
   c. Vent
   d. Deaden

19. MERIT
    a. Deserve
    b. Distrust
    c. Fight
    d. Separate
20. RENOWN
    a. Length
    b. Head
    c. Fame
    d. Loyalty
21. FACILITATE
    a. Turn
    b. Help
    c. Strip
    d. Bewilder
22. AMULET
    a. Charm
    b. Orphan
    c. Dingo
    d. Pond
23. STERILE
    a. Barren
    b. Illegal
    c. Helpless
    d. Tart
24. CORDIAL
    a. Swift
    b. Muddy
    c. Leafy
    d. Affable
25. SQUANDER
    a. Tease
    b. Belittle
    c. Slice
    d. Waste
26. SERRATED
    a. Dried
    b. Notched
    c. Armed
    d. Blunt
27. PLAGIARIZE
    a. Maintain
    b. Intend
    c. Revoke
    d. Pilfer
28. ORIFICE

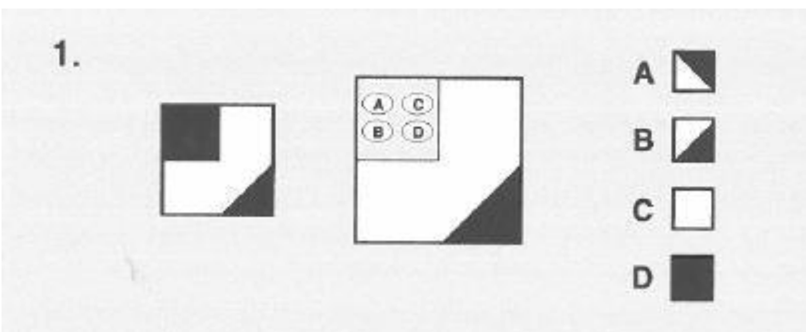
a. Brush
b. Hold
c. Building
d. Lute

29. PRISTINE
    a. Vain
    b. Sound
    c. Unspoiled
    d. Level
30. INNOCUOUS
    a. Powerful
    b. Pure
    c. Medicinal
    d. Harmless
31. JOCOSE
    a. Humorous
    b. Paltry
    c. Fervid
    d. Plain
32. RUE
    a. Deal
    b. Lament
    c. Dominate
    d. Cure
33. INEXORABLE
    a. Untidy
    b. Inviolable
    c. Relentless
    d. Sparse
34. DIVEST
    a. Dispossess
    b. Intrude
    c. Rally
    d. Pledge
35. MOLLIFY
    a. Mitigate
    b. Direct
    c. Pertain
    d. Abuse
36. QUERULOUS
    a. Maniacal
    b. Curious
    c. Devout
    d. Complaining
37. ABET
    a. Waken

    b. Ensue
    c. Incite
    d. Placate
38. DESUETUDE
    a. Disuse
    b. Remonstrance
    c. Corruption
    d. Inanity
39. PEREGRINATE
    a. Contemplate
    b. Mince
    c. Solidify
    d. Traverse
40. QUOTIDIAN
    a. Travesty
    b. Everyday
    c. Calculation
    d. Promise

APPENDIX B: Shipley-II Block Patterns Test

<u>Sample Block Patterns Test</u>



APPENDIX C: Directed Forgetting Task Instructions and Word Lists

Word List 1:

Flower
Bench
Cork
Office
Flash
Passage
Embassy
Insect
Wheat
Tornado
King
Leaf

Word List 2

Match
Shadow
Weapon
Uniform
Turtle
Diamond
Satellite
Reptile
Radish
Meadow
Forest
Lamp

Remember and Forget Cues:

REMEMBER

FORGET

Instructions:

You have **5 minutes** to study the following word list. At the end, you will be asked to either **REMEMBER** or **FORGET** the words you have studied.

After a brief task, you will have another **5 minutes** to study a second list of words. At the end, you will again be asked to either **REMEMBER** or **FORGET** the words you have studied.

Following a final task, you will have **5 minutes** to recall the words you were asked to **REMEMBER**.

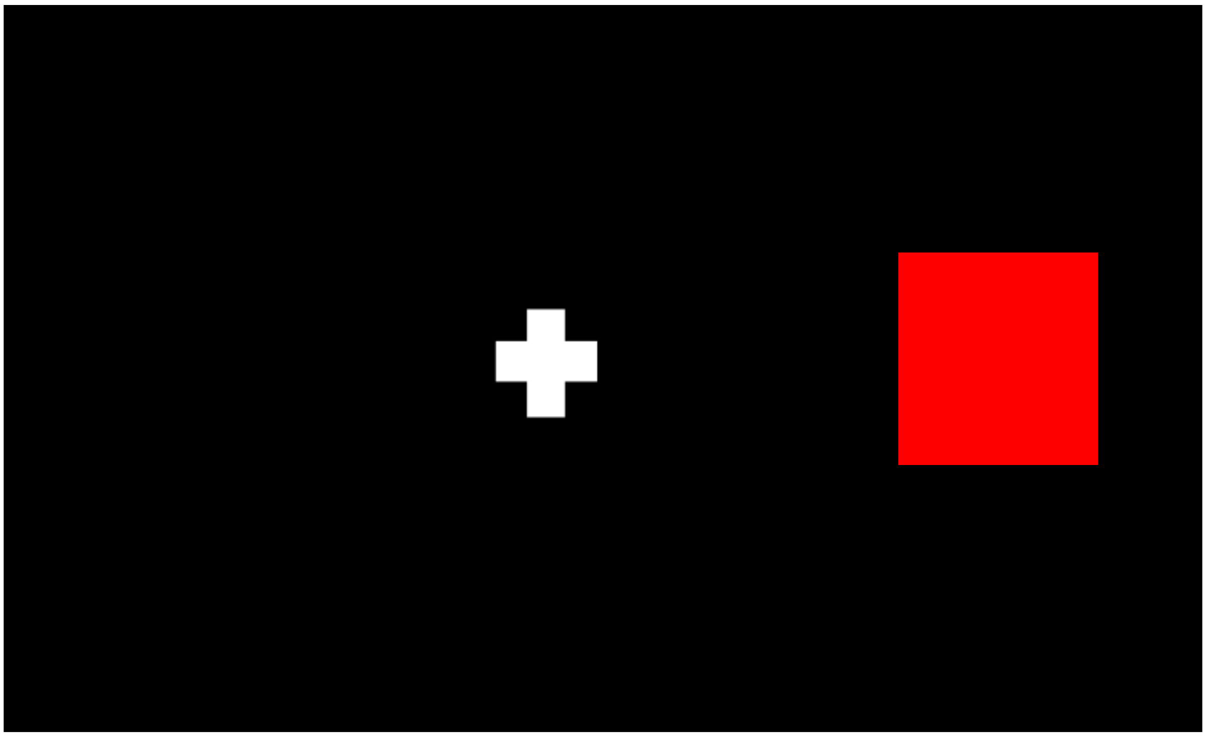
Press the space bar to continue

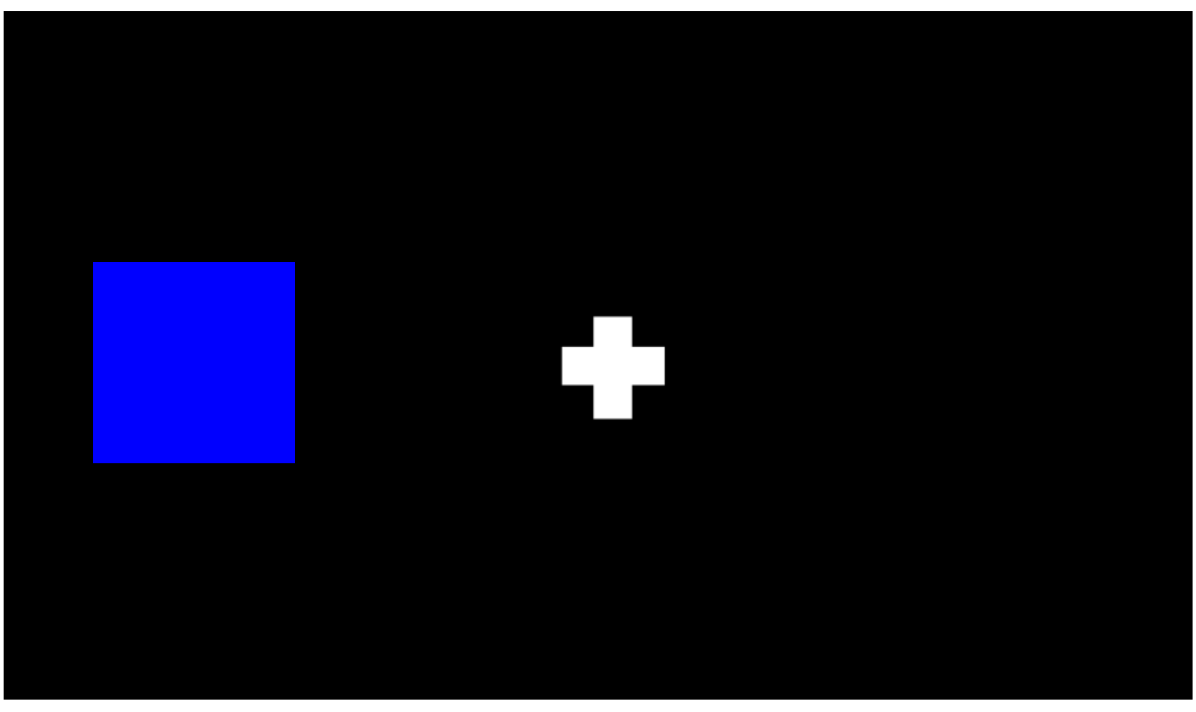
Final Message:

You have completed the task - thank you!
You will now be redirected
back to the study.

APPENDIX D: Simon Task Instructions and Presentation

Example Stimuli Presentation with Preceding Fix-Point:





Instructions:

> Use the **left key ("S")** to respond to a **blue square** as quickly as possible (regardless of its position on the screen).
>
> Use the **right key ("L")** to respond to a **red square** as quickly as possible (regardless of its position on the screen).
>
> *Press the space bar to continue*

Error Message:

> **You made a mistake.**
> Press the left key ("S") if you see a **blue** square.
> Press the right key ("L") if you see a **red** square.

Final Message:

> You have completed the task - thank you!
> You will now be redirected
> back to the study.

APPENDIX E: Task-Switching Paradigm Instructions and Presentation

Instructions:

What to do in the following task?

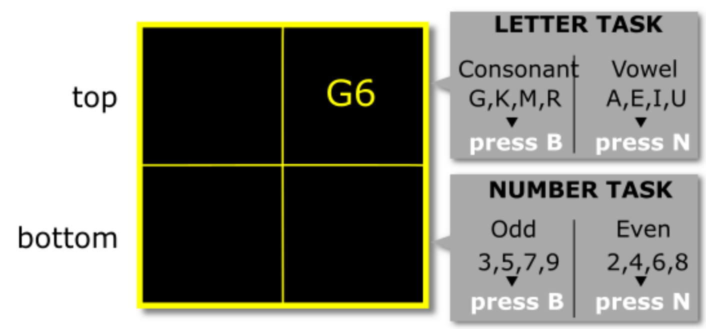
In the following task you respond with button presses to letters and numbers. You will only need two keys (B and N).

You will always see a letter/number combination, e.g. **G1**.

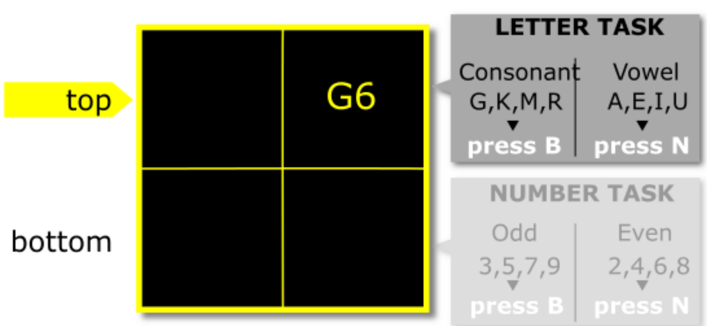
If the letter/number combination appears at the **top** of the screen, you need to respond to the **letter**.

If the letter/number combination appears at the **bottom** of the screen, you need to respond to the **number**.

press the space bar to continue



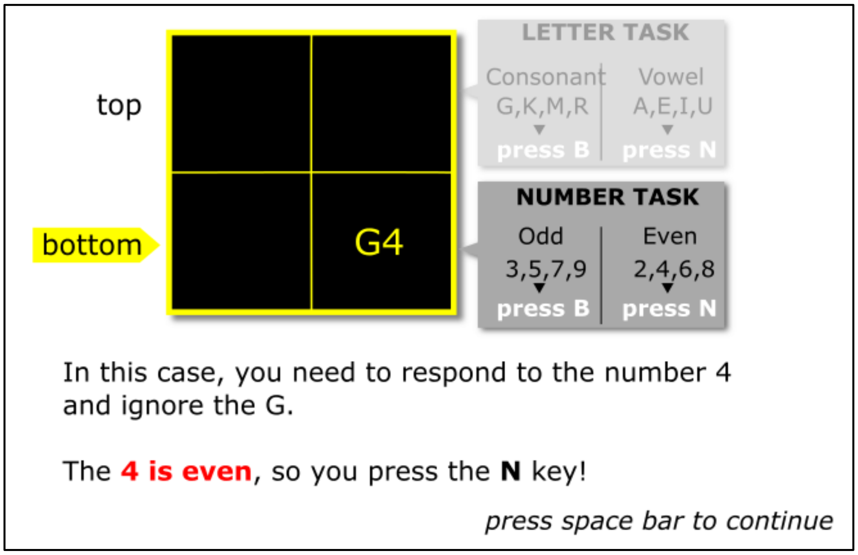
If letter/number combination appears in **top** quadrants, **respond to the letter** (in this case, a "G").

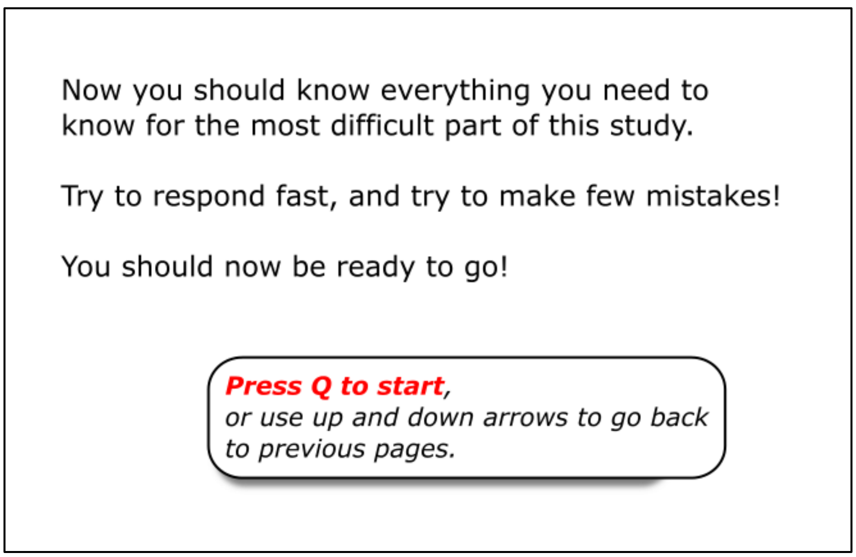


So, in this case, you need to respond to the G and ignore the 6.

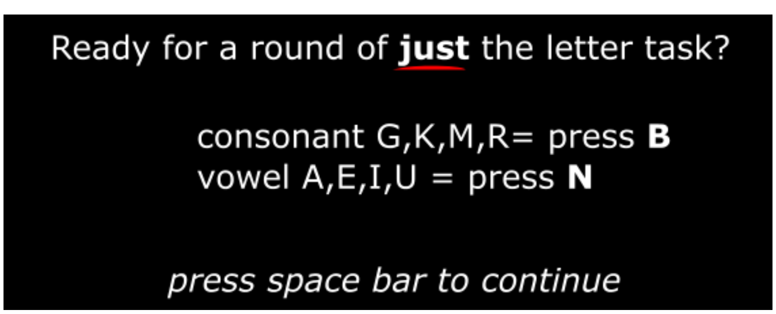
The **G is a consonant**, so you press the **B** key!

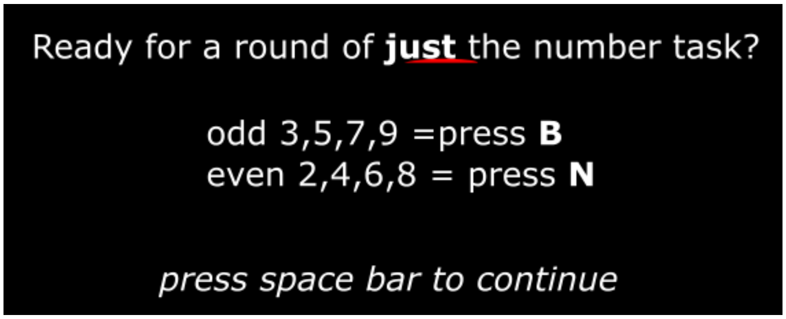
press space bar to continue



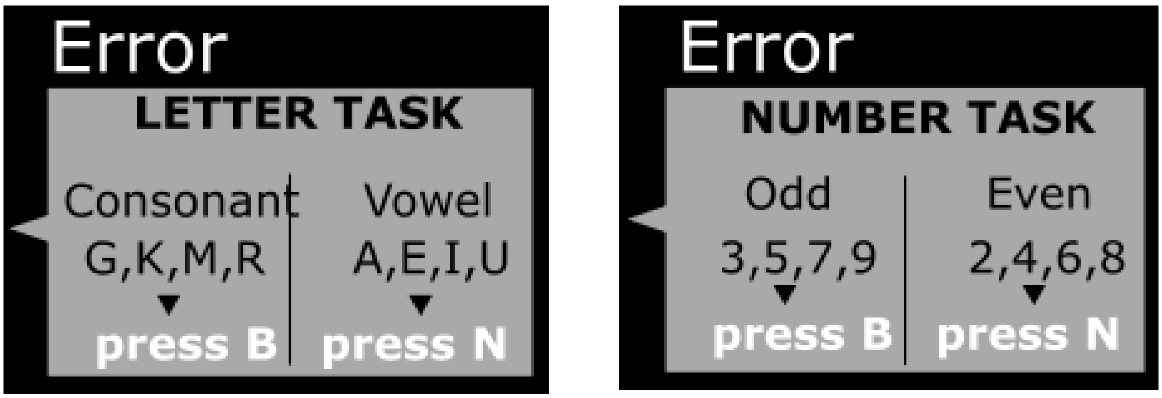


Training Block Instructions:



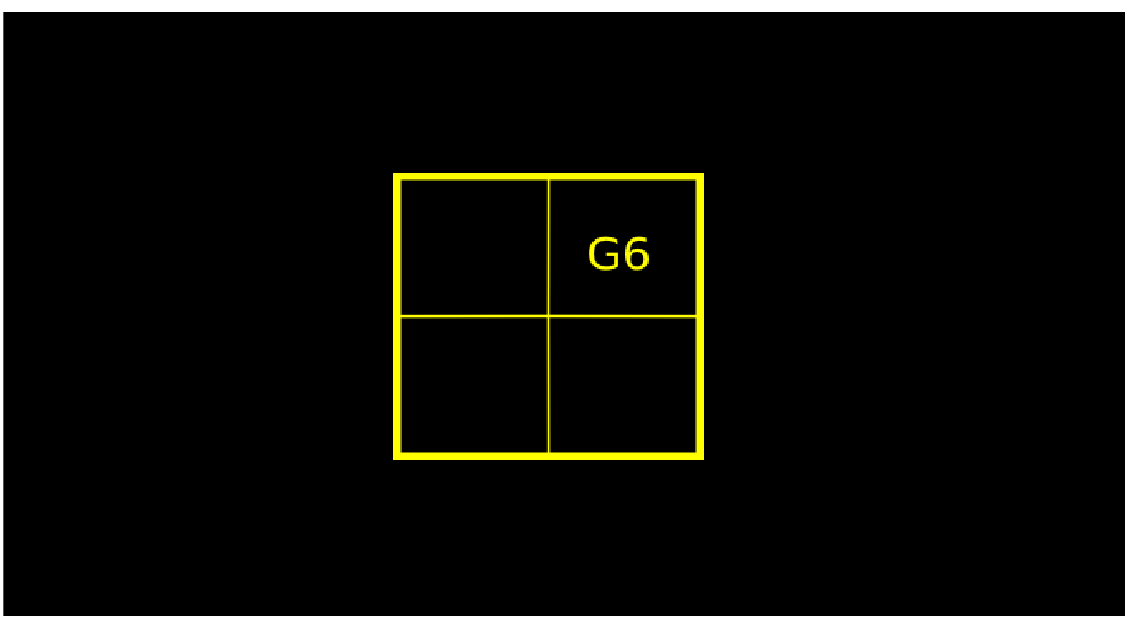


Training Block Error Message:



Test Block Error Message:

Example Stimulus Presentation:



APPENDIX F: Language and Social Background Questionnaire

1. Please enter your age: ___
2. What is your gender?
    a. Male
    b. Female
    c. Other
3. Please indicate your ethnicity: ____
4. What is the highest level of education you have completed?
    a. No schooling completed
    b. High School
    c. Some university credit, no degree
    d. Trade/technical/vocational training
    e. Associate degree
    f. Bachelor's degree
    g. Doctorate degree
    h. Some high school, no diploma
5. What is your employment status?
    a. Unemployed
    b. Self-employed part-time
    c. Self-employed full-time
    d. Part-time employment within organization/company
    e. Full-time employment within organization/company
    f. Out of work and looking for work
    g. Out of work but not currently looking for work
    h. Homemaker
    i. Student
    j. Retired
    k. Unemployed
6. How would you describe your income level?
    a. For my age group, below average national income
    b. For my age group, average national income
    c. For my age group, below national income
7. Are you colorblind?
    a. Yes
    b. No
    c. I don't know
8. How often do you use the computer?
    a. Daily
    b. 4-6 times a week
    c. Once a week
    d. Never
9. Please indicate your preferences in the use of hands in the following activities or objects (-100 = always left, -50 = usually left, 0 = both equally, 50 = usually right, 100 = always right)
    a. Writing

    b. Throwing
    c. Toothbrush
    d. Spoon
10. Do you currently play an instrument?
    a. Yes
    b. No
11. How often do you play the musical instrument?
    a. Daily
    b. 4-6 times a week
    c. 2-3 times a week
    d. Once a week
    e. Never
12. Do you speak any languages in addition to English?
    a. Yes
    b. No
13. If yes, please indicate what additional language you speak: ___
14. In what order did you learn your languages?
    a. Simultaneously (at the same time)
    b. Successively (one after the other in a delayed manner)
    c. Other
15. What is the first language you acquired? (L1) ________
16. What is the second language you acquired? (L2) _______
17. Do you speak a third language (L3) or more?
    a. Yes
    b. No
18. If yes, please indicate what additional language(s) you speak: ________
19. What has been your dominant language for the last 5 years?
    a. L1
    b. L2
    c. Both
    d. Neither (i.e. L3 or any additional language)
20. Did you learn your L1 in a country where your L1 is also the dominant language?
    a. Yes
    b. No
21. Is your L1 the dominant language of your current country of residence?
    a. Yes
    b. No
22. Please indicate at what age your acquired the L1?
    a. 0-5 years of age
    b. 5-11 years of age
    c. 12-17 years of age
    d. 18+ years of age
    e. Never actively used my L1 on a daily basis
23. Please indicate at what age you ACTIVELY used your L1 on a daily basis?
    a. 0-5 years of age
    b. 5-11 years of age

    c. 12-17 years of age
    d. 18+ years of age
    e. Never actively used my L1 on a daily basis
24. Have you had a formal education in your L1? (i.e. schooling in an educational institution, course, or with a tutor?)
    a. Yes
    b. No
25. Who/what facilitated an informal education in your L1?
    a. Guardian
    b. Language learning resource (i.e. book, CD/DVD)
    c. Other
26. Do you identify yourself as a proficient speaker of your L1?
    a. Strongly agree
    b. Agree
    c. Somewhat agree
    d. Neither agree nor disagree
    e. Disagree
    f. Strongly disagree
27. Do you identify yourself as a proficient writer of your L1 (i.e. minimal mistakes, accurate grammar and spelling, capable of analytical deliberations, extensive essay writing experience)?
    a. Strongly agree
    b. Agree
    c. Somewhat agree
    d. Neither agree nor disagree
    e. Disagree
    f. Strongly disagree
28. What do you identify as?
    a. Monolingual
    b. Bilingual
    c. Trilingual
    d. Multilingual
29. Did you learn your L2 in a country where your L2 is also the dominant language?
    a. Yes
    b. No
30. Is your L2 the dominant language of your current country of residence?
    a. Yes
    b. No
31. Please indicate at what age your acquired the L2?
    a. 0-5 years of age
    b. 5-11 years of age
    c. 12-17 years of age
    d. 18+ years of age
    e. Never actively used my L2 on a daily basis
32. Please indicate at what age you ACTIVELY started using your L2 on a daily basis?
    a. 0-5 years of age

b. 5-11 years of age
c. 12-17 years of age
d. 18+ years of age
e. Never actively used my L2 on a daily basis

33. Have you had a formal education in your L2? (i.e. schooling in an educational institution, course, or with a tutor?)
    a. Yes
    b. No
34. Who/what facilitated an informal education in your L2?
    a. Guardian
    b. Language learning resource (i.e. book, CD/DVD)
    c. Other
35. Do you identify yourself as a proficient speaker of your L2?
    a. Strongly agree
    b. Agree
    c. Somewhat agree
    d. Neither agree nor disagree
    e. Disagree
    f. Strongly disagree
36. Do you identify yourself as a proficient writer of your L2 (i.e. minimal mistakes, accurate grammar and spelling, capable of analytical deliberations, extensive essay writing experience)?
    a. Strongly agree
    b. Agree
    c. Somewhat agree
    d. Neither agree nor disagree
    e. Disagree
    f. Strongly disagree
37. In each of the scales below indicate the proportion of use for English and your other language in daily life AT HOME
    100 = the particular activity in that environment is carried out in ALL ENGLISH. 0 = you do not use English at all to carry out the activity.
    a. Speaking
    b. Listening
    c. Reading
    d. Writing
    e. Watching TV
    f. Listening to Radio
38. In each of the scales below indicate the proportion of use for English and your other language in daily life AT WORK/SCHOOL
    100 = the particular activity in that environment is carried out in ALL ENGLISH. 0 = you do not use English at all to carry out the activity.
    a. Speaking
    b. Listening
    c. Reading
    d. Writing

39. Are you more proficient in your L1 than your L2?
    a. Definitely yes
    b. Probably yes
    c. Might or might not be
    d. Probably not
    e. Definitely not
    f. Equally proficient in both
40. Are you more proficient in your L2 than your L1?
    a. Definitely yes
    b. Probably yes
    c. Might or might not be
    d. Probably not
    e. Definitely not
    f. Equally proficient in both
41. Did you learn your L1 and L2 simultaneously? (e.g. guardians spoke both languages to you at the same time, you spoke one language at home and another at school)
    a. Definitely yes
    b. Probably yes
    c. Might or might not be
    d. Probably not
    e. Definitely not
42. Have you experienced first language attrition in your L1 (i.e. a loss of proficiency, such as speaking or writing capability)?
    a. Yes
    b. No
    c. Maybe
43. Have you experienced first language attrition in your L2 (i.e. a loss of proficiency, such as speaking or writing capability)?
    a. Yes
    b. No
    c. Maybe
44. How distracted were you while taking this survey?
    a. Very distracted
    b. Somewhat distracted
    c. Not distracted
45. How fit do you feel?
    a. Very awake and fit
    b. Neither fit nor tired
    c. I feel a bit tired
    d. I feel very tired
46. Where did you take this study?
    a. Alone in a room and it is quiet
    b. Alone in a room and it is not quiet (e.g. listening to music/TV/radio
    c. In a room with other people, but it is quiet
    d. In a room with other people, but it is not quiet
    e. Somewhere else