UNIVERSITY OF CALIFORNIA, SAN DIEGO

SAN DIEGO STATE UNIVERSITY

The Role of Control in Bilingual Verbal Fluency: Evidence from Aging and Alzheimer's Disease.

A dissertation submitted in partial satisfaction of the
requirements of the degree Doctor of Philosophy

in

Clinical Psychology

by

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2010

The Dissertation of Tiffany Sandoval is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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DEDICATION

I would like to dedicate this manuscript to my family for their continual love and support throughout the years. In particular, I would like to thank my soon to be husband, Wilfredo López for his patience and understanding during this long and difficult process. Thank you for helping me move all over the country and overseas and being my companion in all of life's journeys. I could not have done this without you and I appreciate you more than words can express.

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ACKNOWLEDGEMENTS

I would like to acknowledge Dr. Tamar H. Gollan for several years of mentorship throughout my graduate training and for serving as co- chair of my dissertation committee. She has provided invaluable guidance from assisting with methodological design, grant preparation, and the many revisions of this manuscript.

I would also like to acknowledge the rest of my dissertation committee (Drs. David Salmon, Robert Heaton, Claire Murphy, and Paul Gilbert) and express my heartfelt gratitude for all of their support and guidance.

I would also like to give a special thank you to the members of Dr. Gollan's laboratory, and Rosa Montoya in particular. Without her help, this project would not have been possible.

Lastly, I would like to thank the McNair Program staff at the University of Rochester for their support in making it to graduate school in the first place.

Support for this project was provided by a Ruth L. Kirschstein National Research Service Award grant 1F31AG028971-01A1 from the National Institute on Aging (T. Sandoval).

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2008 Master of Science, Clinical Psychology
San Diego State University / University of California, San Diego
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2002 Bachelor of Arts, Psychology
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CLINICAL EXPERIENCE

2009-Present Veterans Affairs Greater Los Angeles Healthcare System
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Responsibilities: Individual therapy with patients in an outpatient mental health clinic with a focus on administering empirically validated treatments for Post Traumatic Stress Disorder, including Prolonged Exposure Therapy and Cognitive Processing Therapy. Co-lead a group of dual diagnosis combat veterans (PTSD and Substance Use) as well as several group therapy sessions for veterans in the Chemical Dependency Treatment Unit as part of a multi-disciplinary team. Individually organize and present weekly psychoeducational classes on emotions management to veterans in recovery from addiction. Participate in a year-long Neuropsychology Seminar that includes didactic instruction and review of neuropathology as well as the assessment of patients and writing neuropsychological reports. Future rotations to be completed during internship will include experience in Health Psychology and Behavioral Medicine as well as in the Outpatient Mental Health Clinic.

2008-2009 Veterans Affairs San Diego Healthcare System
Alcohol and Drug Treatment Program
Instructor in Stress Management and Relapse Prevention Classes
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Responsibilities: Co-lead group therapy session for patients with Substance Use Disorders in various stages of recovery. Establish treatment plans and goals with new members and update treatment goals every three months. Teach weekly classes for inpatient clients in Stress Management and Relapse Prevention, teach principles of Cognitive Behavioral Therapy, assign and review weekly homework, practice skills by leading class in role playing activities.

2008-2009 Advanced Neuropsychological Assessment
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Inpatient Rehabilitation Medicine
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Responsibilities: Assessing hospitalized patients who are in need of physical and occupational rehabilitation for various medical conditions as part of treatment plan development. Administered the Mini Mental State Exam, and Geriatric Depression Scale to assess patients' emotional and cognitive functioning and made recommendations for appropriate follow-up care. Also provided supportive therapy as needed.

2005-2006 San Diego State University Psychology Clinic
Supervisors: Rick Schulte, Ph.D. & Alan J. Litrownik, Ph.D.
Responsibilities: Clinical Assessment using Structured Clinical Interview for the Diagnostic and Statistical Manual – 4th Edition (DSM-IV; SCID) Beck Depression Inventory (BDI) and Beck Anxiety Inventory (BAI). Treated individual clients with Cognitive Behavioral Therapy and other treatments as necessary, such as Progressive Muscle Relaxation.

OTHER CLINICAL SKILLS

- Fluent in spoken English and Spanish; able to read and write proficiently in Spanish.

RESEARCH EXPERIENCE

2004-2010 University of California, San Diego Language Production Lab
Graduate Research Associate
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Responsibilities: Administer language history questionnaire and research protocol in both Spanish and English (typically involving verbal fluency, picture naming tasks, word association tasks, etc) to young and older subjects as well as patients with Alzheimer's disease. Other responsibilities include NRSA grant preparation, data entry and analysis using SPSS, writing abstracts for presentation in professional conferences and writing and editing manuscripts for submission to peer-review journals.

2003-2004 University of Rochester, Information Processing Laboratory
Study Coordinator and Research Assistant
Supervisor: Robert M. Chapman, Ph.D.
Responsibilities**:** Scheduled participants for experimental sessions, coordinated participant eligibility and recruitment with neurologists, psychiatrists and database managers at a geriatric health facility, kept records of subject demographics, and researched subject's medical information. Conducted experimental sessions, which included applying the electrode cap, reducing impedances and either guiding the participant through the research protocol or setting up the protocol via computer and monitoring the EEG readings for artifacts. Assisted in the selection of a battery of 18 neuropsychological tests and developed a HIPAA compliant consent form for research review board approval.

2002-2003 University of Rochester, Sleep and Neurophysiology Laboratory
Volunteer Research Assistant
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Responsibilities: Literature searches, data entry, proof reading grants, articles and abstracts. Attended and participated in seminars on the clinical and research aspects of insomnia sleep apnea, phase-delay syndrome and other sleep disorders. Collaborated on an abstract examining whether gender was a mediating factor in treatment outcome for patients with primary insomnia, using Sleep Latency (SL) and Wake After Sleep Onset (WASO) as variables.

2001-2002 University of Rochester, Me and My Family Project.
Research Assistant
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2000 University of Rochester, Information Processing Laboratory
McNair Program Summer Research Scholar
Supervisor: Robert M. Chapman, Ph.D.
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ABSTRACTS

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Sandoval, T.C, Gollan, T.H., Montoya, R.I , Champion, M., Cera, C., & Salmon, D.P. (2009). Aging effects on cross-language intrusions: Why *octopus* slips into *animales. International Neuropsychological Society conference*.

Sandoval, T.C., Gollan, T.H., Ferreira, V.S. & Salmon, D.P. (2007) Bilingualism affects verbal fluency: The dual-task analogy. *International Neuropsychological Society conference*.

Sandoval, T., Chapman, R.M., & Nowlis, G. (2000) Priming and symmetry as examined by an electrophysiological probe. *McNair Regional Conference*.

ABSTRACT OF THE DISSERTATION

The Role of Control in Bilingual Verbal Fluency: Evidence from Aging and Alzheimer's Disease

by

Tiffany Sandoval

Doctor of Philosophy in Clinical Psychology

University of California, San Diego, 2010

San Diego State University, 2010

Professor Tamar H. Gollan, Chair

Professor David P. Salmon, Co-Chair

Bilinguals have reduced verbal fluency compared to monolinguals and this has been attributed to cross language interference (Rosselli et al., 2000; Gollan et al., 2002). To manage interference, bilinguals may rely on executive control mechanisms to suppress the non-target language. We would therefore expect the bilingual disadvantage to increase with aging and Alzheimer's disease, which are associated with declines in executive control (Perry and Hodges, 1999). To test this account, we examined

bilinguals' verbal fluency with analyses of a) number of correct responses, b) within language errors (c) cross-language intrusions and two measures of executive functioning (Stroop test and Attentional Network Task; ANT, Fan et al., 2002).

In Experiment 1a, we compared matched groups of 10 young and 10 older Spanish-English bilinguals on 18 fluency categories (5 semantic and 4 phonemic categories in Spanish and English) and we examined correlations between age and older bilinguals' (N= 18) performances on both executive control and response measures. In Experiment 1b, we compared a group of older (n=15) and young English monolinguals (n=36) on the same categories as in Experiment 1a. In Experiment 2, we compared matched groups of bilinguals with AD (n=10) with normal bilinguals (n=13), on the same categories as in Experiment 1a. Supporting an interference account, age and cross language intrusions were correlated such that older-old bilinguals produced more intrusions than younger-old bilinguals and cross-language intrusion rates were positively correlated with error rates in the ANT. Also, bilinguals with AD produced more cross language errors in semantic fluency than controls particularly in the non-dominant language. Challenges for the interference model included low rates of cross-language intrusions, even in older bilinguals and in bilinguals with AD. There was little evidence suggesting that production of a nondominant language becomes more difficult in aging and AD. We propose that executive control is important for language selection and monitoring, but after language selection, there is either (a) limited competition for selection between lexical representations across languages, or (b) a specialized mechanism for controlling competition between lexical representations that is less susceptible to cognitive decline. Thus, bilingualism is mostly maintained in aging and AD.

INTRODUCTION

The ability to speak two languages would initially appear to be a difficult task as it requires the knowledge of separate grammar, vocabulary and pronunciation and yet bilinguals seem to effortlessly use the right word in the right context, and can even switch back and forth between languages with little obvious cost. The apparent ease with which bilinguals manage two languages in one brain begs the question: How is this accomplished?

The Role of Executive Control in Bilingualism

Several researchers have proposed that control mechanisms are essential for keeping the languages separate. While a comprehensive understanding of how exactly bilinguals successfully manage two languages is elusive, some clues as to the role of control in bilingual language production may be found from studying cases where only one language is recovered after a brain injury or in cases of pathological language mixing and switching. Supporting the notion that language control relies on general mechanism of executive control functions, was a case study in which an Italian-Friulian bilingual demonstrated pathological language switching between both his languages after a tumor was removed from his left frontal lobe, despite the fact that he did not exhibit any aphasic symptoms on neuropsychological testing (Fabbo, Skrap & Aglioti, 2000). The lack of aphasia may indicate that the mechanisms for language production are separate from those that regulate language selection in bilinguals. Further support for a frontal localization for language control is the observation of greater activity in the dorsolateral prefrontal cortex when bilinguals perform a language switching task (Hernandez, Martinez & Kohnert, 2000). While recovery of language functioning in bilingual aphasia can include a parallel recovery where both languages are regained to similar degree, the finding that some bilinguals initially recover one language and show temporary aphasia with one language that later resolves has lead researchers to propose that at least some cases of bilingual aphasia is explained by an impairment in the ability to access the language, rather than direct damage to the language-representations themselves (Paradis, 2000).

Returning to the question of how bilinguals keep their languages separate, we propose three possible explanations. First, bilingual language control may occur at the level of the whole language, meaning that bilinguals use executive function to select the language they want to speak. Alternatively, bilinguals may utilize language control while speaking one language to both inhibit the non-target language and select words from the target language. Another possible explanation is that language selection in bilinguals is mediated by a specific mechanism that is relatively immune to declines in executive control. To test these hypotheses, we examine bilinguals' verbal fluency and performance on two additional executive functioning measures and how their performance changes with age and Alzheimer's disease (AD) which are both associated with declines in executive control. If bilinguals rely on control to resolve competition for selection between languages, they should have more difficulty speaking a nondominant language, and should exhibit more failures of language control (i.e., produce more cross language intrusions) with increasing age and AD, which we would also expect to be associated with decreased performance on executive functioning measures.

Bilingual Disadvantages Relative to Monolinguals

The literature comparing bilinguals to monolinguals reveals evidence of a greater processing burden associated with maintaining two languages within the same brain including disadvantages for bilinguals in language tasks but greater cognitive reserve outside the language system. Bilinguals name fewer pictures than monolinguals on standardized tests such as the Boston Naming Test (e.g., Roberts, Garcia, Desrochers & Hernandez, 2002) and experience more tip-of-the-tongue states or TOTs than do monolinguals (Gollan & Silverberg, 2001). Several studies have found bilinguals to have reduced verbal fluency compared to monolinguals (Gollan, Montoya, & Werner, 2002; Rosselli et al., 2000, Portocarrero, Burright, & Donovick, 2007; Sandoval, Gollan, Ferriera & Salmon, in press), and that bilinguals are slower than monolinguals to name pictures even when matched for age, education, and age of acquisition of the dominant language and when bilinguals were tested in their first learned and dominant language (Ivanova & Costa, 2008).

However, bilinguals are not universally worse than monolinguals in all tasks, and differences between groups can be eliminated even in some language based tasks. For example, while bilinguals are slower to name pictures than monolinguals they classified the same pictures according to a semantic category (e.g., natural kind vs. human made) as quickly as monolinguals (Gollan, Montoya, Fennema-Notestine & Morris, 2005), and after repeatedly naming the same pictures bilinguals named pictures as quickly as monolinguals (but see Ivanova & Costa, 2008). Another study found that the bilingual disadvantage in verbal fluency disappears when bilinguals and monolinguals are matched for vocabulary knowledge (using the PPVT), and bilinguals even outperformed monolinguals on letter-fluency after vocabulary-matching (Bialystok, Craik, & Luk, 2008).

Hypothesized Mechanism of the Bilingual Fluency Disadvantage

A consensus among researchers of bilingual language production is that bilinguals cannot "turn one language off" and function as monolingual speakers (Kroll & de Groot, 2005). On this view, both languages are assumed to be active even when bilinguals are speaking one language. This notion immediately introduces the possibility of competition between languages as the mechanism underlying bilingual disadvantages. One of the most widely cited theories of bilingual language production is the Inhibitory Control Model (Green, 1998) which posits that bilinguals must suppress the non-target language to allow production in the intended language.

Lexical access in language production is conceptualized to occur in two stages. First, a, concept is selected from a lexicon of *lemmas* – which are representations of words that contain essential defining characteristics. For example, the representation of “dog” would include aspects such as “animal, domesticated, four legs, etc.” Lemmas are organized semantically and words that are similar in meaning become activated and compete for selection. Thus, lemma selection is one processing stage where competition could occur between languages and where there might be a role for executive control or a more language-specific control mechanism in resolving such competition. Once a lemma is selected, the word form is retrieved from a lexicon of *lexemes* which is organized by word form characteristics (Starreveld & La Heij, 1995; Levelt, Roelofs, & Meyer, 1999). It is widely accepted that lexical selection within languages is a competitive process at the lemma level and that ease of word selection is inversely related to the similarity of competitors (Levelt, Roelofs, & Meyer, 1999). Evidence for activation of semantically related items during language production comes from Stroop-like studies showing that speakers name pictures more slowly when presented with a related item (e.g., speakers take longer to name a picture of a *dog* if the word *cat* is written next to it than if an unrelated control – say – *cup* is written next to it (Schriefers, Meyer, & Levelt, 1990).

However, there is a debate as to whether or not competition for selection can occur between languages (for review see Kroll et al., 2008). If there is competition between languages (i.e., if lemma selection is non-language specific) such competition could be particularly fierce (relative to competition in monolinguals) because bilinguals have a lexicon full of translation equivalent representations that match onto the same concept (e.g. the concept for *dog* matches perfectly the meaning associates with both *dog* and *perro*-Spanish for dog). Because translations may differ only by language membership (e.g. English or Spanish) this leaves little to resolve competition between them. Consistent with the notion of competition for selection between languages, when highly proficient Dutch-English bilinguals were presented with a picture (e.g. *mountain*) and heard a distractor word that was phonetically similar (e.g. *bench*) to the translation equivalent (e.g. *berg* = mountain in Dutch), they were slower to name the picture of the mountain (note that the translation itself was never explicitly presented in this study; Hermans, Bongaerts, De Bot, & Schreuder, 1998).

A rival hypothesis posits that lexical selection during language production is language specific and, though both languages are active, only lemmas in the target language are considered for selection. On this view, the concept of "dog" would activate lexical nodes for both *dog* and *perro*; however, since the task requires an English response, only lexical representations tagged as belonging to English would be considered for selection. Evidence supporting this account is the finding that translation equivalents facilitated retrieval in Catalan-Spanish bilinguals when they are explicitly presented simultaneously in the picture-word interference task. For example, bilinguals named a picture of a dog more quickly when the translation equivalent distracter itself was written next to the picture relative to an unrelated control (Costa, Miozzo & Caramazza, 1999; see also Gollan & Acenas, 2004; Gollan et al., 2005). Translation equivalents may facilitate production because shared activation of conceptual representations which could offset any competition at the lemma level. This finding that translation equivalents produce facilitation in the picture-word interference paradigm creates a mystery as to how the Dutch-English study produced interference (as noted above, in that study the translation equivalent was never explicitly presented, but rather a word that was phonemically similar – this could activate the competing lemma without activating conceptual representations thereby leaving only competition effects).

Setting aside this contradictory evidence, some of the strongest evidence that bilinguals must experience competition between languages comes from bilingual advantages in non-linguistic tasks, particularly on measures of executive control. In these studies bilinguals exhibit more efficient executive control abilities than matched monolinguals. These bilingual advantages led to the hypothesis that the constant demand of competition between languages effectively forces bilinguals to develop stronger control mechanisms due to “practice” with resolving response conflict. The effects of practice and neural plasticity are well documented. For example, experienced taxi drivers (who need to have good navigational skills and memory) had greater grey matter volume in an area of the brain related to spatial memory than controls (bus drivers who followed the same route; Maguire, Woollett & Spiers, 2006). Additionally, participants who regularly played video games (3-4 times a week on average) had better visuo-spatial attention skills than participants who did not play video games (Green & Bavelier, 2006). In bilinguals, proficient use of two languages, and early age of acquisition of two languages, is associated with greater density in the left inferior parietal cortex (Mechelli et al., 2004)

Bilingual advantages in executive functioning tasks are found early in development. For example, bilingual children outperformed monolingual children on a card sorting task in which children switch between different sorting rules (e.g. color, shape; Bialystok & Martin, 2004). Other evidence suggests that bilingual advantages persist throughout the bilingual lifespan. In the Attentional Network Task, participants are presented with one of three displays: (a) a row of arrows with heads that all point in the same direction (congruent trial), (b) a single black arrow flanked by lines with no arrow head (neutral trial), or (c) a row of arrows with the center arrow pointing in one direction flanked by arrows pointing in the opposite direction (incongruent trial). Participants are asked to focus on the center arrow and indicate in which direction it is pointing while ignoring the surrounding flankers. Young adult bilinguals' exhibited faster response times in on all trial types in this task relative to matched monolinguals, which the authors attributed to bilinguals' ability to monitor for potential conflict more efficiently than monolinguals (Costa, Hernandez & Sebastián-Gallés, 2008). Consistent with this view, bilinguals were only significantly faster when there was a high need for monitoring; that is, when there were more relatively similar numbers of congruent and incongruent trials in the testing block. When the testing blocks consisted predominantly of one type of trial (either congruent or incongruent), the difference between bilinguals' and monolinguals' response times disappeared (Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009).

Similar bilingual advantages are found in aging. In one study, older bilinguals were better than monolinguals at resolving response conflict in a Simon Task (Bialystok, Craik, Klein, & Viswanathan, 2004). In the Simon task, participants are given a rule to follow (e.g., if the stimuli is red, press the right button, if it is green, press the left), and then are presented with stimuli which elicit a prepotent and sometimes competing response (e.g., a stimulus on the right or left side of the screen). The location of the stimuli presentation varies such that it is either congruent (e.g. on the same side as the response indicated by the rule) neutral (e.g. in the center) or incongruent (e.g. on the opposite side of the indicated response; van der Lubbe & Verleger, 2002). On incongruent trials participants must suppress the prepotent response and follow the rule. Bilingual advantages in the ANT and Simon tasks suggest that similar mechanisms are used for both executive control outside the language system and in bilingual language control, and that executive functioning is required in bilingual language production.

In this view, bilingualism strengthens executive control mechanisms. Similar to other forms of cognitive reserve (e.g., high education level; Stern, 2003), bilingualism has been associated with preserved cognitive functioning longer into old age (Kavé, Eyal, Shorek, & Cohen-Mansfield (2008) and delaying the onset of dementia compared to monolinguals with one study finding the delay to be 4 years later on average (Bialystok, Craik, & Freedman, 2007). Bilinguals did not show a significant delay in dementia onset compared to monolinguals in another study, however there was a significant correlation between number of languages spoken and later age of onset of dementia symptoms such that speaking more languages was associated with later age of diagnosis (Chertkow, Whitehead, Phillips, Wolfson, Atherton, & Bergman, in press).

Much of the bilingual benefit in executive control may come from experience with speaking in the non-dominant language. There is evidence that the degree of competition between languages is asymmetrical such that bilinguals actively suppress the dominant language to speak in their non-dominant language, but perhaps no suppression (or only very little) is needed when bilinguals speak in the dominant language. Supporting this notion when bilinguals switch back and forth between languages, the dominant language suffers a greater switch cost than the non-dominant language (e.g., Meuter & Allport, 1999). It may seem paradoxical that switching back into the dominant language is more costly than the reverse; however, since suppressing the dominant language to speak the non-dominant language is more difficult, the suppression persists for a while after a language switch. Similarly, a study that examined event-related-potentials (ERP) while bilinguals were engaged in a switching task revealed an increased negativity in the frontal region (which is usually associated with an inhibition response) that was significant only when subjects switched from their dominant to non-dominant language, but not for switching into their dominant language from the non-dominant language (Jackson, Swainson, Cunnington, & Jackson, 2001; but see Christoffels, Firk, Schiller, 2007).

The degree to which the non-dominant language interferes with dominant language production is less clear. Some picture-naming studies have found the dominant language is relatively unaffected by interference from the non-dominant language (Gollan et al., 2005; Gollan, Montoya, Cera & Sandoval, 2008), and that this may be particularly true for more balanced bilinguals (Costa & Caramazza, 1999; Costa & Santesteban, 2004). However, in a recent verbal fluency study, we found that nearly half of bilinguals tested (20 out of 45) mistakenly intruded one or several dominant language words into fluency trials in the nondominant language. In contrast, only one bilingual intruded the nondominant language into the dominant language on one occasion. This asymmetry of intrusions suggests that it is more difficult for bilinguals to control activation of the dominant language (Sandoval et al., in press), than the reverse. In sum, although there is still debate as to whether bilinguals experience cross language interference, and at what processing level such interference arises, it seems likely that executive control has some role in bilingual language production. The effect of language control in bilinguals may be particularly evident in open-ended production tasks such as verbal fluency, and which are established tests of executive functioning (Lezak, Howieson, Loring, Hannay & Fischer, 2004; Strauss, Sherman, & Spreen, 2006).

Interference in Aging and AD

Very few studies have examined the interaction between bilingualism and aging, and bilingualism and AD, though these could provide a powerful test of the interference hypothesis. Tasks that require inhibitory control (e.g., the Simon Task) become more difficult with increased age (e.g., Bialystok et al., 2004; van der Lubbe & Verleger, 2002). In addition, patients with Alzheimer's disease have been shown to have difficulty with executive functioning tasks (e.g., Perry and Hodges, 1999). Bilinguals may rely on executive functioning to manage dual language activation and related processes (Green, 1998), such as identifying the appropriate language for the particular context, and maintaining this target language by actively inhibiting the nontarget language (Friedland and Miller, 1999; Rodriguez-Fornells, Balaguer de Diego, & Munte, 2006). On this basis, we predict that the effects of bilingualism will become greater with increased age and with AD. Consistent with this hypothesis, older bilinguals exhibit increased language switch costs relative to young bilinguals (Hernandez & Kohnert, 1999). Similarly, preliminary studies have found that bilinguals with AD are less able than controls to take advantage of bilingual search strategies in verbal fluency tasks. When given the option of using either language during the verbal fluency trials, healthy elderly bilinguals chose to switch languages, but bilinguals with AD did not, presumably because of a general difficulty patients with dementia have with shifting set (De Picciotto and Freidland, 2001).

The interference account predicts that production of the nondominant language should be particularly difficult for older bilinguals, and for bilinguals with AD, if (as outlined above) control of cross-language interference is particularly important for speaking the less dominant language. Studies of bilingual aphasia have demonstrated a variety of recovery patterns including parallel recovery of both languages, and better recovery of the non-dominant language. This may seem inconsistent with the inhibitory control account. If inhibitory control is impaired by brain injury, and inhibitory control is important especially for production of the nondominant language, then selective recovery of a non-dominant language should not be observed. Nevertheless, it is important to note that a typical recovery pattern in bilingual aphasia has yet to be established (Paradis, 2001, Green, 2005). In addition, AD is likely to differ from aphasia in a number of ways because of the distinct underlying brain pathology (Terry, Peck, DeTeresa, Schechter, & Horoupian, 1981). In particular, some cases of aphasia may result from damage to lexical representations in a dominant language without any damage to inhibitory control.

Although cross language intrusions are rare, verbal fluency is one task in which such errors are produced, even in young, healthy bilinguals with presumably intact mechanisms for cognitive control (Sandoval et al., in press). Thus, verbal fluency may be a particularly sensitive task for revealing the mechanisms underlying bilingual language control including aging and the effects of AD.

Verbal Fluency

Verbal fluency tasks typically require speakers to generate words belonging to a restricted category (e.g. animals) or beginning with a specific letter (e.g. the letter *F*; Benton & Hamsher, 1976; Lezak et al., 2004). Both category and letter fluency tasks involve more activation of the left hemisphere which has long been associated with language functioning (Birn, Kenworthy, Case, Caravella, Tyler, Bandetti & Martin, 2010). Category fluency is thought to assess the integrity of semantic networks and conceptual knowledge and has been shown to depend on lateral and inferior temporal lobes (Rascovsky, Salmon, Hansen, Thal, & Galasko, 2007; Gourovitch, Kirkby, & Goldberg, 2000; Hirono et al., 2001; Kitabayashi et al., 2001; Mummery, Patterson, Hodges, & Wise, 1996) whereas letter fluency tasks require the use of orthographic or phonological cues as guides. Letter fluency places more demand on executive functioning (Delis, Kaplan & Kramer, 2001) and frontal regions are essential for the retrieval of words based on a phonemic cue (Baldo, Schwartz, Wilkins, & Dronkers, 2006). The retrieval of words based on a phonemic cues is thought to be more demanding than in semantic categories (Martin, Wiggs, Lalonde & Mack, 1994; Moscovitch, 1994) given that language production is a semantically driven process, searching by sound it is not a common search strategy and there is no pre-existing classification system that organizes words according to initial phonology (Strauss et al., 2006; Luo, Luk, & Bialystok, 2010). Thus, not surprisingly, adults generally produce fewer words on average in letter than semantic categories (but see Azuma et al., 1997) and this remains true with aging (Mirtushina, Boone & D'Elia, 1999; Kozora & Cullum, 1995).

Some of the strongest evidence supporting distinct anatomical substrates of letter and category fluency comes from studies examining the effect of different types of dementias on verbal fluency performance. Alzheimer's disease is a neurodegenerative progressive dementia involving neurofibrillary tangles and neuritic plaques that have a tendency to develop in medial temporal lobes structures, particularly the hippocampus, subiculum and entorhinal cortex (Rascovsky et al., 2007, Hyman¸Van Hoesen, & Damasio, 1990). Disease processes that affect the temporal lobe (namely Alzheimer's disease) are associated with disproportionate impairments in semantic vs. phonemic fluency tasks (Rascovsky et al., 2007; Marczinski & Kertesz, 2006; Cerhan, Ivnik, Smith, Tangalos, Petersen, & Boeve, 2002; Baldo, Schwartz, Wilkins, & Dronkers, 2006, but see Suhr & Jones, 1998). Atrophy of temporal lobe structures is thought to affect patient's semantic memory causing Alzheimer's patients to quickly exhaust their pool of available exemplars in the beginning of the trial, thus reducing their overall output (Taylor, Salmon, Monsch & Brugger, 2005; Rohrer, Wixted, Salmon, & Butters, 1995; Rohrer, Salmon, Wixted & Paulsen, 1999). One study concluded that having Alzheimer's patients complete verbal fluency tasks in 30 seconds instead of the full 60 seconds revealed the same amount of information regarding their verbal fluency ability (Fernaeus, Ostberg, Hellstrom & Wahlund, 2008). In addition, a qualitative analysis of exemplars participants produced during a verbal fluency trial revealed that speakers with AD produce fewer subordinate exemplars than controls (Taylor, Salmon, Monsch & Brugger, 2005; Martin & Fedio, 1983; Tröster, Salmon, McCullough, & Butters, 1989). That is, AD reduces the integrity of semantic memory, leaving reduced knowledge of specific exemplars (e.g. *parrot*) as dementia progresses and leading speakers with AD to produce mostly broader category names (e.g. *birds*). Whether the semantic networks themselves cease to exist (Salmon, Heindel, & Lange, 1999; Rohrer, Wixted, Salmon, & Butters, 1995) or whether they remain intact, but are inaccessible (Nebes & Brady, 1990; Auchterlonie, Phillips, & Chertkow, 2002) remains debated.

Frontal temporal dementia (FTD) is caused by atrophy of the neocortex of the frontal and anterior temporal lobes (Rascovsky et al., 2007) Supporting the hypothesis that letter fluency requires more frontal lobe involvement is the finding that patients with FTD demonstrated greater impairment in phonemic vs. semantic fluency tasks (Rascovsky et al., 2007). Other neurological disorders that affect frontal-striatal connections and basal ganglia, such as Huntington's and Parkinson's disease also show decreased verbal fluency in both semantic and letter fluency tasks (Monsch et al., 1994; Troyer, Moscovitch, Winocur, Leach & Freedman, 1998). However, Parkinson's patients' semantic verbal fluency were not impaired when they were provided with subcategories (e.g. *farm animals* vs. *animals*; Randolph, Braun, Goldberg, & Chase, 1993) which is consistent with the hypothesis that fluency deficits in Parkinson's disease are due primarily to retrieval deficits rather than deficits in semantic memory as are found in Alzheimer's disease. Similarly, Huntington's disease is not thought to cause semantic memory deficits (Butters, Salmon, Heindel & Granholm, 1988; Salmon, Shimamura, Butters & Smith, 1988), their reduced verbal fluency is attributed to retrieval deficits typically seen with subcortical dysfunction as well as severe bradyphrenia (Monsch et al., 1994).

Demographic Effects on Verbal Fluency

Both phonemic and semantic fluency performance has been shown to decline with age (Delis et al., 2001) with some studies showing a relatively greater decline in semantic than in letter fluency (Brickman et al., 2005; Heaton et al., 2004; Troyer et al., 2000, Kozora & Cullum, 1995). Interestingly, as already noted above, a similar pattern of greater decline in semantic vs. phonemic fluency is found in Alzheimer's disease (Butters et al., 1987) which may imply that AD is an accelerated form of aging. The decline in verbal fluency with age may be greater in people with lower levels of education and IQ (Loonstra, Tarlow & Sellers, 2001), although it should be noted that some studies have failed to find age effects on verbal fluency (Axelrod & Henry, 1992; Boone, 1999).

Some studies have found women perform slightly better overall then men on phonemic fluency tests (Loonstra et al., 2001; Bolla, Lindgren, Bonaccorsy, & Bleeker, 1990) and that this is particularly true with women with higher levels of education (Anderson et al., 2001; Barr, 2003, Strauss, Sherman, & Spreen, 2006) while others found no gender difference (Tombaugh, Kozak, & Rees, 1999). Semantic fluency has shown mixed results with some studies finding no difference between men and women (Heaton et al., 2004; Strauss, Sherman, & Spreen, 2006) while others gender differences that depend on the particular category being used with women outperforming men

(Acevedo et al., 2000; Kosmidis et al., 2004). Reading proficiency is more highly correlated with phonemic fluency performance, and significantly but less correlated with category fluency (using the *animals* category; Johnson-Selfridge, Zalewski, & Abourdarham, 1998). This has been attributed at least in part, by the fact that initial letter fluency tasks may be facilitated by the ability to identify individual speech sounds and awareness of this may increase with more proficient reading (Ratcliff, Ganguli, Chandra, Sharma, Belle, Seaberg, & Pandav, 1998). Higher levels of education are associated with better performance in both letter and semantic fluency tasks (Acevedo et al., 2000; Backman et al., 2004; Crossley, D'Arcy, & Rawson, 1997; Strauss, Sherman, & Spreen, 2006) but accounted for more variation in phonemic than semantic fluency performance (Tombaugh et al., 2001).

In examining bilinguals' verbal fluency in aging and AD, we have independent reasons to expect effects on both semantic and letter fluency. Since both AD (Rascovsky et al., 2007; Marczinski & Kertesz, 2006) and bilingualism are associated with reduced verbal fluency and seem to disproportionately affect semantic fluency (Butters et al., 1988; Gollan et al., 2002; Rosselli et al., 2002), we could predict that the joint effects of bilingualism, aging and AD might be particularly evident in semantic fluency tasks. However, given that executive functions may be essential for bilingual language control, and are also utilized to a greater extent in letter fluency, we could also predict greater joint effects of bilingualism, aging and AD on phonemic fluency. Thus we investigated the effects of bilingualism and aging (Experiments 1a and 1b), and bilingualism and AD (Experiment 2), on both letter and semantic fluency categories.

EXPERIMENT 1A METHODS

In Experiment 1 we tested the prediction that aging bilinguals will have particular difficulty with nondominant language production using verbal fluency responses in young and older adult bilinguals. We tested bilinguals in both their dominant and non-dominant languages, since the cross language interference model assumes that bilinguals would rely more heavily on executive functioning to speak the non-dominant language.

Experiment 1a Participants

Forty-nine young adult bilinguals and eighteen older adult bilinguals (Spanish-English) participated in the study. To examine the effect of aging on bilingual verbal fluency, we first compared a matched subset of older and younger bilinguals, with ten participants in each group. We then examined possible relationships between bilingualism, aging and executive control effects using performances on executive functioning measures and age as continuous predictors of verbal fluency responses in all 18 older bilinguals tested. Elderly participants were recruited from the Alzheimer's Disease Research Center (ADRC) through which they receive annual medical, neurological and neuropsychological evaluations. Younger bilinguals were undergraduate students at the University of California at San Diego who participated for course credit. Participants completed a language history questionnaire to assess their exposure to, and proficiency in, each language. Bilinguals were speakers of English and Spanish with limited or no proficiency in a third language. Bilinguals were classified as either balanced, English dominant, or Spanish dominant based on their self-rated ability to speak English and Spanish. Participants who rated themselves as equally proficient in English and Spanish, were classified as English dominant because of their immersion in an English speaking culture. Only English dominant and balanced bilinguals were included in the matched older versus young analyses in Experiment 1.

Participants to be included in the matched analyses were selected based on several matching criteria which included years of education, age of first exposure to English, percent of daily English use, and participants' ratings of their spoken English and Spanish proficiency. Although we tested 18 older and 49 younger bilinguals we were only able to match 10 older and young bilinguals because of stringent matching criteria across several variables (see table 2). Since higher levels of education are associated with greater verbal fluency, it was important to have the comparison groups closely matched for education (Acevedo et al., 2000; Loonstra et al., 2001). Match failures (i.e., older adults who could not be matched to young adults were excluded predominantly because of low education levels when compared with bilinguals at UCSD. Other bilinguals (from both age groups) were excluded because of larger discrepancies (greater than 3 in a scale ranging from 0 to7) of self-rated English versus Spanish speaking ability. Similarly, late bilinguals who had learned English after 8 years of age also not included. Our focus on relatively balanced and early bilinguals is a logical starting point for a first investigation of the effects of aging and AD on the ability to maintain bilingual verbal fluency. Although as a group the bilinguals we tested were relatively balanced, t-tests revealed significant language-dominance effects such that both younger (English mean = 6.8; Spanish mean = 6.0) and older bilinguals (English mean = 5.9; Spanish mean = 4.9), rated their ability to speak English as significantly better than their ability to speak Spanish (both *p*s $<.05$; see Table 2).

Participant characteristics are shown in Table 2. Matched older and younger bilinguals did not differ significantly in years of education, or age of first exposure to English. However, younger bilinguals reported speaking English slightly but significantly more often (about 15% more often) on a daily basis than older bilinguals. In addition, although we matched young and older bilinguals for the degree of difference in proficiency rating between languages, young bilinguals rated their ability to speak both languages as higher on the rating scale than did the older bilinguals. This may reflect older bilinguals' subjective sense of age related decline in language proficiency, or a tendency for older subjects to be more conservative in their self-ratings than younger subjects, rather than a difference in proficiency. Consistent with the latter notion, previous studies have found that older monolinguals rate themselves as less proficient on self report measures than younger controls even when matched on objective measures of proficiency (Gollan & Brown, 2006; Gollan et al., 2008). In the matched subsets, five out of ten young bilinguals, and five out of ten older bilinguals rated themselves as being equally proficient in English and Spanish. In the larger group of 18 older bilinguals 5/18 rated themselves as being equally proficient in both languages, and 7/18 rated themselves as Spanish-dominant.

Experiment 1a Materials and Procedure

Materials are listed in Table 1. We included 5 semantic categories and 4 letter categories. Semantic categories were divided into two lists, each containing five categories which were counterbalanced across languages between participants. Letter categories were selected from tests of verbal fluency in English (letters F, A, S, L) and Spanish (P, M, R. D). Previous studies found the letters F,A,S in English and P,M,R in

Spanish were matched for difficulty between languages (Artiola I Fortuny, Heaton, & Hermosillo, 1998), thus, letter categories were not counterbalanced across language. Semantic categories were chosen based on previous findings of sensitivity to bilingual effects. Participants completed 9 categories in English first (5 semantic, 4 letter) followed by 9 categories in Spanish in a different random order for each participant. Participants were tested in English first because the majority were English-dominant, and English is also the language dominant in the environment in San Diego. This procedure avoided language switching, which can impair ability to speak particularly a dominant language (Meuter & Allport, 1999; Christoffels, Firk, & Schiller, 2007), prior to testing in the dominant-language for most participants.

Participants were tested individually by two Spanish-English bilingual experimenters who instructed them to name as many members as they could think of that belonged to each category until they were told to stop. For English trials, participants were given instructions in English, and prior to Spanish trials the instructions were repeated in Spanish. Each trial lasted 60 seconds. The participant's responses were recorded manually as well as by audiotape for later verification during scoring.

Flanker Task

Target stimuli consisted of congruent displays of five black arrows all pointing in the same direction (→→→→→), neutral displays with a single black arrow flanked by two black lines without arrow-heads (——→——), and incongruent displays which consisted of black arrows pointing in one direction flanked by two arrows on each side pointing in the opposite direction and incongruent(→→ ← → →). Each display type had 48 trials with the same number of left-pointing and right-pointing center arrows.

Of note, there were two procedural differences in our design from the traditionally used flanker task (the Attentional Network Task; Fan et al., 2002). Research with young adult bilinguals indicated they produced the strongest evidence for a bilingual advantage when stimuli were preceded by a cue (Costa et al., 2008). Accordingly, in the current study trials were always preceded by a cue that indicated the location of the upcoming stimulus. In addition, to increase the overall task difficulty (thereby possibly increasing sensitivity to bilingual effects), trials were evenly divided between presentation in the center, left side, or the right side of the screen. To prevent the presentation of several trials of the same type occurring in succession, materials of each type (congruent, neutral, incongruent crossed with left, middle, and center of the screen) condition were presented at least once in a random order before proceeding to any condition for a second (or third, etc.) time. There were no interactions between screen-location and any of the effects reported, thus we collapse across this variable in reporting the results. Each trial followed the following sequence: presentation of a central fixation point for 400 ms, followed by presentation of a location cue for 100 ms, followed by continued presentation of the fixation point for another 400 ms, after which the target stimulus was presented for 1700 ms or until a response was recorded. The interval between trials was 1700 ms. Participants indicated arrow direction by pressing a red button which was on the left side of a response box, or a purple button on the right side of the response box.

Prior to the experimental trials participants completed four practice blocks with appropriate instructions before each block. The first block included six trials of the neutral flankers, the second block included six trials of congruent flankers, the third block included six trials of incongruent flankers, and the fourth block included nine trials with equal numbers of the three different flanker types and screen locations presented in a random order.

English Stroop

As a measure of executive control in the dominant-language participants completed a version of the Stroop color-naming task in English. Target stimuli consisted of four color names (*red, blue, green, yellow*) and four neutral words (*big, prime, deep, legal*). The use of neutral words as a baseline and unblocked presentation of trial types (congruent, neutral, incongruent) was based on recommendations of Spieler, Balota, and Faust (1996) who argued that neutral words provide a better baseline than series of Xs or color blocks for several reasons. First, they argue that non-linguistic stimuli are qualitatively different than the linguistic stimuli used in the interference trials and therefore do not provide a good measure of baseline processing speed. Secondly, there is evidence that older and younger adults process the non-lexical stimuli differently, and thus using non-lexical stimuli as a baseline may underestimate the level of interference older adults experience. The experiment consisted of a word naming block and a color naming block each of which had 36 congruent trials, 36 incongruent trials, and 32 neutral trials. In the congruent trials each of the four color names appeared nine times in its corresponding color. In the incongruent trials, each color name appeared three times in each of the three non-matching colors. In the neutral trials, each of the four neutral words appeared twice in each of the four colors. The order of presentation of congruent, neutral and incongruent trials was randomized in each block, with the restriction that a word or color was not repeated more than twice on consecutive trials. A different random order was used for each block and for each participant. Task order (color naming or word reading) was counterbalanced between participants; only the color naming data are considered below (because the color naming task is most sensitive to executive control). The sequence of events for each trial in both tasks was a fixation point for 700 ms, a blank screen for 50 ms, and the presentation of the target stimulus for 3000 ms or until a response was recorded. The interval between trials was 500 ms. Before each task participants completed a practice block of 16 trials. Participant responses were coded for accuracy online by an experimenter, and were also audio-taped for subsequent verification of accuracy. Participants were instructed to either read the word aloud (while ignoring the color) in the word-naming task, and to name the color of the ink the word is printed in while ignoring what it says in the color-naming task.

Task Order

Participants completed the flanker task, English-Stroop, or English-verbal fluency, in counterbalanced order with each task occurring in each position a roughly equal number of times between participants. Bilinguals were tested on verbal fluency trials in Spanish at the end of the experimental session.

EXPERIMENT 1a RESULTS

Verbal fluency correct responses were given one point. A system for coding correct responses was devised prior to scoring to ensure consistency. For semantic categories, superordinate exemplars (e.g. *fruit*) were credited only if no subordinate exemplars (e.g. *apple*) were given. Errors were calculated as a percent of total responses (correct and incorrect) to characterize the tendency to make mistakes as a function of total fluency. For example, a subject who makes one error, but has 19 correct responses would have a 5% error rate (1/20 *100), where as someone who makes one error out of 7 responses would have a 12.5% error rate (1/8 *100). Errors were scored as either within language errors or between language errors. Within language errors consisted of any wrong answer that was given in the appropriate language for the trial. For example, if a participant said *pharmacy* when asked to name words that begin with F, this would be marked as a within language error, as would a response of *egg* when the category was *fruits and vegetables*. Cross language intrusions were any response in the non-target language of the trial (e.g., saying *perro* (Spanish for dog) on an English *animals* trial). Questionable responses were highlighted and then reviewed by another experimenter before final scoring.

We conducted three 2 x 2 mixed model ANOVAs with participant type (older vs. young bilinguals) as a between subjects variable, and language dominance (dominant vs. non-dominant language) as a within subjects variable. The three dependent variables were: (a) number correct, (b) within language errors rates and (c) cross language intrusion error rates. Participant means and standard deviations for semantic categories are shown in Table 3.

Matched-Group Comparisons Semantic Categories

Young and older bilinguals produced the same number of correct responses (no main effect of age), $F(1,18) = 2.38$, $MSE = 24.2$, $\eta^2_p = .12$, $p = .14$. Bilinguals produced more correct responses in the dominant vs. the non-dominant language (a main effect of language), $F(1,18) = 20.07$, $MSE = 9.73$, $\eta^2_p = .53$, $p < .01$. Of interest, there was a marginally significant interaction between age and language, $F(1,18) = 3.40$, $MSE = 9.73$, $\eta^2_p = .16$, $p = .08$. However, the nature of this interaction runs counter to the predictions of the inhibitory control model since the dominant language, $F(1,18) = 4.64$, $MSE = 19.18$, $\eta^2_p = .205$, $p = .05$, but not the non-dominant language, $F(1,18) = 1.68$, $MSE = 14.77$, $\eta^2_p = .01$, $p = .74$, exhibited robust age-related decline. Stated differently, only young bilinguals produced more correct responses in the dominant than the non-dominant language (i.e., a language dominance effect), $F(1,9) = 22.81$, $MSE = 8.54$, $\eta^2_p = .72$, $p < .01$, whereas older bilinguals produced similar numbers of words in both languages, $F(1,9) = 3.10$, $MSE = 10.92$, $\eta^2_p = .26$, $p = .11$.

Older bilinguals made slightly, but not significantly more errors than young bilinguals (a marginally significant effect of age), $F(1,18) = 3.15$, $MSE = 103.37$, $\eta^2_p = .15$, $p = .09$. There was no effect of language, $F(1,18) = 1.96$, $MSE = 62.92$, $\eta^2_p = .02$, $p = .18$ and no interaction, $F < 1$.

Contrary to expectations that language control declines with age, older bilinguals did not make more cross language intrusion errors overall compared to young bilinguals, $F(1,18) = 2.10$, $MSE = 1.86$, $\eta^2_p = .10$, $p = .17$. However, in support of the Inhibitory Control Model both younger and older bilinguals made more cross language intrusions in the non-dominant than in the dominant language, $F(1,18) = 4.51$, $MSE = 1.89$, $\eta^2_p = .20$, $p = .05$. Also, consistent with the Inhibitory Control Model, there was a marginally significant interaction, $F(1,18) = 2.81$, $MSE = 1.89$, $\eta^2_p = .14$, $p = .11$, trending in the predicted direction that older bilinguals would be particularly disadvantaged in the non-dominant language. However, planned comparisons revealed that older and younger bilinguals made similar numbers of cross language intrusions in both the dominant, $F(1,18) = 1.00$, $MSE = .05$ $\eta^2_p = .05$, $p = .33$, and non-dominant languages, $F(1,18) = 2.48$, $MSE = .3.69$ $\eta^2_p = .12$, $p = .13$.

Matched-Group Comparisons Letter Categories

Young and older bilinguals produced the same number of correct responses, $F < 1$ with marginally significant language dominance effects, $F(1,18) = 3.34$, $MSE = 3.79$, $\eta^2_p = .16$, $p = .08$, and no evidence that older bilinguals had more difficulty in the non-dominant language (no interaction), $F < 1$.

Consistent with an age related decline in executive functioning, older bilinguals made significantly more within language errors than younger bilinguals, $F(1,18) = 6.12$, $MSE = 21.75$, $\eta^2_p = .25$, $p = .02$. Both older and younger bilinguals had significantly more errors in the non-dominant language, $F(1,18) = 6.12$, $MSE = 21.75$, $\eta^2_p = .25$, $p = .02$. However, older bilinguals did not show the predicted interaction between age and language dominance, $F < 1$. Rather, they demonstrated a similar disparity between errors in the dominant vs. nondominant language to young bilinguals.

Providing partial support for the notion of age related decline in inhibitory control, older bilinguals produced more cross language intrusions than younger bilinguals, $F(1,18) = 6.27$, $MSE = 2.11$, $\eta^2_p = .26$, $p = .02$, although equally so in the two languages, $F < 1$, and there was no interaction, $F < 1$.

Overall, the matched groups of young and older bilinguals provided little evidence to support the ICM (Inhibitory Control Model), and weak evidence for an age related decline in language control. In semantic fluency, older bilinguals did not produce more cross-language intrusions than younger bilinguals, though there was a trend towards an interaction in the predicted direction with greater age-effects on intrusion rates of the dominant into the nondominant language. In letter fluency, there was a significant age-related increase in cross-language intrusion errors, however again this was without the predicted interaction with language dominance. The analyses of number correct revealed no trends in the predicted direction. Instead, only the dominant-language semantic fluency produced robust age effects. Similarly, the analyses of within-language errors produced no evidence of age-related decline in language control; older adults produced more errors in both languages particularly in letter-fluency.

The ICM predicted that older bilinguals should have more difficulty speaking a nondominant language because of the greater need to manage cross language interference in production of a weaker language, and because older adults may have inhibitory control deficits (Hedden & Park, 2001). One reason why we might fail to observe older adults having more difficulty with speaking a nondominant language is if they are more proficient bilinguals than the younger bilinguals. Importantly, we matched participants carefully for several proficiency variables, although there was nevertheless a small but significant difference between young and older bilinguals in their self-reported use of the non-dominant language. As an additional test of the prediction that language control declines in older age we focused a second set of analyses exclusively on the older bilinguals. Similarly, matching for degree of bilingualism is difficult.

Correlations Between Fluency and Executive Functioning Tests in Older Bilinguals

Our procedure of matching young and old bilinguals for demographic characteristics as well as language history limited the number of participants we could include in our matched age-contrasted analyses. Furthermore, although we tested each participant with a relatively large number of fluency categories (a total of 18), after dividing these by language and by category type (semantic versus letter) there was limited power to detect differences. In addition, one of the most compelling forms of evidence for competition between languages is cross language intrusion errors. Interestingly, both young and older bilinguals produced very few cross language errors overall. However, this too limits the power for detecting age effects. Another limitation of the matched groups approach is possible flaws in the assumptions underlying this matching. For example, while bilinguals were matched on absolute education level, all of the young bilinguals were students enrolled in college and their ultimate level of education would therefore likely be higher, whereas the older bilinguals' education level was a stable representation of their educational achievement.

To address these limitations, we further explore the relationship between aging and language control by looking within all 18 older bilinguals tested (without comparison to young bilinguals) for correlations between age and cross language intrusion errors. To further increase power, for this purpose we collapsed together all cross-language intrusions produced regardless of category type (semantic and letter), and regardless of language (English, Spanish) thereby considering any intrusion error as evidence for loss of language control together in a single analyses.

Of great interest, there was a significant correlation between age and intrusion rates, such that the number of cross language intrusions increased with advancing age ($r = .481$, $p = .043$). This result is consistent with the predictions of the inhibitory control model and with the notion of age-related decline in executive control (which in this case impairs the ability to prevent cross-language intrusion errors).

The correlation between age and cross-language intrusion errors provides support for the notion that bilingual language control declines with age. To determine if this decline is related to other forms of age-related decline in cognitive control we looked for correlations between verbal fluency measures (cross-language intrusion rates, within-language error rates, and number of correct responses) and performance on other measures of executive control (Stroop and Attentional Network Task). The mean RTs and error rates for these two tasks are presented in Table 4. RTs in both the Attentional Network Task, $F(1,16) = 25.77$, $MSE = 11{,}257.19$, $\eta^2_p = .62$, $p < .01$, and the Stroop Test, $F(1,17) = 100.59$, $MSE = 2{,}697.15$, $\eta^2_p = .86$, $p < .01$, were significantly slower on incongruent than on neutral trials indicating significant interference effects. Similarly, bilinguals produced significantly more errors on incongruent trials than on neutral trials of both the Attentional Network Task, $F(1,16) = 34.86$, $MSE = 0.02$, $\eta^2_p = .69$, $p < .01$, and Stroop Test, $F(1,17) = 6.78$, $MSE = .02$, $\eta^2_p = .29$, $p = .02$, again indicating significant interference effects in both tasks.

As both the Attentional Network Task and Stroop test are sensitive measures of cognitive control, we investigated if there was any relationship between these executive functioning tasks and bilingual language control (as predicted by the Inhibitory Control Model). Correlations between executive control measures, age, and four fluency variables (raw number of cross language intrusions, intrusion rates, raw numbers of within language errors produced, within-language error rates, and number of correct responses) are shown in Tables 5 and 6. The intrusion rates measures (instead of raw numbers of intrusions; the number of intrusions and errors as a proportion of total responses produced) adjusts for the fact that speakers who are highly fluent have greater opportunity to produce an error because they produce more responses.

Response Time in the Attentional Network Task

As can be seen in Table 4, the rate of errors in the ANT was very high on incongruent trials (50% on average). Although we still observed highly robust interference scores in the RT measures (see above), the high error rates likely led to some unexpected and difficult to interpret correlations between RT interference scores (incongruent minus neutral) and the dependent variables of interest. For example, there was a negative correlation between interference scores and the number of cross-language intrusions such that smaller interference scores (better control ability) was associated with increased intrusion errors (worse language control). Given the high rate of errors in the incongruent trials this result may have reflected a speed-accuracy trade-off such that people who made more errors responded more quickly. Thus, we do not report these correlations in detail, and instead focus on the interference scores as measured by error rates.

Attentional Network Task and Cross-Language Intrusions

Higher cross language intrusion rates (calculated as a percentage of total fluency output) were associated with more errors in congruent (*r* = .681, *p* = .003), neutral (*r* = .618, *p* = .008), and incongruent trials (*r* = .725, *p* <. 001) on the Attentional Network Task. We included unadjusted (raw) numbers of cross language intrusions to see whether the correlations would change as a result, and we found similar correlations between all three trial types, although it should be noted that correlations for neutral(*r* = .436, *p* = .080) and congruent trials (*r* = .445, *p* = .074) no longer reached significance. Incongruent trial errors remained significantly correlated with raw numbers of cross language intrusions *r* = .545, *p* = .024), indicating this was a robust effect. Older bilinguals who produced higher intrusion rates also experienced greater interference (as measured by number of errors in incongruent trials minus the number of errors in neutral trials) in the Attentional Network Task (*r* = .618, *p* = .008). Unadjusted (raw numbers of) cross-language intrusion errors were also correlated with interference (calculated in the same way as above) on the Attentional Network Task (*r* = .492, *p* = .045).

Attentional Network Task and Within-Language Errors

In notable contrast, significant correlations between executive functioning measures and within language errors were largely absent with one exception that was not as robust statistically as the correlations with cross-language intrusion errors. Higher rates of within language errors were associated with increased errors on the incongruent trials of the Attentional Network Task (r =.492, p = .045) and were associated with higher error rates on congruent, (.*r* = .405, *p* = .107,) and neutral trials, *r* = .397, *p* = .115), although not significantly so. Examining raw numbers of within language errors revealed no association with within language errors across all trial types (all *p*s < .535). It seems that overall the correlations between within language errors and errors on the Attentional Network task are smaller in size, and the majority of them do not reach significance. In sum, there is not much evidence that within language errors are mediated by executive control mechanisms as measured by the ANT. Further evidence that executive control is required to manage interference, but not within language errors, was the finding that increasing age is associated with more cross language intrusions ($r = .481$, $p = .043$), but was not associated with more within language errors ($r = -.174$, $p = .489$).

<u>Attentional Network Task and Number Correct</u>

Supporting previous findings of verbal fluency as a measure of executive functioning, high numbers of correct responses (again collapsing across both languages and category type) were associated with fewer errors across all trial types of the ANT (congruent; $r = -.646$, $p = .005$, neutral; $r = -.628$, $p = .007$, incongruent; $r = -.709$, $p = .001$), with lower interference scores (measured by number of errors in incongruent trials minus the number of errors in neutral trials; r = - .583, p= .014). Examining these correlations separately by language dominance, we found no evidence that correlations were stronger for the nondominant (congruent; r = -.535, p= .027, neutral; r = -.479, p= .052, incongruent; r = -.478, p= .052), vs. dominant language (congruent; r = -.552, p= .022, neutral; r = -.571, p= .017, incongruent; r = -.698, p= .002), as the Inhibitory Control Model would predict.

<u>Age Effects, Fluency and the Attentional Network Task</u>

In addition to age effects on number of cross language intrusions, age was also significantly associated with errors on the Attentional Network Task, with older bilinguals producing more errors in congruent, (*r* = .488, *p* = .047), neutral,(*r* = .614, *p* = .009), and incongruent trials(*r* = .595, *p* = .012). Response times were significantly slower with increasing age for both congruent, (*r* = .660, *p* = .004), and neutral trials, (*r* = .757, *p* < .001), but not for incongruent trials(*r* = .401, *p* = .110). However, as previously discussed the high number of errors in incongruent trials decreased the number of usable data points, thus reducing power. Increased age was associated with reduced verbal fluency, (*r* = -.583, *p* = .014), but not with a higher rate of within-language errors,(*r* = .095, *p* = .709).

Correlations with the Stroop Test

Examining correlations between age, cross language intrusions, within language errors and verbal fluency and response times and errors on the Stroop test revealed very few significant correlations. One notable exception was a robust association between performance on neutral trials in the Stroop (i.e., the ability to name the color of the ink for words like *deep*), and the rate of within-language errors. Bilinguals with faster response times on neutral trials, (*r* = .498, *p* = .036), and fewer errors on neutral trials, (*r* = .736, *p* < .001), made fewer within-language errors on the Stroop. The appearance of some highly robust correlations in neutral but not incongruent trials makes it somewhat harder to interpret the relationship between Stroop performance and fluency; however, these results in concert with those reported for the ANT do suggest that different mechanisms are involved in preventing within-language errors versus cross-language intrusions.

In addition, as for the ANT, greater numbers of incongruent errors (*r* = .477, *p* = .046) and higher interference scores on errors (neutral minus incongruent errors; *r* = -

.470, p = .049) were both significantly correlated with higher raw numbers of cross language intrusions, but these were much weaker compared with comparable correlations using the ANT, and were no longer significant after adjusting for production rate. There were some weak correlations between increased age and slower response times neutral (r = .381, p = .119) and incongruent (r = .406, p = .095) trials, however they did not reach significance. Although previous research has found that performance on the Stroop test declines with age (Van der Lubbe & Verleger, 2002), it should be noted that this study compared young and older adults, whereas we examined age effects within older adults. Age effects are likely to be more robust with a 50 year contrast built in (20 year olds versus 70 year olds). Our findings suggest that the greatest declines in performance on the Stroop test may occur between young and old adulthood, but decline less noticeably in older age. However, the fact that performance on the Attentional Network Task declined with age despite the restricted age range may indicate that the Attentional Network Task is more difficult and therefore more sensitive to age related decline, or both. Indeed as noted above, error rates were quite high in the ANT (and one older bilingual could not complete the task at all). Our modification of the ANT (manipulating both flanker types and the side of the screen on which the display appeared) seems to have made the task much more difficult than the published version.

Experiment 1a Results Summary

In sum, these data provide support for the notion that bilingual control mechanisms rely (at least in part) on general mechanisms of executive control that decline in older age. In the General Discussion we consider further the specific pattern of correlations observed here and speculate as to why the ANT seemed to be more related to bilingual language control than the Stroop.

EXPERIMENT 1b METHODS

In Experiment 1 we found mixed evidence for an age related decline in language control in bilinguals. Although we found significant relationships between executive control and language control and age-related deficits in the ability to prevent errors, older bilinguals did not have obvious difficulty with producing correct responses in a nondominant language. One result that was particularly unexpected based on the assumptions of the Inhibitory Control Model was the robust age-effects on production of correct responses in the dominant but not in the nondominant language. This finding could potentially be the result of the particular categories we chose, rather than an age effect in bilingual language control. To examine the effect of aging on verbal fluency independent of bilingualism, we tested a group of young and older monolinguals on the same categories tested in Experiment 1a.

Experiment 1b Participants

Thirty-six young adult monolinguals and fifteen older adult monolinguals participated in the study. Young monolinguals were University of California at San Diego students who participated in the experiment for course credit. Older monolinguals were recruited from the Alzheimer's Disease Research Center (ADRC). Participants completed the same language history questionnaire as bilinguals. Monolinguals were speakers of English only, with limited proficiency in or exposure to a second language above and beyond basic language requirement classes. Participant characteristics are shown in Table 7. Older and younger monolinguals did not significantly differ in years of education.

Experiment 1b Materials

Materials were the same as in Experiment 1a.

Experiment 1b Procedure

Participants were tested in English and completed 5 semantic categories and 4 letter categories (letters F, A, S, L). Semantic categories were divided into two lists, each containing five categories. Each monolingual completed one of two semantic lists with list counterbalanced between subjects. The procedure was the same as in Experiment 1a.

EXPERIMENT 1B RESULTS

Correct responses and errors were coded in the same way as in Experiments 1a. We conducted two one-way ANOVAs with participant type (older vs. young monolinguals) as the between subjects variable for two dependent variables including: (a) number correct, (b) within language errors for semantic and letter categories. Participant means are shown in Table 8.

Experiment 1b Matched-Group Comparisons Semantic Categories

Younger monolinguals produced more correct responses in semantic fluency than older monolinguals, $F(1,50) = 11.85$, $MSE = 18.71$, $\eta^2_p = .20$, $p < .01$, with a non-significant trend in the same direction in the errors analysis, $F(1,50) = 3.14$, $MSE = 19.99$, $\eta^2_p = .06$, $p = .08$.

Experiment 1b Matched-Group Comparisons Letter Categories

Older and younger monolinguals produced similar number of correct responses (no effect of age), $F(1,50) = 1.77$, $MSE = 15.79$, $\eta^2_p = .04$, $p = .19$; however older monolinguals made significantly more errors than younger monolinguals, $F(1,50) = 17.21$, $MSE = 17.30$, $\eta^2_p = .26$, $p < .01$.

EXPERIMENT 1 DISCUSSION

The results of Experiment 1 suggest distinct age effects on production of correct responses and prevention of errors in the verbal fluency task, and that these hold for monolinguals and bilinguals alike. Semantic fluency categories produced a robust age-related decline in ability to produce correct responses in monolinguals in the one language they know, and in bilinguals in their more dominant language. In contrast, in letter fluency there were no robust age effects on the production of correct responses although there were robust age effects on the ability to prevent within-language errors (again in monolinguals and bilinguals alike). The difference in age-effects across semantic and letter fluency may reflect the greater need for executive function in letter versus in semantic fluency.

Our results showing greater decline in semantic vs. letter fluency tasks is consistent with other studies showing larger age effect for semantic fluency (Brickman et al., 2005; Kozora & Cullum, 1995, Tombaugh et al., 1999; Tomer & Levin, 1993). However, one study failed to find disproportionate declines in semantic vs letter fluency with age, although it should be noted that subjects in that study were highly educated, intelligent and predominately Caucasian which may limit the generalizability of their results to other groups (Bolla, Gray, Resnick, Galante & Kawas, 1998). Compared to monolinguals in our study who averaged 13.9 years of education, the highly educated subjects' mean education levels (which were separated by age and gender) ranged from 15.8 to 18.1 years, indicating that the majority of their subjects had obtained graduate level education. Older adults reduced category fluency has been attributed to difficulties with retrieval from semantic networks in normal aging (Kozora & Cullum, 1995) as older old subjects(85 years or older) who were diagnosed as being cognitively normal after being screened on the Modified Mini-Mental State Exam (Teng & Chui, 1987) showed greater difficulty with retrieval from semantic categories from moderately old (75-84 years of age) and young old subjects (65-74 years of age; Crossley et al., 1997). Reduced semantic fluency has also been attributed to the decline of semantic networks in AD, (Butters et al., 1987), whereas phonological knowledge necessary for phonemic fluency remains relatively intact (Jorm, 1986). The similar decline in semantic fluency in both aging and AD raises the concern that age effects are a result of pre-clinical or undiagnosed AD or Mild Cognitive Impairment in the study samples. However, semantic fluency declines were still observed in older adults who were carefully screened for cognitive impairment utilizing neuropsychological assessments and screenings (Tombaugh et al., 1999; Crossley et al., 1997). In our study, it is unlikely that the older adults were cognitively impaired as all were recruited from the Alzheimer's Disease Research Center and received comprehensive neurological and neuropsychological examination, and were screened using the Mini-Mental State Exam (MMSE; Folstein, Folstein & McHugh, 1975) and Dementia Rating Scale-2 (Jurica, Leitten, & Mattis, 2001). Another possible explanation for reduced semantic fluency in older adults comes from imaging studies that look at brain functioning during verbal fluency tasks. Both older and younger adults showed strong lateralization to the left hemisphere during phonemic fluency tasks, but older adults showed greater bilateral activity during the semantic fluency task than younger adults which was negatively correlated with semantic fluency (Meinzer et al., 2009). Older adults were screened for cognitive decline and were given both the MMSE and the neuropsychological test battery established by the

Consortium to Establish a Registry for Alzheimer's disease (CERAD). Greater recruitment of the right hemisphere in older adults has been attributed to decreased efficiency in specialized regions of the brain (Rajah & D'Esposito, 2005), but has also been explained as indicating greater difficulty of the task that requires more cognitive resources (Braver et al., 2000). Whatever the explanation, semantic fluency seems to become more difficult a task for older adults than phonemic fluency and it remains unclear as to whether this is moderated by higher levels of education with some studies finding that decline in semantic fluency was not moderated by education level (Brickman et al., 2005) while others found that older adults with higher levels of education produced more exemplars in both semantic and letter categories than adults with lower levels of education (Crossley et al., 1997).

Summarizing the results to this point, we obtained some evidence for age-related decline in language control particularly in the ability to prevent cross-language intrusion errors and in the production of correct responses and this seemed related to performance on the ANT. In contrast, Stroop was not strongly related to language control and instead seemed related to the ability to prevent within-language errors. Additionally, we obtained evidence for age-related decline in dominant language semantic fluency in both bilinguals and monolinguals.

As a final test of the Inhibitory Control Model we examined if bilinguals with AD have more difficulty with controlling interference from a non-target language, and particular difficulty with speaking a non-dominant language. To test these predictions, we compared bilinguals with Alzhemer's disease to age-matched cognitively normal bilinguals on the same verbal fluency categories that were used in Experiment 1a.

EXPERIMENT 2 METHODS

Experiment 2 was designed to examine the role of executive functioning in bilingual language production in verbal fluency tasks in bilinguals with dementia (e.g. Alzheimer's disease). Executive functioning has been found to decline in Alzheimer's patients (Collette, Van der Linden, & Salmon, 1999). For example, the ability of speakers with AD to inhibit irrelevant stimuli (as measured in the Stroop task, for example) is impaired relative to age matched controls (Bondi, Serody, Chan, Eberson-Shumate, Delis, Hansen & Salmon, 2002). If bilingualism requires suppression of the non-target language as hypothesized by the Inhibitory Control Model, then bilinguals with Alzheimer's disease would be less able to manage cross language interference than age matched controls. Since inhibition of the dominant language is more difficult, then bilinguals with AD should be particularly disadvantaged when speaking the non-dominant language.

Experiment 2 Participants

Thirteen cognitively normal older adult bilinguals and ten bilinguals diagnosed with Alzheimer's disease participated in the study. Participants completed the same language history questionnaire described in Experiment 1 and were tested in English first. Bilinguals were speakers of English and Spanish with limited or no proficiency in a third language and were classified as either balanced, English dominant, or Spanish dominant based on their self-rated ability to speak English and Spanish using the same procedure as in Experiment 1. For the statistical analyses, dominant and non-dominant languages were coded such that Spanish-dominant speakers' Spanish responses were dominant and English responses as nondominant, and vice versa for English-dominant speakers. Ten of the thirteen control bilinguals were included in the matched age contrasts in Experiment 1.

All participants were recruited from the Alzheimer's Disease Research Center (ADRC) through which they receive annual medical, neurological and neuropsychological evaluations. Alzheimer's patients were diagnosed with probable AD by two senior staff neurologists according to criteria developed by the National Institute of Neurological and Communicative Disorders and Stroke (NINCDS) and the Alzheimer's Disease and Related Disorders Association (ADRDA) McKhann, Drachman, Folstein, Katzman, Price, & Stadlan, 1984). Both bilinguals with AD and normal controls' scores on the Mini Mental State Exam (MMSE) were considered as part of selection criteria. Normal participants' MMSE scores ranged from 25 to 30. Bilinguals with AD's MMSE scores ranged from 16 to 27.

Thirteen of the 18 bilinguals tested in Experiment 1a were included in our analyses because of our matching criteria. Participants were matched for age and education (Strauss, Sherman, & Spreen, 2006), and for age of first exposure to English, percent of daily spoken English, and self-rated proficiency in both Spanish and English.

Participant characteristics are shown in Table 9. Older bilinguals and bilinguals with AD did not significantly differ in age, years of education, age of first exposure to English, age at which they began to use English regularly, percent of daily spoken English, or self-rated spoken English or Spanish ability. Bilinguals who rated themselves as equally balanced in both languages were considered English-dominant for the purposes of our study, given that English is the dominant language spoken in most everyday interactions. Ten control bilinguals were English-dominant, and three were

Spanish-dominant. Seven bilinguals with AD were English-dominant, and three were Spanish-dominant. Interestingly, five out of thirteen controls rated themselves as equally proficient in both languages, whereas none of the bilinguals with AD rated their English and Spanish speaking ability to be equivalent. This difference could reflect bilinguals' with AD subjective sense that they are not as balanced bilinguals as they used to be. Importantly, bilinguals with AD did not rate their ability to speak the non-dominant language as significantly worse than older controls, $F(1,21) = 1.51$, $MSE = 1.35$, $\eta^2_p = .07$, $p = .23$.

Experiment 2 Materials

We used the same materials as in Experiment 1.

Experiment 2 Procedure

The procedure was the same as in Experiment 1.

EXPERIMENT 2 RESULTS

Responses were coded in the same manner described in Experiment 1. We conducted three 2 x 2 mixed model ANOVAs using participant type (older vs. AD bilinguals) as the between subjects variable and language dominance (dominant vs. non-dominant language) for three dependent variables including: (a) number correct, (b) within language error rates and (c) cross language intrusion error rates. Participant means are shown in Table 10.

Experiment 2 Matched-Group Comparisons Semantic Categories

Bilinguals with AD produced fewer correct responses than controls, $F(1,21) = 19.38$ $MSE = 18.12$, $\eta^2_p = .48$, $p < .01$. Participants produced similar numbers of exemplars in each language, $F(1,21) = 1.61$ $MSE = 8.00$, $\eta^2_p = .07$, $p = .22$, (no main effect of language-dominance) suggesting the groups were relatively balanced bilinguals. Of great interest, there was no evidence that bilinguals with AD have more difficulty producing responses in the non-dominant language as there was no significant interaction between participant group and language-dominance, $F < 1$.

In the analysis of within language errors, bilinguals with AD made significantly more incorrect responses, $F(1,21) = 12.40$, $MSE = 127.50$, $\eta^2_p = .37$, $p < .01$. Both bilinguals with AD and normal controls made similar numbers of errors in both the dominant and non-dominant languages, $F(1,21) = 1.07$, $MSE = 61.77$, $\eta^2_p = .05$, $p = .31$, and there was no interaction, $F < 1$.

Consistent with the hypothesis that AD impairs language control, bilinguals with AD made marginally more cross language intrusions than controls, $F(1,21) = 3.37$, $MSE = 10.45$, $\eta^2_p = .14$, $p = .08$. All speakers made more intrusions of the dominant language into the non-dominant language than the reverse, $F(1,21) = 6.75$, $MSE = 5.24$, $\eta^2_p = .24$, $p = .02$. Also of interest, and again consistent with the hypothesis that AD impairs language control, there was a trend towards an interaction between participant type and language dominance in the predicted direction, $F(1,21) = 3.08$, $MSE = 5.24$, $\eta^2_p = .13$, $p = .09$. Planned comparisons revealed that bilinguals with AD made more cross language intrusions than controls in the non-dominant language, $F(1,21) = 4.33$, $MSE = 11.44$, $\eta^2_p = .17$, $p = .05$, but not in the dominant language, $F < 1$. Additionally, patients made more cross language errors in the non-dominant language than the dominant language, $F(1,9) = 7.72$, $MSE = 5.68$, $\eta^2_p = .46$, $p = .02$, whereas controls made similar numbers of cross language intrusions in both languages, $F < 1$. These results support the predictions of the Inhibitory Control Model, as well as the speakers' subjective reports such that healthy speakers were relatively balanced bilinguals, but bilinguals with AD have more difficulty with preventing intrusions from the dominant language into the non-dominant language.

Experiment 2 Matched-Group Comparisons Letter Categories

Bilinguals with AD produced fewer correct responses than controls, $F(1,21) = 10.77$, $MSE = 21.94$, $\eta^2_p = .34$, $p < .01$. Both older controls and bilinguals with AD produced more correct responses in the dominant than the nondominant language, $F(1,21) = 5.88$, $MSE = 3.89$, $\eta^2_p = .22$, $p = .02$. However, bilinguals with AD but did not show greater difficulty with the non-dominant language as predicted as the interaction was not significant, $F < 1$.

Bilinguals with AD made more within language errors than controls, $F(1,21) = 229.18$, $MSE = 61.00$, $\eta^2_p = .63$, $p < .01$. Both controls and bilinguals with AD made more errors in the non-dominant than in the dominant language, $F(1,21) = 7.02$, $MSE = 114.42$, $\eta^2_p = .25$, $p = .02$. In addition, although the effect of AD on production of within-language errors was numerically much larger in the non-dominant language, this interaction was not significant, $F(1,21) = 2.02$, $MSE = 114.42$, $\eta^2_p = .09$, $p =.17$.

While the interference account would predict that bilinguals with AD should produce more cross language intrusions particularly in the non-dominant language, there was no evidence to support this in the letter fluency data. Bilinguals with AD did not produce more cross language intrusions than controls, $F(1,21) = 1.60$, $MSE = 8.42$, $\eta^2_p = .07$, $p =.22$, and both older and bilinguals with AD produced similar numbers of intrusions in both languages, $F < 1$. There was no significant interaction, $F < 1$. Contrasting these data with the analyses in the previous section on semantic fluency, it seems that the effect of AD on language control can be seen only in the semantic fluency task.

EXPERIMENT 2 DISCUSSION

The results of Experiment 2 reveal some evidence that AD impairs bilingual language control. In particular, when compared with matched healthy controls, bilinguals with AD had more difficulty preventing cross-language intrusion errors in semantic fluency. Research on the effects of AD on verbal fluency in monolinguals have revealed that semantic fluency is particularly difficult with the onset of AD (e.g., Monsch, Bondi, Butters, Salmon, Katzman, & Thal, 1992), and similar effects have been reported for the two languages in bilinguals with AD (i.e., greater declines in semantic than in letter fluency in both languages; Salvatierra et al., 2007). Research on bilingual verbal fluency has suggested that competition between languages is more fierce during semantic than letter fluency (e.g., Gollan et al., 2002; Sandoval et al., in press),

To consider if bilinguals with AD in the current study showed disproportionate reduction in semantic vs. letter fluency compared to controls, we conducted two 2 x 2 mixed model ANOVAs with participant type (controls vs. bilinguals with AD) as a between subjects variable, and category type (letter vs. semantic) as a within subjects variable with number correct in the dominant and non-dominant languages as the dependent variable. For the dominant language, all participants produced significantly more exemplars in semantic (M = 9.56) than letter (8.06) categories, $F(1,21) = 7.44$, $MSE = 3.46$, $\eta^2_p = .26$ $p = .01$, which was consistent with previous research comparing older bilinguals and bilinguals with AD (Salvatierra et al., 2007). There was a main effect of participant type as bilinguals with AD (M = 6.23) showed reduced verbal fluency compared to controls (M = 11.40) across both categories, $F(1,21) = 16.21$, $MSE = 18.70$, $\eta^2_p = .44$, $p < .01$, which was also found by Salvatierra et al. In contrast, there was no interaction between participant type and category type, $F(1,21) = 1.88$, $MSE = 3.46$, $\eta^2_p = .08$, $p = .18$, unlike Salvatierra et al. who found a significant interaction between participant and category types such that controls and bilinguals with AD produced similar numbers of exemplars in letter categories in both Spanish and English, but produced significantly fewer exemplars in semantic fluency trials across both languages. We found the same pattern of results for the non-dominant language with participants producing more exemplars in semantic (M = 8.50) than letter (M = 6.64) categories, $F(1,21) = 5.70$, $MSE = 6.91$, $\eta^2_p = .21$, $p = .03$, and bilinguals with AD producing significantly fewer exemplars than normal controls, $F(1,21) = 12.19$, $MSE = 22.87$, $\eta^2_p = .37$, $p < .01$. Again, there was no interaction between participant type and category type, $F < 1$.

The absence of an interaction between diagnosis and category type in our study may be related to the type of categories we used (see further analyses in General Discussion). By far the most widely used category to measure semantic fluency is *Animals* and it is often used as the only measure of semantic fluency (Tombaugh, Kozak & Rees, 1999) as it was in the Salvatierra study. In contrast, we used a total of semantic categories, with each participant completing five in English and five in Spanish. Several other differences between our study and the Salvatierra et al., study that might have produced the different pattern of results were that we used different letters across languages, whereas they used the same letters in both English and Spanish, we classified responses by language dominance (dominant vs. non-dominant languages) whereas Salvatierra compared Spanish and English. We always tested in the dominant language first whereas they counterbalanced language testing order. Finally, we tested different categories in each language whereas they tested the same single category in both languages.

Summarizing the results of Experiment 2, bilinguals with AD produced fewer correct responses, and made more within language errors than controls, but there was no evidence that they had greater difficulty producing the non-dominant language. On the other hand, there was evidence for impaired language control in AD in the rate of cross-language intrusion errors, particularly in semantic fluency in the nondominant language.

GENERAL DISCUSSION

The current study explored the role of executive control in bilingual language production by examining how bilingual verbal fluency responses are affected by aging and Alzheimer's disease. The Inhibitory Control Model (ICM) posits that in order to speak one language, bilinguals must suppress the non-target language, and that the dominant language is must be inhibited more than the non-dominant language during bilingual language production (Green, 1998; Meuter & Allport, 1999; for reviews see Kroll et al., 2006, 2008). Since aging and AD have been associated with declines in executive functioning we predicted that bilinguals should have difficulty maintaining their bilingualism as they age or with cognitive decline if managing interference is essential for bilingual language production. Additionally, this would be particularly evident in the non-dominant language where greater control is needed to prevent intrusions from the dominant language.

Evidence Supporting the Inhibitory Control Model

The strongest evidence we obtained to support the ICM (Inhibitory Control Model) of bilingual language control was the significant correlation between age and cross-language intrusion errors. Intrusion errors provide an obvious form of evidence for interference between languages, and in some sense seem to constitute indisputable evidence for some form of competition between language systems, and failures in increased age to either detect, or to prevent such errors, or both. A true skeptic could argue that older old bilinguals were more willing than younger old bilinguals to occasionally relax the extent to which they followed instructions (to produce words in language X or Y). After all the production of words in the other language is a communicatively sensible thing to do given that both experimenters were bilingual and the participants were fully aware of this point. However, we obtained additional independent evidence for the role of executive control in bilingual fluency performance, and age related decline in such control. Specifically, bilinguals who made the most cross-language intrusion errors also made more errors on the ANT, and to some extent also in incongruent trials of the Stroop Test. The fact that cross language errors are correlated with worse performance on executive functioning measures suggests that the bilingual language control relies on similar mechanisms to those used to inhibit responses and resolve conflict outside the language system.

Examining the relationships between bilinguals' production of cross language errors and performance on executive functioning tasks allows us to address whether older bilinguals are making more of these intrusions than younger bilinguals because of decreased ability to control and monitor such errors, or if they simply feel more comfortable with utilizing either language. Language mixing or code switching is a fairly common occurrence when bilinguals communicate with each other and this is particularly true in a bilingual environment, where both languages are being spoken (Heredia & Altarriba, 2001). While cued language switching has been associated with increased processing costs, voluntary language switching can sometimes facilitate language production and improve naming accuracy in confrontational naming tasks, such as the Boston Naming Test (Gollan & Ferreira, 2009; Gollan, Montoya, Fennema-Notestine, & Morris, 2005). The association between cross language errors and measures of executive control is significant because it suggests that cross language intrusions don't appear in older bilinguals' verbal fluency responses more often simply because they feel more comfortable blending language responses than younger-old bilinguals. Rather it clearly connects their increased intrusions to decreased performance on measures of executive control. This finding is consistent with literature demonstrating that language switching in bilinguals may be related to executive control and frontal lobe functioning (Fabbo Skrap, & Aglioti, 2000).

One finding that was surprising was that bilinguals' response times in incongruent trials of the ANT were not significantly correlated with increasing age, (r = .401, p =.110). This finding was inconsistent with the Inhibitory Control Model which would have predicted that the largest effect on response times would have been in the incongruent trial which requires conflict resolution, and given the robust correlation between incongruent errors and age, (r = .595, p =.012). One explanation why the correlation between RTs on incongruent trials and cross-language intrusions did not reach significance whereas RTs on congruent and neutral trials were significantly correlated with intrusion rates, may be related to the greater number of errors produced in incongruent trials. The very high error rate in incongruent trials means that fewer response times were averaged into the mean RT for incongruent trials, thus these data may have been less reliable given that only correct response RTs were analyzed.

A second source of support for the ICM was the finding that bilinguals with AD produced significantly more cross language intrusions than controls, and this was especially true in semantic categories. The limitation of this result to semantic trials may reflect the relatively high intrusion rate for older bilinguals (in Experiment 1a) in letter fluency, and the greater susceptibility of semantic than letter fluency to the effects of dementia. It is not clear why older bilinguals did not also experience a greater intrusion rate in semantic fluency given previous arguments that interference between languages is greater in semantic than in letter fluency (Gollan et al., 2002; Rosselli et al., 2000; however, the very low overall rate of intrusions may be a factor here; see below). That the AD effect was restricted to intrusions of the dominant language into the nodominant language is also quite consistent with the ICM which posits more control is needed to suppress the dominant language. Similarly, bilinguals with AD produced more intrusion in the non-dominant than the dominant language (again in semantic fluency), whereas normal controls produced similar numbers of intrusions in each language.

Challenges for the Inhibitory Control Model

One challenge to an interference based account of bilingual language production is that aging and impaired bilinguals did having clear difficulty in producing the non-dominant language. That is, although we obtained some evidence for effects of aging and AD on cross language intrusion rates, there was no evidence of increased language dominance effects in aging and AD as predicted by the Inhibitory Control Model for the number of correct responses or within language errors rates. This lack of evidence for the ICM is powerful because the majority of responses (even for patients with AD) are correct responses, and thus the result leads one to wonder if the exclusive role for control is preventing intrusions when these only very occasionally become active enough to compete for selection.

An important consideration in interpreting these results is that several of the bilinguals in the current study reported being relatively balanced in their ability to speak and use both languages. It is possible that stronger age-effects would be seen in terms of decline in ability to speak a nondominant language if less balanced bilinguals were included in the experimental design. Degree of language use may also be an important consideration. Although younger and older bilinguals both rated the difference between their dominant (English) and non-dominant languages (Spanish) to be similar (a difference of 0.8 and 1.0 respectively), the older bilinguals reported speaking English 67% of the time on an average day, implying that they speak Spanish 33% of the time. By contrast, younger bilinguals reported speaking English 83.5% of the time, meaning they only speak Spanish about17.5%, roughly half as often as the older bilinguals. Because older bilinguals spend roughly a third of their day speaking Spanish, they may practice both languages more often than younger bilinguals and may be less susceptible to language dominance effects. On the other hand, less balanced bilinguals are effectively "less bilingual" and it was of interest to begin examining age-effects by looking to see what happens to language control in proficient bilinguals as they age. Moreover, in Experiment 2, all bilinguals with AD indicated greater proficiency in their dominant than in the non-dominant language, and still demonstrated relatively intact ability to produce fluency responses in a nondominant language (for similar findings with a picture-naming task see Gollan et al., in press). Thus, a first challenge for the Inhibitory Control Model is to explain why ability to produce correct responses in a nondominant language seems to be relatively resistant to age and AD.

Our unexpected result was that bilinguals with AD did not exhibit greater difficulty with semantic fluency compared to letter fluency. This differs from the results of previous studies that examined the effects of AD on verbal fluency including one on bilinguals by Salvatierra et al. (2007). More specifically, we found that bilinguals with AD produced fewer correct responses in both letter and semantic categories, and that was true for both dominant and nondominant language production. In contrast, Salvatierra et al. found no difference between groups on letter fluency in either English or Spanish. As noted above, the many differences between our study and that by Salvatierra could explain this difference in results across studies. Another possible factor was that the semantic categories included here were more susceptible to age-effects (which in turn would diminish the interaction between diagnosis and category type). This result was also unexpected based on the interference hypothesis – that is, the greatest age-effects in Experiment 1a were observed in production of correct responses in the dominant language in semantic fluency categories.

To determine if this finding was specific to the bilingual case we conducted Experiment 1b, and found a similar pattern of results in monolinguals; older and younger monolinguals revealed robust age effects in producing correct responses in semantic (but not in letter) fluency. This finding is consistent with previous research showing semantic fluency declines with age (Brickman et al., 2005; Troyer et al., 2000, Kozora & Cullum, 1995). The fact that monolinguals show similar patterns implies that the ability to produce correct responses in semantic fluency declines with age and implies that this aspect of the results of Experiment 1a is likely not specific to mechanisms used to manage interference in bilingualism. Also, if older bilinguals' reduced semantic fluency was related to executive control, we would expect to see a similar age effect in letter categories, which are used to measure executive functioning. That is older bilinguals and monolinguals should have produced fewer correct responses than young controls in letter fluency. However, in both Experiments 1a and 1b, only semantic fluency was affected.

One important consideration regarding semantic fluency is the finding that different categories can affect speakers' performance on the task. While the age effect on semantic fluency appears to be consistently found in the literature (but see Bolla et al., 1998) other factors such as education, gender, culture and language of the fluency task have all been shown to be sensitive to different semantic categories being used (Acevedo et al., 2000). Spanish speakers produced fewer animal names than speakers of Chinese, Vietnamese and English in one study and this difference was attributed to the relatively longer names in Spanish (Dick et al., 2002). Similarly, Greek speakers produced fewer animal names than subjects in other studies who were tested in English and Spanish and this difference was also attributed to the greater average number of syllables in Greek animal names (Kosmidis et al., 2002). Researchers investigating verbal fluency have used a wide variety of semantic categories (Acevedo et al., 2000). There is evidence that more specific categories (e.g. *farm animals*) have the potential to be easier than broader categories (e.g. *animals*) and the use of subcategories has been shown to improve fluency performance in speakers affected by neurological disease (Randolph, Braun, Goldberg & Chase, 1993).

To investigate whether the age effect on semantic fluency is being influenced by the categories we used in the study, we did an items analysis comparing older and younger bilinguals separately on each semantic fluency category. Older and younger bilinguals significantly differed in responses on only two English semantic categories (*occupations* and *musical instruments*) with younger bilinguals producing more exemplars. While other comparisons did not reach significance, in all cases younger bilinguals trended in the right direction with higher semantic fluency scores for young than for older bilinguals across all English semantic categories. We examined English categories only because none of the bilinguals in Experiment 1a reported Spanish as their dominant language. A similar analysis in the monolinguals' data showed that younger monolinguals produced significantly more exemplars in six catgories including *animals, adjectives, colors, fruits and vegetables, countries and sports*. Thus, there was some difference across groups in terms of which specific categories were most sensitive to age effects. There may be multiple mechanisms for the age-effects reported here some related, and others unrelated to, language control and bilingualism per se.

Perhaps the greatest challenge to the assumptions of the Inhibitory Control Model was the fact that the rate of cross language errors was so low, even in aging bilinguals and in bilinguals with AD. Looking at Table 3 for example, older bilinguals produce within language errors between 8.4 and 15.3 percent of the time, but hardly ever produced cross-language intrusions only 0.1 or up to less than 1.7 percent of the time. Similarly, in Table 10, bilinguals with AD produce within language errors between 18.1 and 31.1 percent of the time, and cross-language intrusions only 1.3% or up to 4.2% of the time. The contrast in error rates within versus between languages implies that cross-language errors are much more easily detected (and inhibited) than within language errors. This is surprising given that nothing other than language membership distinguishes a cross-language intrusion from a correct response (i.e., the words fit the designated category perfectly).

The Role of Control in Bilingual Language Production

The set of facts that needs to be explained given the data reported here is as follows: First, there seems to be a powerful relationships between non-linguistic executive control and the ability to prevent cross-language intrusions errors, this relationship leads to age-related and AD-related decline in ability to prevent cross-language intrusion errors (and the bilingual advantages in executive control as well as cognitive reserve related to bilingualism). Second, despite the relationship between language production and executive control in bilinguals, the overall rate of cross-language intrusions remains very low even in aging and cognitively impaired bilinguals. Finally, there is no profound decline in ability to speak a nondominant language in aging and AD, although there may be some subjective decline in AD as none of the bilinguals with AD, but several of the cognitively healthy older bilinguals, in the current study reported balanced ability to speak both languages.

The current set of results is consistent with other studies that have found subtle effects of cross language interference in bilingual verbal fluency (Sandoval et al., in press). While there is still debate as to whether or not bilinguals do experience competition for selection between languages (Costa, 2005; La Heij, 2005), to the extent that bilingual language production does depend on the resolution of competition between languages, it would appear that this mechanism is amazingly robust and resilient not only to the aging process, but also to the more extreme effects of dementia. Given that other executive functions clearly decline and become impaired in Alzheimer's disease, the fact that bilingualism has been shown to be mostly maintained in both the present study as well as others (see also Gollan, Salmon, Montoya, & da Pena, in press) would suggest some profound limitations on the role of control mechanisms in bilingual language use.

One way to limit the effects of control is to propose that there is no competition for selection between translation equivalent lexical representations (e.g., Costa et al., 1999), and to assign general control mechanisms the role of language selection and monitoring. In this view, both languages are always active but lexical representations (lemmas; see Introduction section) between languages do not compete directly for selection. Nevertheless, occasionally a selection error occurs (e.g., for a variety of possible reasons), and must be stopped before it is produced. For this purpose, executive control is needed (relatively more than for preventing within-language errors) because the only thing to distinguish a translation and its equivalent is language membership. The lack of direct competition between translation equivalent lexical representations would explain why intrusion rates remain so low even in aging bilinguals and AD, and why nondominant language production does not seem to become much more difficult in aging and AD. An equally possible alternative is that there is competition for selection between lexical representations but that there is a language-specific control mechanism that is used to resolve competition between lexical representations both within and between languages in monolinguals and bilinguals alike, and that this mechanism is relatively immune to the effects of age- and AD-related decline in executive control.

Although speculative, the specific pattern of relationships found between verbal fluency performance and the two executive control measures provides some support for the notion that there are different types of control mechanisms at work modulating within-language errors and cross-language intrusions during verbal fluency. The ANT seemed to be more related to language control predicting both intrusion rates and the number of correct responses but not (or only weakly predicting) within language errors. In contrast, Stroop performance was only weakly associated with ability to prevent cross-language intrusions and age effects, but neutral trial responses (RTs and errors) in the

Stroop were strongly associated with ability to monitor responses within a single language (within-language fluency errors). That is, there seemed to be overlap in executive mechanisms required for preventing cross-language intrusion errors, and errors in the flanker task (ANT), but only to a weaker extent Stroop errors on incongruent trials). It is somewhat surprising to find stronger relationships between ability to prevent failures in language control, and the non-linguistic flanker task rather than the Stroop. It might be suggested that the Stroop test used here was simply not as sensitive to age effects, and executive control ability, and that a more difficult Stroop test would reveal relationships with language control. Importantly, we obtained significant interference effects in both Stroop and ANT tasks (see Table 4), and we did observe some significant (one highly robust) correlation between fluency performance and the Stroop. These results increase confidence that the Stroop task we used was reliable. Thus, the contrast between Stroop and ANT results seems to suggest that (at least partially) distinct mechanisms of control operate within a single language versus between languages . This notion is consistent with previous proposals that special mechanisms prevent interference from a non-target language in bilingual language production (e.g., Santesteban & Costa, 2004).

Another possible explanation for why ANT performance showed stronger associations with cross language intrusions than Stroop performance may be related to the nature of the tasks. Stroop requires inhibition of an overlearned response (reading) in favor of a relatively unusual and not often practiced task which is to name the color of the ink in which the word is written. This level of active suppression might describe bilinguals who are very unbalanced, or people who are just starting to learn a language;

however, for bilinguals who are proficient in both languages and in particular those who acquired both languages at a young age, speaking even the non-dominant language would not require this level of inhibition seen on Stroop Tests. For more balanced bilinguals, such as those in our study, speaking both languages constitute highly practiced responses, but requires some executive control to manage. The ANT does not require inhibition of an over-learned response, but rather active monitoring to determine trial type and the relationship of the flankers to the desired response. The ability to monitor would seem highly related to the kind of processes needed for preventing intrusion errors. On this view, when bilinguals speak one language they are constantly monitoring selected responses prior to producing them (a final check for target language membership), similar to in the ANT. This monitoring process that is used to manage cross language interference and stimuli on the ANT would not be associated with within language errors because once a person is proficient in speaking, there is less need to inhibit representations in the non-target language. This is consistent with the proposal that inhibitory control plays less of a role in proficient bilingual language production (Costa et al., 2006), and with recent demonstrations that the bilingual advantage in the ANT appears only when monitoring demands are high (depending on the proportion of congruent and incongruent trials; Costa et al., 2009).

Conclusions

Our two proposed solutions for the pattern of effects observed here both have larger implications for understanding the role of executive function in language production in all speakers (bilingual or monolingual). A priori it would seem that bilinguals tested in a verbal fluency task (known to tap executive functioning), should provide the strongest test-case for possible effects of direct competition for selection between lexical representations, and for a direct role for executive control for resolution of competition effects within the language system itself. The fact that even in this case it seems necessary to place the role for executive control outside the domain of lexical selection to a more peripheral error-checking mechanism implies some degree of separation between language processing and executive control, in the spirit of modular theories of language processing (Fodor, 1983; Forster, 1979). Of course other interpretations are possible, as noted above perhaps a clearer association between executive control and production of a non-dominant language could be found by testing less balanced bilinguals. Nevertheless, without such evidence we suggest that at the moment the existing evidence seems to call for some compelling limitations on the role of executive control in language processing.

APPENDIX

Table 1: Materials in Experiments 1a, 1b, and 2

Letter categories		Semantic categories	
English	Spanish	English	Spanish
F	P	musical instruments	instrumentos musicales
A	M	adjectives	adjetivos
S	R	supermarket	supermercado
L	D	colors	colores
		sports	deportes
		countries	paises
		animals	animals
		occupations	trabajos
		fruits and vegetables	frutas y verduras
		nouns	sustantivos

Table 2: Means and Standard Deviations of Participant Characteristics in Experiment 1a

	Young bilinguals (n=10)		Older bilinguals (n=10)				
	M	*SD*	*M*	*SD*	F-ratio[b]	*p* value	η_p^2
Age	18.8	0.8	79.0	6.5	873.18	<.01	0.98
Education	13.4	0.8	13.0	1.5	<1	0.41	0.04
Age of First Exposure to English	3.3	2.5	4.0	3.0	<1	0.60	0.02
% English used daily	83.5	12.0	67.0	18.9	5.43	0.03	0.23
Self-rating[a] for spoken English	6.8	0.6	5.9	0.7	9.42	<.01	0.34
Self-rating[a] for spoken Spanish	6.0	1.2	4.9	1.2	4.37	0.05	0.20

[a] Proficiency level based on self-ratings using a scale of 1-7 with 1 being “little to no knowledge” and 7 being “like a native speaker.”

Table 3: Means and Standard Deviations of Response Measures in Experiment 1a

	Semantic Categories											
	Number Correct				Within-language Error Rates				Cross-language Intrusion Rates			
	dominant		nondom		dominant		nondom		dominant		nondom	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Young bilinguals	17.0	5.2	10.8	3.0	6.1	4.9	9.4	10.9	0.0	0.3	0.3	0.6
Older bilinguals[a]	12.8	3.4	10.2	4.5	11.6	9.8	15.3	9.6	0.1	0.0	1.7	2.6
Difference scores (OA-YA)	*-4.2**		*-0.6*		*5.5*		*5.9*		*0.1*		*1.4*	
age x dominance	*p* = 0.08				*F < 1*				p = 0.11			

	Letter Categories											
	Number Correct				Within-language Error Rates				Cross-langauge Intrusion Rates			
	dominant		nondom		dominant		nondom		dominant		nondom	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Young bilinguals	10.9	3.9	10.0	3.9	3.9	2.6	6.4	4.8	0.0	0.0	0.0	0.0
Older bilinguals	10.7	4.5	9.3	3.6	8.4	3.3	13.2	7.0	1.2	1.7	1.1	2.7
Difference scores (OA-YA)	*-0.2*		*-0.7*		*4.5**		*6.8**		*1.2**		*1.1*	
age x dominance	*F < 1*				*F < 1*				*F < 1*			

* $p < .05$, † $p < .10$

Table 4: Means and Standard Deviations of Response Measures in Experiment 1

	Attentional Network Task (ANT)						
	Congruent Trials		Neutral Trials		Incongruent Trials		Incongruent –Neutral trials
	M	*SD*	*M*	*SD*	*M*	*SD*	
Response times	1014	208	1007	205	1192	192	185*
Errors	12.25	16.29	16.54	18.70	45.47	33.16	29**

	Stroop Test						
	Congruent Trials		Neutral Trials		Incongruent Trials		Incongruent – Neutral trials
	M	*SD*	*M*	*SD*	*M*	*SD*	
Response times	839	148	1000	1845	1174	225	174*
Errors	0.15	0.65	0.71	1.3	11.55	17.45	10.84*

* $p < .05$, ** $p < .01$

Table 5: Pearson Bi-Variate Correlation Values (r) and Two-Tailed t-Test p-Values for Correlations Between the Attentional Network Task Fluency Scores and Age for 17 Bilinguals Tested in Experiment 1a

		Cross-language Intrusions	Cross-language Intrusions over TOTAL	Within Errors	Within Errors over TOTAL	TOTAL CORRECT	Age
Congruent RTs	*r*	0.185	0.330	-0.050	0.303	-0.593	0.660
	p	0.478	0.196	0.849	0.237	0.012	0.004
Neutral RTs	*r*	0.297	0.415	0.063	0.410	-0.623	0.757
	p	0.247	0.098	0.810	0.102	0.007	0.000
Incongruent RTs	*r*	0.144	0.067	0.180	0.250	-0.213	0.401
	p	0.581	0.798	0.490	0.332	0.412	0.110
Congruent Errors	*r*	0.445	0.681	-0.011	0.405	-0.646	0.488
	p	0.074	0.003	0.967	0.107	0.005	0.047
Neutral Errors	*r*	0.436	0.618	0.028	0.397	-0.628	0.614
	p	0.080	0.008	0.914	0.115	0.007	0.009
Incongruent Errors	*r*	0.545	0.725	0.114	0.492	-0.709	0.595
	p	0.024	0.001	0.662	0.045	0.001	0.012
Errors Interference[a]	*r*	0.492	0.618	0.162	0.441	-0.583	0.409
	p	0.045	0.008	0.535	0.076	0.014	0.103
Age	*r*	0.412	0.481	-0.174	0.095	-0.544	1.000
	p	0.090	0.043	0.489	0.709	0.019	

r = Pearson Bivariate Correlation *p* = 2 tailed significance N = 17

[a]RT interference scores not shown because of high error rates on incongruent trials

Table 6: Pearson Bi-Variate Correlation Values (r) and Two-Tailed t-Test p-Values for Stroop Test for 18 Bilinguals Tested in Experiment 1a

		Cross-language Intrusions	Cross-language Intrusions over TOTAL	Within Errors	Within Errors over TOTAL	TOTAL CORRECT	Age
Congruent RTs	*r*	0.146	0.119	0.172	0.251	-0.120	0.196
	p	0.563	0.638	0.496	0.315	0.634	0.436
Neutral RTs	*r*	0.312	0.332	0.262	0.498	-0.395	0.381
	p	0.207	0.179	0.293	0.036	0.105	0.119
Incongruent RTs	*r*	0.241	0.274	0.154	0.397	-0.391	0.406
	p	0.335	0.271	0.541	0.103	0.109	0.095
Congruent Errors	*r*	-0.153	-0.180	-0.114	-0.195	0.171	0.031
	p	0.545	0.476	0.653	0.438	0.498	0.902
Neutral Errors	*r*	0.011	-0.056	0.712	0.736	-0.079	0.174
	p	0.965	0.826	0.001	0.000	0.755	0.490
Incongruent Errors	*r*	0.477	0.361	0.166	0.218	-0.116	0.192
	p	0.046	0.141	0.511	0.384	0.646	0.445
Errors Interference	*r*	0.470	0.361	0.109	0.159	-0.109	0.176
	p	0.049	0.141	0.667	0.529	0.667	0.484

r = Pearson Bivariate Correlation *p* = 2 tailed significance N =18

Table 7: Means and Standard Deviations of Participant Characteristics in Experiment 1b

	Young monolinguals (n=36)		Older monolinguals (n=15)				
	M	*SD*	*M*	*SD*	F-ratio[b]	*p* value	η_p^2
Age	20.1	1.7	78.1	7.1	2185.71	<.01	0.98
Education	14.4	0.1	13.9	2.0	1.26	0.27	0.03

Table 8: Means and Standard Deviations of Response Measures in Experiment 1b

	Semantic Categories			
	Number Correct		Within Language Error Rates	
	M	*SD*	*M*	*SD*
Young monolinguals	20.3	4.3	5.9	4.7
Older monolinguals	15.7	4.4	8.4	3.9
Difference scores (OA-YA)	*-4.6**		*2.5*†	

	Letter Categories			
	Number Correct		Within Language Error Rates	
	M	*SD*	*M*	*SD*
Young monolinguals	14.7	3.9	3.8	3.6
Older monolinguals	13.0	4.0	9.1	5.7
Difference scores (OA-YA)	*-1.7*		*5.3**	

* $p < .05$, † $p < .10$

Table 9: Means and Standard Deviations of Participant Characteristics in Experiment 2

	Older bilinguals (n=10)		AD bilinguals (n=10)				
	M	*SD*	*M*	*SD*	F-ratio[b]	*p* value	η_p^2
Age	79.8	1.5	80.7	1.7	< 1	0.68	0.01
Education	12.2	2.1	13.4	2.7	1.34	0.26	0.06
Age of First Exposure to English	6.2	5.2	6.6	7.5	< 1	0.89	< .01
% English used daily	62.2	27.5	68.4	32.5	< 1	0.62	0.01
Self-rating[a] for spoken English	5.7	0.8	5.6	1.2	< 1	0.67	0.01
Self-rating[a] for spoken Spanish	5.4	1.4	4.8	1.4	< 1	0.33	0.05
Mini Mental State Exam Score	28.9	1.9	22.1	3.8	32.93	< .01	0.61

[a] Proficiency level based on self-ratings using a scale of 1-7 with 1 being "little to no knowledge" and 7 being "like a native speaker."

Table 10: Means and Standard Deviations of Response Measures in Experiment 2

	Semantic Categories											
	Number Correct				Within-language Error Rates				Cross-langauge Intrusion Rates			
	dominant		nondom		dominant		nondom		dominant		nondom	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Older bilinguals	12.5	3.1	11.1	4.8	11.9	8.5	14.2	8.9	0.7	1.5	1.3	2.4
AD bilinguals	6.6	2.6	5.9	3.1	23.7	11.9	26.2	9.9	1.3	2.7	4.2	4.4
Difference scores (AD-OA)	*-5.9*		*-5.2*		*11.8*		*12.0*		*0.6*		*2.9*	
diagnosis x dominance	$F < 1$				$F < 1$				$p = 0.09$			

	Letter Categories											
	Number Correct				Within-language Error Rates				Cross-langauge Intrusion Rates			
	dominant		nondom		dominant		nondom		dominant		nondom	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Older bilinguals	10.3	4.3	9.0	3.9	8.6	3.7	12.5	6.9	1.0	1.6	0.8	2.4
AD bilinguals	5.9	2.6	4.3	2.9	18.1	10.2	31.1	14.9	1.7	4.0	2.3	4.7
Difference scores (AD-OA)	*-4.4*		*-4.7*		*9.5*		*18.6*		*0.7*		*1.5*	
diagnosis x dominance	$F < 1$				$p = 0.17$				$p = 0.08$			

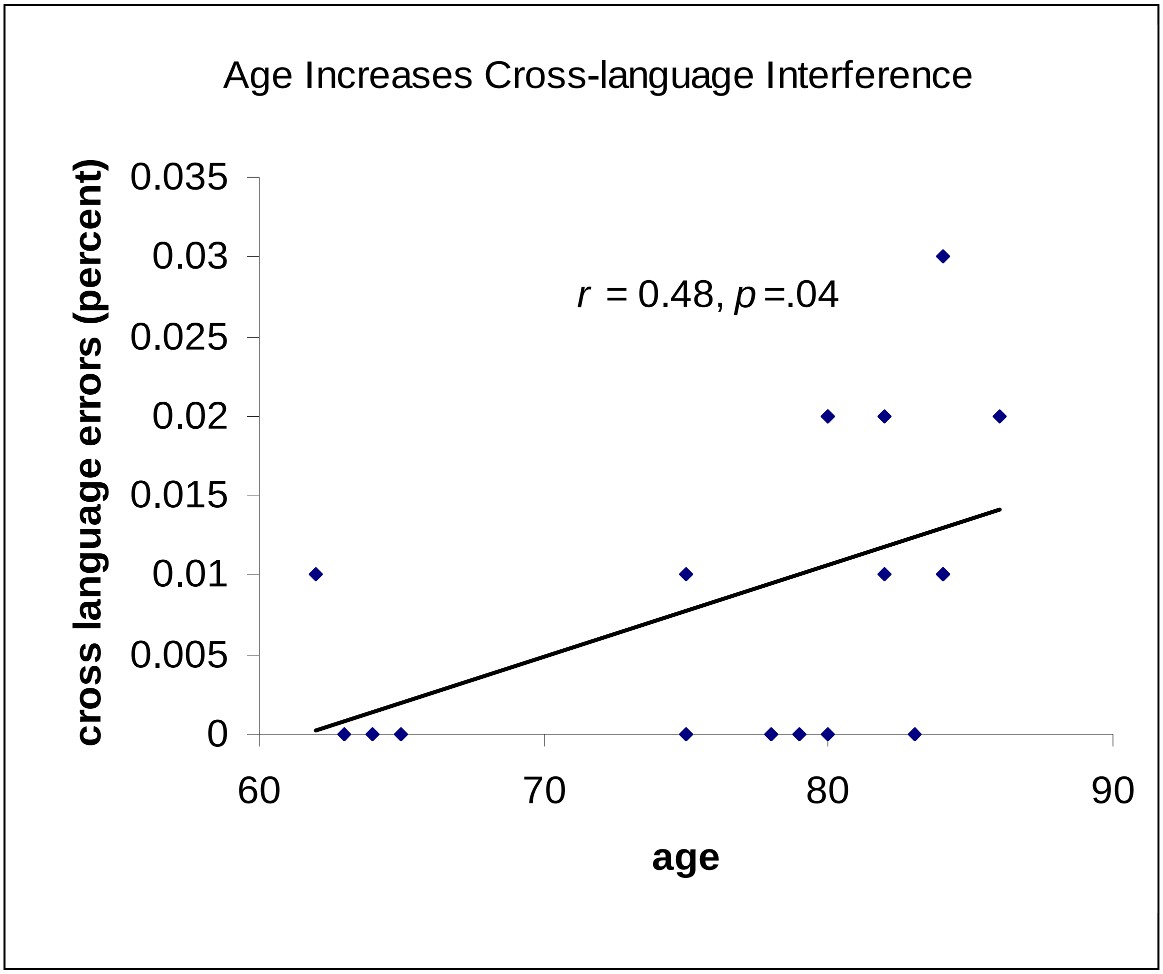

Figure 1: Age increases cross-language interference.

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