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Bilingualism, Cognition, and Successful Aging

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This dissertation aimed to answer the following questions: (1) Does bilingualism affect performance in an implicit sequence-learning task and an executive control task? (2) Specifically, do older bilinguals show increased performance measures than older monolinguals in an implicit sequence-learning task and an executive control task? (3) Are second language proficiency, language usage, and age of acquisition important factors in acquiring cognitive benefits? College-aged and older adult Spanish-English bilinguals and English monolinguals participated. With traditional analyses, young bilinguals demonstrated greater executive control than young monolinguals, but the older groups performed the same. Novel distributional analyses uncovered differences among the older groups, such that older bilinguals had better executive control than older monolinguals. Bilinguals and monolinguals performed equivalently on the implicit-sequence learning task. Second language proficiency and language usage did not affect performance on either task, but bilinguals who had been speaking two languages from a young age performed better than people who learned a second language later in life on both the implicit sequence-learning task and the executive control task. Implications are discussed.

This dissertation by Jennifer C. Romano fulfills the dissertation requirement for the doctoral degree in Applied/Experimental Psychology approved by James H. Howard, Jr., Ph.D., as Director, and by Darlene V. Howard, Ph.D., Deborah M. Clawson, Ph.D., and Rebecca L. M. Fuller, Ph.D. as Readers.

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Dedication

This dissertation and degree are dedicated to my parents, Salvatore and Josephine. Without the two of you, none of this would have been possible, nor would it have meant so much. Thank you for all your support and encouragement through the past 30 years and through this long process. I think back to the lessons of "You can achieve anything…all it takes is lots of hard work and dedication," and I think that this degree supports those lessons completely. I look forward to passing them on. Congratulations to you both. This is as much yours' as it is mine.

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1.0 Introduction

In the United States, 19.4 percent of the population, or 47 million Americans, spoke a language other than English at home in 2000, up from 15 million Americans in 1990 (US Census Bureau, 2000). Fifty-five percent of those people reported that they spoke English "very well." Among those, 11 million spoke Spanish, making it the second most spoken language in the U.S. The nation will be more racially and ethnically diverse by the year 2040 when minorities are expected to be the majority (US Census Bureau, 2008). Furthermore, by 2030, when all baby boomers will be 65 and older, approximately one in five U.S. residents is expected to be 65 and older. By 2050, the number of people in the U.S. who are 65 and older will be more than double the number of people who were 65 and older in 2008, and a majority of them will be bilingual.

There has been a significant increase in bilingualism in children in the U.S. (Gutierrez-Clellen, Calderon & Weismer, 2004) likely due in part to the growth of the minority, and in the world, bilingualism is often the rule rather than the exception (Gollan, Montoya, Fennema-Notestine & Morris, 2005). Bilingualism in young age has been shown to lead to many cognitive benefits, such as better verbal skills, goal-attaining strategies, and attentional skills. See Appendix A for a complete review. As most earlier work has investigated the cognitive benefits of bilingualism in children and young adults, the purpose of the present study was to investigate the cognitive benefits in older adults, and in particular to investigate bilingual effects on implicit learning, an area that has been largely overlooked.

Ianco-Worall (1972) found that bilingual children reach semantic maturity 2-3 years earlier than their monolingual peers, and argued that this is because they experience two different symbols for almost every object in their environment, thus enabling them to perceive relationships between words in terms of symbolic rather than acoustic properties at a younger age than monolinguals. Similarly, Ben-Zeev (1977) and Cromdal (1999) have suggested that bilinguals have a better understanding of syntactic structure than monolinguals, which enables them to swap arbitrary names for objects, a skill that requires one to ignore semantic meanings and rules that govern the usual relationships among words. Bochner (1996) found that bilingual students are more inherently interested in what they learn and are more inclined to regard learning and education as a mode to compete and achieve and as a source of positive self-esteem, compared to monolinguals. Bilinguals also use more appropriate strategies to attain their goals of acquiring new knowledge compared to monolinguals (Bochner, 1996). Additionally, Ben Zeev (1977) found that bilinguals have an inclination to search for structure in perceptual situations and to reorganize perceptions in response to feedback.

Bilingualism has been shown to have beneficial effects on non-linguistic cognitive functioning. Bilinguals recall more in both semantic and episodic memory tests (Kormi-Nouri, Moniri & Nilsson, 2003; Kormi-Nouri, Shojaei, Moniri, Gholami, Maradi, Akbari-Zardkhaneh & Nilsson, 2008) and have better sociolinguistic awareness, which enhances their theory of mind, compared to monolinguals (Goetz, 2003). Bilingual children's control of processing, an aspect of selective attention, is more fully developed than it is in their monolingual counterparts, likely due to extended practice in switching between languages (Bialystok and Majumber, 1998). Bilinguals in essence become experts in executive control, enabling them to quickly distinguish between relevant and irrelevant information, leading to enhanced processing of non-linguistic tasks requiring control of attention compared to monolinguals (Bialystok, 1999; Bialystok, Craik, Klein & Viswanathan, 2004; Bialystok & Majumber, 1998; Carlson & Meltzoff, 2008; Tzelgov, Henik & Leiser, 1990). In addition to the abovementioned work with children and young adults, work with older adults has suggested that older bilinguals have better executive control than older monolinguals (Bialystok et al., 2004; Bialystok, Craik & Ryan, 2006; Bialystok, Craik & Luk, 2008), as well as a four-year delay of dementia symptoms compared to their monolingual counterparts (Bialystok, Craik & Freedman, 2007). Bilingualism has also been shown to potentially be a determinant of cognitive state in old age (Kavé, Eyal, Shorek & Cohen-Mansfield, 2008). See Appendix A for a detailed review of the aforementioned studies.

Bialystok et al. (2004), Bialystok et al. (2006) and Bialystok et al. (2008) demonstrated enhanced executive control in middle-aged and older adult bilinguals. Bilinguals and monolinguals performed the Simon task, a task that assesses the ability to ignore irrelevant spatial information and improve performance on relevant non-spatial information. In the Simon task, two different colored stimuli are presented on either the right or left side of the screen and each color is associated with a response key: one on the right side of the keyboard and one on the left. On congruent trials, the response key side is the same as the side the associated colored square appears on, and on incongruent trials, the colored square appears on the opposite side of the screen as the associated response key. Irrelevant location information typically results in longer reaction times for incongruent trials. This longer reaction time for incongruent trials minus the shorter reaction time for congruent trials is referred to as the "Simon Effect." Bialystok et al. (2004), Bialystok et al. (2006), and Bialystok et al. (2008) found young, middle-aged, and older adult bilinguals showed a reduced Simon Effect compared to monolinguals of the same age, implying that the lifelong experience of managing two competing languages reduces the natural age-related decline in inhibitory processing efficiency.

Inhibitory processing has implications in other areas of cognition. For example, implicit-sequence learning involves executive control and inhibition. To do well in implicit sequence learning tasks, individuals must unconsciously ignore irrelevant, unpredictable stimuli in order to learn predictable stimuli. Implicit learning is involved in acquiring a new language, learning motor skills, and other tasks that require shifts of attention (Cherry & Stadler, 1995; Conway & Christiansen, 2001; Jimenez & Mendez, 1999). No study to date has examined the effects of bilingualism on implicit learning.

Implicit learning can be examined by exposing people to subtle regularities (Reber, 1993) and is said to occur if individuals improve in the speed and/or accuracy of responses to predictable versus non-predictable events, and yet they are unable to describe such regularities. One form of implicit learning involves learning sequential structure (e.g., Howard & Howard, 1997; Nissen & Bullemer, 1987). In the Alternating Serial Reaction Time task (ASRTT) (Howard & Howard, 1997), people respond to a series of stimuli, such as circles changing from white to black, on a computer screen by pressing corresponding response keys. Alternate stimuli follow a predetermined pattern, and the remaining stimuli are selected randomly. For example, the pattern 1234 (representing four horizontally-arranged circles on the screen, where 1 stands for the left-most position and 4 stands for the right-most) would be presented as 1r2r3r4r, where r represents a randomly chosen position of one of the four. The simplest predictive relationship in the sequence is between non-adjacent events on pattern trials (trial n minus 2 predicts the stimulus on pattern trial n).

Because predictable (pattern) and unpredictable (random) events alternate in the ASRTT, some successive runs of three events or *triplets* occur more often than others. For example, for the sequence 4r3r1r2r, the triplets 433 and 132 occur often (on pattern trials, and sometimes by chance, on random trials), whereas the triplets 134 and 312 occur rarely (on random trials only). The former are referred to as *high-frequency* triplets and the latter as *low-frequency* triplets. Participants are not informed of any pattern, and learning is measured by the difference in performance (reaction time and/or accuracy) on the high-frequency versus the low-frequency triplets (cf. D.V. Howard, Howard, Japikse, DiYanni, Thompson & Somberg, 2004). See Appendix B for a detailed review of implicit sequence-learning literature.

The present study examines the effects of bilingualism on executive control and implicit sequence learning. Previous research on implicit learning using the ASRTT has demonstrated that while both young and older adults learn sequence-specific skills, older adults show less learning compared to young adults (for example, see Howard & Howard, 1997). Because bilinguals are in essence experts at executive control, shifting attention, and inhibiting irrelevant stimuli, all of which are involved in the ASRTT, it is hypothesized that this expertise will facilitate learning new sequential regularities, and thus lead to more implicit sequence learning, compared to monolinguals. Older bilinguals are expected to show less age-related cognitive decline on implicit sequence learning, compared to older monolinguals. It is also expected that results will replicate previous findings that bilinguals have better executive control, and thus they will perform better on the Simon task compared to monolinguals (Bialystok et al., 2004; Bialystok et al., 2006; Bialystok et al., 2008). Since language learning exercises the procedural system and involves executive control, and executive control is involved in performance on the ASRTT, it is expected that performance on the Simon task will correlate with performance on the ASRTT. In other words, individuals who have excellent executive control will perform optimally on the Simon task *as well as* the ASRTT, and individuals who have poor executive control will perform poorly on both the Simon task and the ASRTT.

Proficiency, language usage, and age of acquisition will also be examined in the present study. As previous results have been inconsistent, there are no pre-conceived hypotheses regarding which factors are necessary to reap cognitive benefits. This dissertation aims to clarify the importance of these factors.

To summarize, this dissertation aims to answer the following questions:

1. Does bilingualism affect performance in an implicit sequence-task and an executive control task?

2. Specifically, do older bilinguals show increased performance measures than older monolinguals in an implicit sequence-learning task and an executive control task?

3. Are second language proficiency, language usage, and age of acquisition important factors in acquiring cognitive benefits?

2.0 Method

2.1 Participants

Young participants were recruited through an undergraduate psychology participant pool at The Catholic University of America. Older participants were recruited from the community via advertisements in two local newspapers: *The Senior Beacon,* and *The Washington Hispanic*. Twenty-five young Spanish-English bilinguals (mean age = 20.24; 10 male), 22 young English monolinguals (mean age = 20.09; eight male), 19 older Spanish-English bilinguals (mean age = 71.37; three male) and 21 older English monolinguals (mean age = 76.86; 10 male) participated. Questions to define bilingualism were asked when people were initially recruited. Based on these questions, bilinguals were fluent in reading, writing, speaking, and listening in English and Spanish; bilinguals spoke both languages regularly, were able to switch between the two at will, and had been speaking both languages since childhood.

When participants came to the lab to participate in the study, they were given a questionnaire designed to quantitatively define bilingualism[1]. (See Appendix C for the Bilingualism Questionnaire.) The questionnaire began with introductory open-ended questions about how and when people acquired their second language and how often they spoke both languages and then was arranged into four parts: Parts 1 and 2 examined

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[1] The questionnaire, developed by the author, correlated with the Woodcock-Muñoz Language Survey-Revised (WMLS-R) (see Section 2.2.4.2 of this paper), as measured from the scores of the 16 older bilinguals that answered both questionnaires, $r = 0.60$, $p < 0.01$. The WMLS-R is a test that measures oral language proficiency in speakers of English as a second language. The paper-based Bilingualism questionnaire that participants answered was shorter to administer than the WMLS-R (approximately 5 minutes vs. approximately 20 minutes), and both bilinguals and monolinguals answered it. As half of the tasks on the WMLS-R are administered in Spanish, only bilinguals could answer them. For this study, a questionnaire that could be administered to both bilinguals and monolinguals was necessary.

participants' language ability in the first language and Parts 3 and 4 examined participants' language ability in their second language. Parts 1 and 3 asked questions in which participants chose the option that best described their ability for their first language (Part 1) and for their second language (Part 3). For example, for listening comprehension, participants chose an option ranging from "I can understand a limited number of high frequency words and common conversational set expressions such as 'How are you?' or 'My name is…'" to "I can understand everything at normal speed like a native speaker." Using a Likert scale, Part 2 (for first language) and Part 4 (for second language) asked participants to select how well they could do a specific thing, such as understand a short message on an answering machine. Responses ranged from "I cannot do it at all" to "I can do it comfortably." For Parts 1 and 3, the lowest value for each question (the first option) was 1 and the highest value (the sixth option) was 6, for a minimum score of 5 and a maximum score of 30. For Parts 2 and 4, the lowest value for each question was 1 and the highest was 5, for a minimum score of 40 and a maximum score of 200. As all participants were fluent in their first language (and scored optimally on the sections examining first language ability), bilingualism scores were calculated based on responses to the sections examining second language ability. A mean score was calculated separately for Parts 3 and 4 and then the following formula was used for each person: [(Part 3 mean x 4) + (Part 4 mean)] / 2.

A mean and standard deviation bilingualism score was calculated for each group. See Table 1 for scores. Participants in each group with scores greater than or less than two deviations from the mean were excluded. This exclusion was necessary as a wide range of people with bilingual experiences (i.e., monolinguals with some experience with

Table 1. ***Mean (and Standard Deviation) Bilingualism Scores***

	Young adults		Older adults	
	Bilinguals	Monolinguals	Bilinguals	Monolinguals
Bilingualism score	32.31 (4.14)	16.87 (7.03)	33.15 (5.45)	9.71 (3.86)
N	25	55	19	21

a second language or bilinguals who had experience with a second language but were not "bilingual") responded to the advertisements, and the goal was to test balanced bilinguals and "true" monolinguals. Two people were excluded from the young bilingual group, one person was excluded from the older bilingual group, and one person was excluded from the older monolingual group (bilingualism scores: 22.05, 23.85, 13.20, and 17.60, respectively). Two additional people were excluded from the young monolingual group as one did not complete the Bilingualism Questionnaire and the other's first language was Indonesian.

Table 2. ***Mean (and Ranges of) Bilingualism Demographics***

	Young bilinguals	Older bilinguals
N	23	18
Years bilingual	15.04 (3-24)	53.83 (36-70)
Age of acquisition	5.65 (2-18)	18.00 (2-45)
First language	14 Spanish / 9 English	11 Spanish / 7 English
Language most used	15 Spanish / 8 English	6 Spanish / 12 English

For the final analyses reported here, there were 81 participants divided among 23 young bilinguals (mean age = 20.22; nine male), 20 young monolinguals (mean age = 19.65; six male), 18 older bilinguals (mean age = 71.83; three male), and 20 older monolinguals (mean age = 76.60; nine male). Young bilinguals had been speaking two languages for an average of 15.04 years (*SD* = 5.15), and older bilinguals had been speaking two languages for an average of 53.83 years (*SD* = 11.82). Thirty-nine percent of the young bilinguals (nine participants) spoke English as their first language, and 39 percent of the older bilinguals (seven participants) spoke English as their first language. The average age that the young bilinguals learned their second language was 5.65 years (*SD* = 5.26), and the average age that the older bilinguals learned their second language was 18 years (*SD* = 11.98). See Table 2 for the ranges for each group. There was no difference in mean age between the young bilinguals and the young monolinguals, but older monolinguals were significantly older than the older bilinguals, $F(1, 36) = 5.89$, $p < 0.05$.

The number of years of formal education was compared across groups. There was no difference in mean education years between the young bilinguals, 13.61 years (*SD* = 1.27) and the young monolinguals, 12.80 years (*SD* = 1.54), or between the older bilinguals, 16.72 years (*SD* = 3.48) and the older monolinguals, 16.10 years (*SD* = 2.85). However, the older participants had significantly more years of education that the younger participants, $F(1, 79) = 35.35$, $p < 0.0001$.

2.2 Tasks

Participants completed two hours of testing on each of two days within the same week. Upon reading and signing an informed consent form approved by Catholic University's IRB, individuals completed biographical, health screening, and bilingualism questionnaires. On each day, they performed tasks designed to examine executive control or implicit sequence learning. In order to define the demographics of the population tested, participants completed a battery of standardized neuropsychological tasks examining working memory, short-term memory, visual-motor speed and coordination, and full-scale intelligence. Executive control was tested with the Simon task (Bialystok et al., 2004), and implicit sequence learning was assessed with the ASRTT (Howard & Howard, 1997). Working memory tasks consisted of forward and backward Spatial Span for visuo-spatial working memory (Lezak, Howieson & Loring, 2004; WMS-III, Wechsler Memory Scale, 3rd edition, Wechsler, 1997b); Operation Span, Letter-Number Sequencing, and backward Digit Span for auditory working memory (Lezak et al., 2004; Turner & Engle, 1989; WAIS-III, Wechsler Adult Intelligent Scale, 3rd edition, Wechsler, 1997a, Wechsler, 1997b). Short-term memory tasks consisted of forward Digit Span, Consonant Trigrams, and Digit-Symbol Pairing and Free Recall (Lezak et al., 2004; Peterson & Peterson, 1959; Wechsler, 1997a). Visual-motor speed and coordination was assessed with Digit-Symbol Coding (Lezak et al., 2004; Wechsler, 1997a). Participants completed the Vocabulary and Matrix-Reasoning subtests of the Wechsler Abbreviated Scale of Intelligence (WASI), which taken together give a score for full-scale intelligence (Lezak et al., 2004; WASI, Wechsler Abbreviated Scale of

Intelligence, Wechsler, 1999). In addition, 16 older bilinguals completed the Woodcock-Muñoz Language Survey-Revised (WMLS-R) Test 1 and Test 3 in both English and Spanish (Woodcock, Muñoz-Sandoval, Ruef & Alvarado, 2005) to assess Spanish-English bilingualism and to provide validation for the bilingualism questionnaire used in this study. All participants completed the tasks in the following order:

Day 1	Day 2
Biographical/demographic questionnaire	WMLS-R (older bilinguals only)
Simon task	Digit span (forward, backward)
ASRT task	Spatial span (forward, backward)
	Letter-number sequencing
	Consonant trigrams
	Digit symbol coding
	Digit symbol pairing
	Digit symbol free recall
	Vocabulary
	Matrix reasoning
	Operation span
	Bilingualism questionnaire

2.2.1 Executive Control

Simon task. Stimuli were presented on a desktop computer with a 38 cm monitor. Each trial began with a fixation cross in the center of the screen that remained visible for 800 ms and was followed by a 250 ms blank interval. Following the interval, a red or blue square appeared either on the left or the right side of the screen. Participants were instructed to press a specified left key on the keyboard (marked “X”) when they saw the blue square and a specified right key on the keyboard (marked “O”) when they saw the red square. The timing began with the onset of the stimulus, and the (correct or incorrect) response terminated the stimulus. Following a 500 ms blank interval, the next trial began. The stimulus remained on the screen for 1,000 ms if there was no response. The experiment began with four practice trials, and participants had to successfully complete all four trials to proceed to the experimental trials. If a mistake was made, participants were given additional practice until all four trials were completed without error, but only two participants needed to repeat the practice set to achieve error-free performance. The 240 experimental trials were presented in a randomized order. Approximately half of the trials were congruent (stimulus appeared on the same side of the screen as the response key), and half were incongruent (stimulus appeared on the opposite side of the screen as the response key).

2.2.2 Implicit Sequence Learning

Alternating Serial Reaction Time Task (ASRTT). Stimuli were presented on a desktop computer with a 38 cm monitor. Participants were instructed to place their middle and index fingers of their left hand on the keys marked “z” and “x” (on the left side of the keyboard), and the middle and index fingers of their right hand on the keys marked “.” and “/” (on the right side of the keyboard). The keys corresponded to four equally-spaced circles on the computer screen. On each trial, one circle became black and remained so until the participant pressed the key corresponding to the target. After a delay of 120 ms, the next target appeared.

Six patterns were counterbalanced across participants: 1r2r3r4r, 1r2r4r3r, 1r3r2r4r, 1r3r4r2r, 1r4r2r3r, and 1r4r3r2r. The numbers 1, 2, 3, and 4 correspond to the circles on the screen, from left to right respectively, and r indicates a randomly selected event. The patterns were randomized for all participants in each group, so that approximately 14 participants received each pattern.

Participants completed 10 practice trials consisting entirely of random events. They then completed eight epochs consisting of 20 blocks of 80 trials each. Each block had 10 repetitions of the eight-element pattern. The computer guided participants to an accuracy level of about 92 percent by asking them to focus more on speed or accuracy. If accuracy for a block was above 93 percent, the computer instructed participants to focus more on speed; if accuracy was below 91 percent, the computer instructed participants to focus more on accuracy. Upon completion, participants were asked questions regarding strategy to improve performance as in previous studies with this task (e.g., D.V. Howard et al., 2004).

To further examine explicit awareness, after learning, participants performed a card-sorting task in which they sorted 7.6 cm by 12.7 cm white index cards that displayed three rows of four circles. Each line represented the four circles seen on the screen throughout the experiment. One circle on each line was black, so that each card represented three successive trials (a triplet), some of which had occurred frequently during the task and some of which had occurred rarely. Participants placed each card into one of two piles, labeled “Frequent” and “Rare,” depending on how often they believed the triplet sequence had occurred during the ASRTT.

2.2.3 Standardized Neuropsychological Tasks

2.2.3.1 Working Memory. For the Spatial Span task, stimuli consisted of an array of wooden blocks attached to a wooden base. The blocks were randomly arranged and had numbers printed on them on one side. The experimenter and the participant sat at a table facing each other and the apparatus was placed on the table between them so that the side with the numbers faced the experimenter and was not visible to the participant. There were two conditions: forward and backward. In each, following a practice trial, the experimenter tapped a series of blocks, and participants were required to tap the same blocks in the same order (forward condition) or in reverse order (backward condition). Sequences increased by one block, every other trial. The test began with two sets of a sequence of two blocks, then increased to two sets of three blocks, then increased to two sets of four blocks, etc., as long as the participant correctly responded to one of the two sets in a series. The test ended when the participant incorrectly responded to both sets in a given sequence length. For both the forward and backward conditions, the score was the total number of correctly recalled sequence lists.

Similar to backward Spatial Span, backward Digit Span stimuli were items that participants were required to verbally recall in reverse order. Following three practice trials, the experimenter began the test with two sets of a sequence of two numbers, then increased to two sets of three numbers, etc., until the participant incorrectly responded to both sets in a given sequence length. The score was the total amount of correctly recalled sequences.

For the Operation Span task, stimuli were presented on a desktop computer with a 38 cm monitor. Participants were required to solve a series of math problems while trying to remember a set of unrelated words. The math problem-word pairs were presented one at a time. For each trial, the participant read the problem aloud, solved it, stated whether the answer presented on the screen was correct or not, and then read the word aloud. Immediately after the participant read the word aloud, the experimenter pressed the space bar, and then the next trial began. Set size ranged from two items to five items, and then three question marks appeared in the center of the screen. Participants then wrote down as many words as they could recall, in the same order that they were presented. Participants were instructed to leave a blank space if they could not recall a word. Three trials of each list-length set were presented randomly, so that a trial of two items could precede a trial of five items which could precede a trial of three items, etc. The score was the percentage of correctly recalled words, in the same order and position as they were presented. Arithmetic answers did not have to be correct for the words to be counted as correct, even though all participants achieved very high accuracy on the math problems.

Stimuli for the Letter-Number Sequencing task were items that participants were required to verbally recall. The experimenter verbally presented a sequence of intermixed numbers and letters, and the participant was required to recall first the numbers in ascending order, then the letters in alphabetical order. The experimenter began with sequences two items long (a number and a letter) and increased set size until a participant incorrectly recalled three sequences in a set. The score was the total number of correctly recalled sequences.

2.2.3.2 Visual-Motor Speed and Coordination. The Digit-Symbol Coding task was printed on a piece of white paper. Stimuli consisted of seven rows containing 20 empty squares each, paired with randomly assigned numbers from one to nine, which were in squares located above the empty squares. At the top of the paper was a printed key that paired each number with an arbitrary nonsense symbol. Following a practice trial of 10 items, participants were required to fill in as many symbols as possible while being timed for 120 seconds. The score was the number of correctly filled-in squares.

2.2.3.3 Short-Term Memory. For the forward Digit Span task, stimuli were items that participants were required to verbally recall in the exact order as administered. Following three practice trials, the experimenter began the test with two sets of a sequence of two numbers, then increased to two sets of three numbers, then increased to two sets of four numbers, etc., until the participant incorrectly responded to both sets in a given sequence length. The score was the total amount of correctly recalled sequences.

For the Consonant Trigrams task, stimuli were items that participants were required to verbally recall in order following a distracter task. Following two practice trials, the experimenter verbally presented the participant with a sequence of three letters, followed by a number. Participants were required to count backward from the given number until instructed to recall the given letters. For example, the experimenter said, “NDJ, 75,” and the participant counted backward from 75, “75, 74, 73, 72…” until the experimenter said, “Recall.” Then the participant recalled, “NDJ.” Delay (time spent counting backward) was randomized among 12 test items for zero, three, nine or 18 seconds. The score was the total amount of correctly recalled letter combinations out of 12.

The Digit-Symbol Pairing task followed Digit-Symbol Coding. Participants were presented with a piece of white paper that had two rows of empty squares, paired with the numbers one through nine, which were located in squares above the empty squares. Participants were required to recall the symbols that were paired with each number in the Digit-Symbol Coding task and record them in the correct boxes. The score was the total number of correctly recalled digit-symbol pairs.

Following Digit-Symbol Coding and Digit-Symbol Pairing, participants completed the Digit-Symbol Free Recall task. Participants were given a blank sheet of paper and were required to recall as many symbols as possible from the Digit-Symbol Coding task. The free recall task was not timed. The score was the total amount of correctly recalled symbols out of nine.

2.2.3.4 Full-Scale Intelligence. Stimuli consisted of two subtests of the WASI: the Vocabulary test and the Matrix Reasoning test. The raw scores of the two subtests were converted to age-scaled scores then added together and converted into a full-scale intelligence (FSIQ) score by using pre-defined tables in the WASI manual.

For the Vocabulary task, stimuli consisted of a list of 42 words that the experimenter asked the participant to define. Words increased in difficulty, and the test continued until the participant failed at five consecutive words. Each item was given a score of one or two based on accuracy, precision, and aptness, according to definitions in the WASI manual. The score was the total combined score of all test items. This test measures verbal functions but can also be combined with the Matrix Reasoning score to derive a FSIQ score, as previously mentioned.

For the Matrix Reasoning task, the stimulus consisted of a booklet that presented 35 increasingly difficult visual pattern completion problems. The participant viewed each page and selected the option from the bottom of the page that completed the visual pattern problem. The test continued until the participant incorrectly chose four consecutive items or four items in five consecutive problems. The score was the total number of correctly chosen items. This test measures concept formation and reasoning but can also be combined with the Vocabulary score to derive a FSIQ score, as previously mentioned.

2.2.4 Spanish-English Bilingualism

2.2.4.1 Woodcock-Muñoz Language Survey-Revised (WMLS-R). Stimuli consisted of booklets that contained pictures of common objects. First, participants completed Test 1: Picture Vocabulary and Test 3: Letter-Word Identification in English, then they completed both tests in Spanish. For Test 1, the experimenter showed the participant pictures and asked the participant to name (in English or Spanish) the object. For Test 3, the experimenter showed the participant words and asked the participant to say the word (in English or Spanish) aloud. The English tests were administered in English, and the Spanish tests were administered in Spanish. The score for each test, for each language, was the total number of correctly named items. The mean scores are reported in Table 3. This test measures proficiency in oral language in speakers of English as a second language, but for this study it was used to validate the Bilingualism Questionnaire. See the next section for details about the questionnaire.

Table 3. ***Mean Scores (and Standard Deviation) for Bilingualism Tasks by Age and Language Group***

	WMLS-R English		WMLS-R Spanish			
Group	Picture vocabulary	Letter-word identification	Picture vocabulary	Letter-word identification	WMLS-R mean	Bilingualism questionnaire
Young monolingual	-	-	-	-	-	15.64 (6.08)
Young bilingual	-	-	-	-	-	33.12 (3.16)
Older monolingual	-	-	-	-	-	9.31 (3.50)
Older bilingual	42.86 (5.19)	72.43 (2.76)	45.56 (2.87)	71.44 (2.78)	58.08 (2.01)	34.26 (2.59)

2.2.4.2 Bilingualism Questionnaire. As previously mentioned in Section 2.1 of this paper, the stimulus was on a piece of paper and participants recorded answers to each item. (See Appendix C for the full questionnaire.) The questionnaire was arranged into four parts that examined participants' first and second language abilities. In Parts 1 and 3, participants chose the options that best described various abilities. In Parts 2 and 4, participants selected how well they could do a specific activity, such as understand a short message on an answering machine. Scores were calculated based on responses to Parts 3 and 4, which were for participants' second language only. A mean score was calculated separately for Parts 3 and 4 and then the following formula was used for each person: [(Part 3 mean x 4) + (Part 4 mean)] / 2. Mean scores for each group are reported in the right-most column of Table 3.

The relationship between the WMLS-R and the Bilingualism Questionnaire was examined. As only the Spanish scores from the questionnaire were used in this study, first only the Spanish WMLS-R scores were examined. Then the mean scores of both the Spanish and English WMLS-R were examined. As shown in Table 4, results suggest that the score for the WMLS-R is related to the score for the Bilingualism Questionnaire (r = 0.60, $p < 0.01$; $r = 0.58$, $p < 0.05$, Spanish version only and mean Spanish and English versions, respectively). This analysis suggests that the Bilingualism Questionnaire is a valid indicator of Bilingualism.

Table 4. ***Correlations Between the WMLS-R and the Bilingualism Questionnaire***

Measure	Bilingualism questionnaire
1. Bilingualism questionnaire	-
2. Spanish WMLS-R	.600*
3. Spanish and English WMLS-R mean	.579**

Note: $n = 16$. * $p < 0.01$. ** $p < 0.05$.
WMLS-R = Woodcock-Muñoz Language Survey-Revised.

Bilingualism scores were submitted to a 2 x 2 (age group x language group) ANOVA. There was a main effect of age group, such that young adults had higher bilingual scores than older adults (mean for young adults: 24.99; mean for older adults: 21.13), F (1, 77) = 8.21, $p < 0.01$. There was a main effect of language group, such that bilinguals' scores were higher than monolinguals' scores (mean for bilinguals: 33.62; mean for monolinguals: 12.48), F (1, 77) = 549.24, $p < 0.0001$, and there was an interaction, F (1, 77) = 17.03, $p < 0.0001$, demonstrating a greater difference between the older bilinguals and older monolinguals compared to the young groups. When young and older adults were examined separately, for both age groups, bilinguals' scores were significantly higher than the monolinguals, F (1, 41) = 145.56, $p < 0.0001$; F (1, 36) = 611.06, $p < 0.0001$, young and older adults, respectively. See Figure 1 for bilingualism scores by age group and language group.

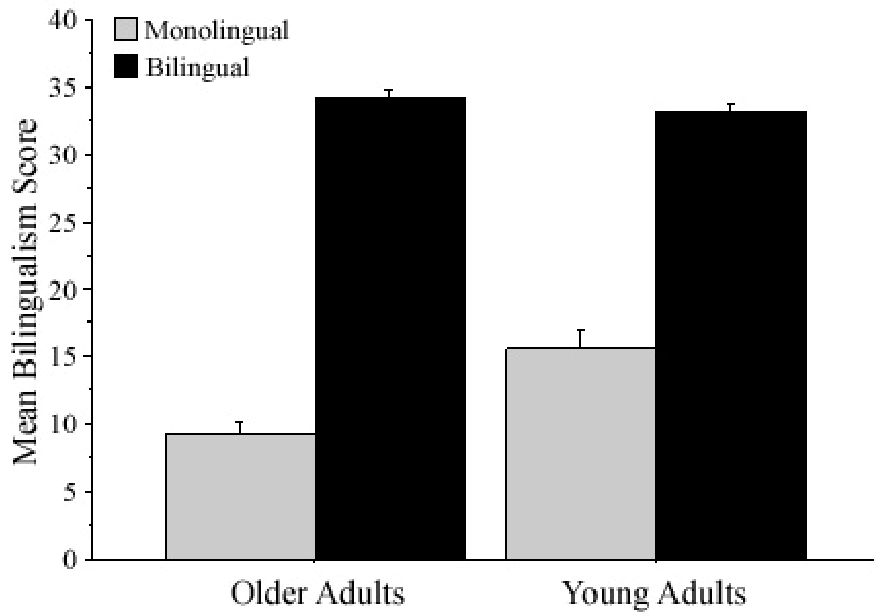

Figure 1. ***Bilingualism scores by age group and language group.***

3.0 Results and Discussion

3.1 Executive Control on the Simon Task

Due to technical problems, the Simon data for four participants (one older monolingual, one older bilingual, two young monolinguals) were not stored on the computer. In addition, data from two young participants were discarded due to extremely high error rates (71% and 57% in the congruent condition).

3.1.1. Overall Performance

The mean accuracy for all groups was high- at or above 94%. Table 5 displays the mean accuracy for all groups by age group and language group. Results were submitted to a mixed-design 2 x 2 x 2 (age group x language group x trial type) ANOVA, with repeated measures on the trial-type factor. There was a main effect of age group, such that older adults were more accurate across congruent and incongruent trials than young adults, F (1, 71) = 10.65, $p < 0.01$, but there was no main effect of language group, F (1, 71) = 2.75, *ns*, indicating that overall, bilingualism did not influence accuracy, and there was no age group x language group interaction, F (1, 71) = 2.00, *ns*. There was a main effect of trial type, F (1, 71) = 68.00, $p < 0.0001$, such that the congruent trials were more accurate than incongruent trials when averaged over the four groups.

The mean reaction times (RTs) for correct trials by age group and language group are shown in Figure 2. Results were submitted to a mixed-design 2 x 2 x 2 (age group x language group x trial type) ANOVA, with repeated measures on the trial-type factor. There was a main effect of age group, such that older adults were slower than young adults, F (1, 71) = 36.54, $p < 0.0001$, but there was no main effect of language group, F (1, 71) = 1.46, *ns*, indicating that overall, bilingualism did not influence RT, and there was no age group x language group interaction, F (1, 71) = 0.68, *ns*. There was a main effect of trial type, F (1, 71) = 103.23, $p < 0.0001$, such that the incongruent trials were slower than congruent trials when averaged over the four groups, indicating that overall, people revealed a Simon Effect.

Table 5. Mean (and Standard Deviation) Accuracy for All Groups on the Simon Task

Young adults		Older adults	
Bilinguals	Monolinguals	Bilinguals	Monolinguals
0.96 (.038)	0.94 (.048)	0.97 (.039)	0.97 (.027)

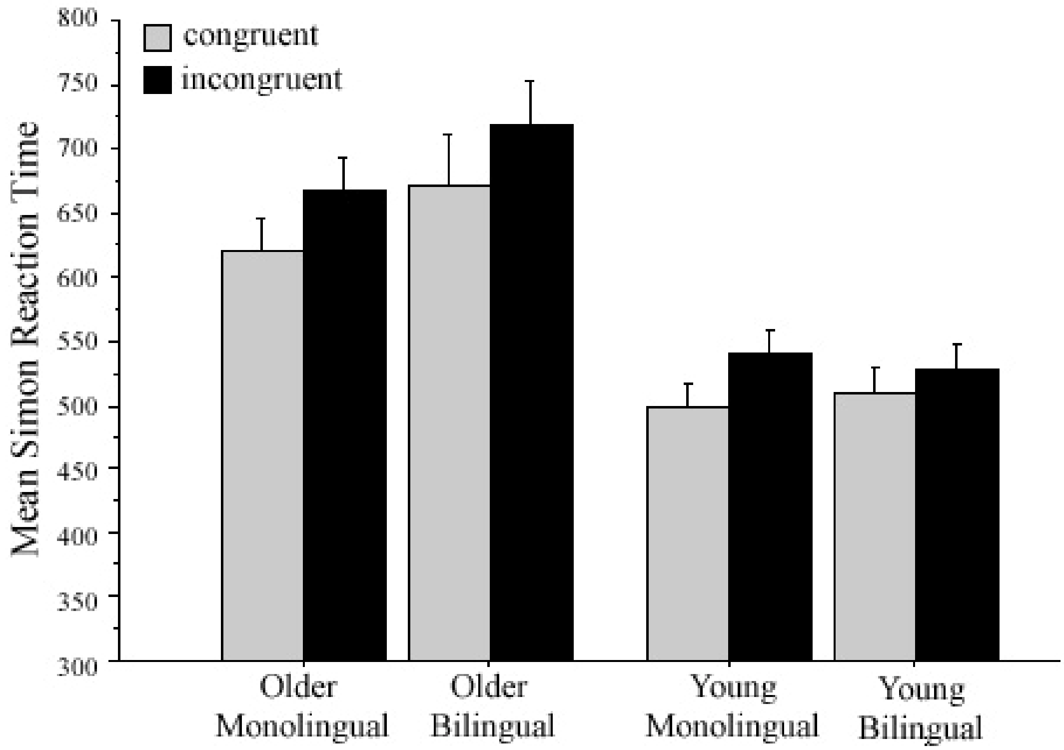

Figure 2. ***Simon reaction time (RT) scores by age group and language group.***

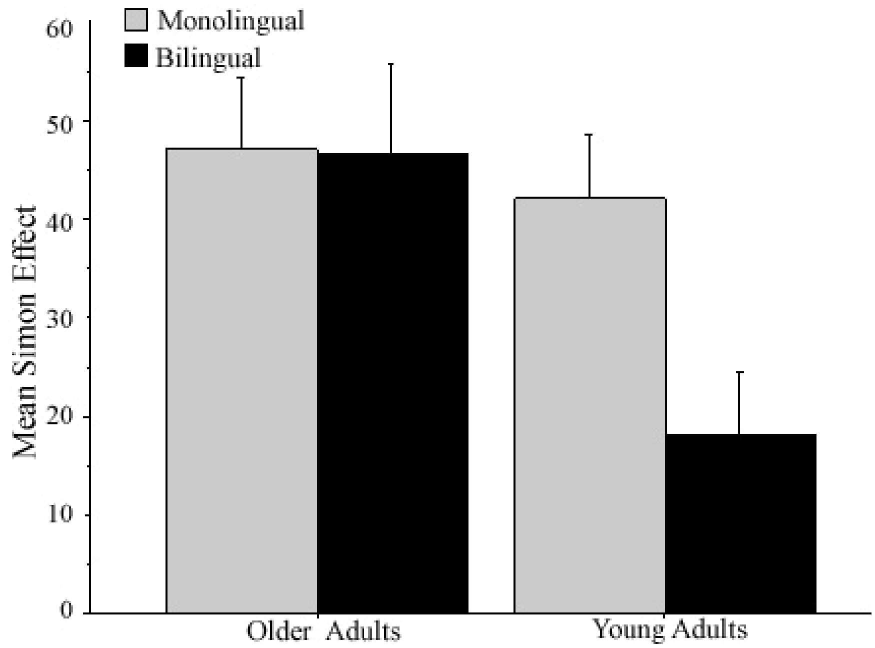

Figure 3. ***Simon Effect scores by age group and language group.***

The Simon Effect (incongruent trial minus congruent trials) can be more clearly seen in Figure 3. The mean Simon Effect was 18.14 ms (*SD* = 30.49 ms) for young bilinguals, 42.02 ms (*SD* = 27.91 ms) for young monolinguals, 46.51 ms (*SD* = 38.17 ms) for older bilinguals and 47.06 ms (*SD* = 32.20 ms) for older monolinguals. Single sample *t*-tests confirmed that each Simon Effect score was significantly above zero, t (21) = 2.55, p = 0.02, t (16) = 6.29, p < 0.0001, t (16) = 5.02, p = 0.0001, t (18) = 6.37, p < 0.0001, young bilinguals, young monolinguals, older bilinguals, older monolinguals, respectively. A 2 x 2 (age group x language group) ANOVA revealed a main effect of age group, F (1, 71) = 7.00, p = 0.01, indicating a greater Simon Effect for older adults compared to young adults, with older adults revealing slower RT on incongruent trials than congruent trials. The main effect of language group was not significant, F (1, 71) = 2.67, p = 0.11, indicating no difference in Simon Effect for monolinguals compared to bilinguals, and there was no age group x language group interaction, F (1, 71) = 2.43, *ns*.

Consistent with previous research (cf. Bialystok et al., 2004; Van der Lubbe & Verleger, 2002), overall, older adults were slower than young adults on the Simon task and showed greater interference, and overall, people responded slower to incongruent trials than congruent trials. However, in this study, bilingualism did not have a significant effect on performance: there was no difference in Simon Effect for monolinguals compared to bilinguals. The lack of a language group effect and a three-way language group x age group x trial type interaction is likely a reflection of large variance, and thus, low power and/or large individual differences. This is discussed further in the next section.

Since a prediction in this study was that bilinguals would demonstrate better performance and thus a smaller Simon Effect, and since the figures appear to suggest a bilingual advantage for young adults and not older adults, planned comparisons were carried out on each age group to investigate the Simon Effect further. Post-hoc two-tailed *t*-tests confirmed a difference for the young adults, such that the young bilinguals demonstrated a smaller Simon Effect than the young monolinguals, t (1, 36) = 2.49, p = 0.02. However, there was no difference between the older bilinguals and monolinguals, t (1, 34) = 0.05, *ns*, suggesting that bilingualism has a beneficial effect on executive control for young adults but not for older adults.

Consistent with previous research, young monolinguals had a greater Simon Effect than young bilinguals: young monolinguals responded significantly slower to incongruent than congruent trials, but for young bilinguals, incongruence did not significantly interfere with response time. In this study, however, contrary to previous findings, older monolinguals and bilinguals did not differ in Simon Effect.

3.1.2 Distributional Analyses.

Further analyses were carried out on the Simon task data to examine performance as a function of response speed (cf. Forstmann, van den Wildenberg & Ridderinkhof, 2008; Ridderinkhof, Scheres, Oosterlaan & Sergeant, 2005; Stins, Polderman, Boomsma, & de Geus, 2007; Wiegand & Wascher, 2007). When people respond very quickly in this task, the executive control process that prevents the inappropriate response to stimulus location does not have time to develop, and thus fast responses to incongruent trials tend to be associated with lower accuracy than slow responses (Forstmann et al., 2008). The traditional analyses carried out in Section 3.1.1 of this paper measure the average response time on correct congruent versus incongruent trials over the entire session. Therefore, they do not take potential differences in accuracy within congruent and incongruent trials into account. Furthermore, average performance does not generally capture how the Simon Effect might vary with overall response time. Accordingly, distributional analyses were carried out to examine individual differences in executive control that the traditional analyses do not account for. Two different processes, both key aspects of executive control, were examined. (1) *Direct response capture* focuses on the effect of trial type (congruent or incongruent trials) on error rate (Stins et al., 2007), and (2) *selective response inhibition* focuses on the relationship between interference effects (the Simon Effect) and response speed (Ridderinkhof et al., 2005).

3.1.2.1 Direct Response Capture. Fast responses to incongruent stimuli tend to be associated with low accuracy because they are more likely to be habitual-like impulsive responses (Forstmann et al., 2008; Osman, Lou, Muller-Gethmann, Rinkenauer, Mattes, & Ulrich, 2000; Stins et al., 2007). Impulsive responses involve an incomplete or less-considered decision, like a reflex, as opposed to a well-thought non-impulsive decision. The following analyses were carried out to examine such speed-related accuracy differences that are likely to occur in the Simon task.

Conditional Accuracy Functions (CAFs) were calculated and plotted as a function of response speed. For each person, the RTs for all trials (whether correct or not, and regardless of trial type) were first sorted by speed (slowest to fastest) and then divided into four 100-ms bins (as described below). Then, for each subject and for each trial type (congruent and incongruent), a mean accuracy score was calculated for each bin. Bins that contained only one or two data points (e.g., a person only had one congruent trial that they responded to between 400 and 500 ms) were excluded. This was necessary, as data from one response or two responses (with a 50% chance of 100% accuracy) were uninformative. The mean accuracy values were then averaged across participants in each group, resulting in CAFs.

Although one could construct CAFs spanning the entire RT range, an upper and lower limit to the RT bins was set. This range was necessary as typically, very slow responses were almost always accurate and thus uninformative. Very fast responses were rare, and thus, accuracy for those responses was also uninformative. (See Appendix D for a frequency table of responses for each RT bin.) Different bin limits were constructed for each age group, since older adults performed slower than young adults, overall[2]. For young adults, data were organized into the following four bins: 300-399; 400-499; 500-599; and 600-699; for older adults, data were organized into the following four bins: 400-499; 500-599; 600-699; and 700-799. The mean accuracy for each RT bin by trial type (congruent and incongruent) and language group (bilinguals and monolinguals) are plotted in Figure 4 (young adults: upper graph; older adults: lower graph).

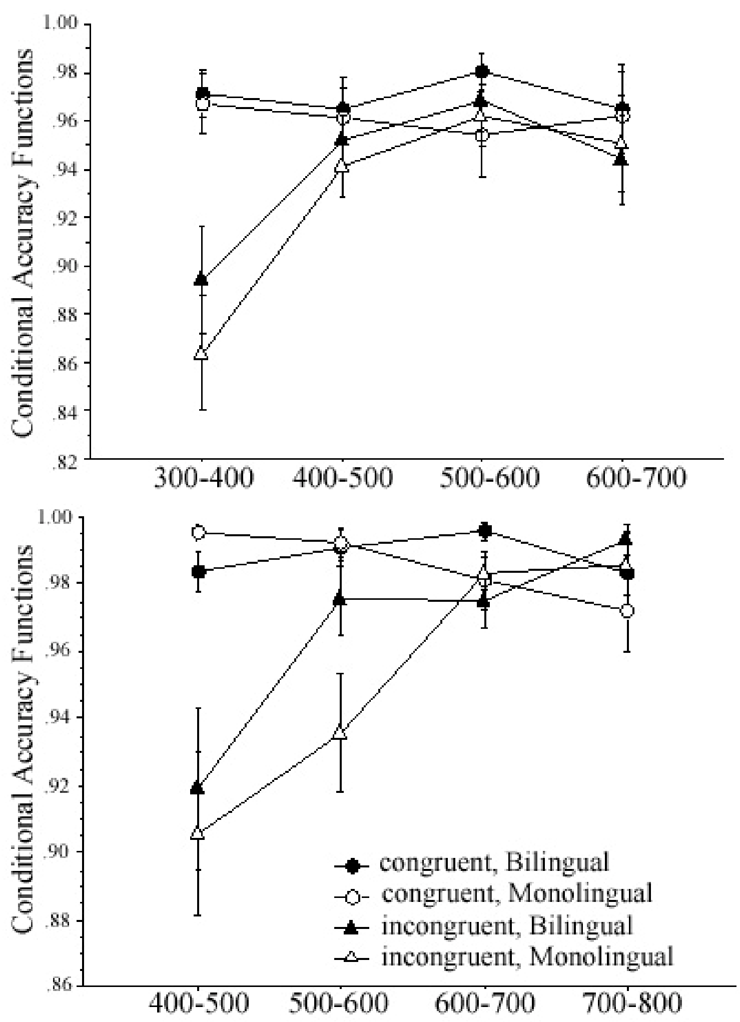

Figure 4. ***CAFs: Mean percentage correct in the Simon task as a function of RT bin by language group and congruence (young adults: upper graph; older adults: lower graph).***

[2] Appendix D displays the frequencies for each bin by language group and age group.

As shown in Figure 4, for all groups, very fast incongruent responses were more error prone than slow incongruent responses. Slope values were calculated by subtracting the faster bin values from the adjacent, slower bin values. Using one-tailed *t*-tests, slope 1 (the left-most, steepest slope between the first and second bins) was compared to the other slopes (slopes 2 and 3, left to right, respectively, where slope 3, between the third and fourth bins, is the least steep). For incongruent responses, averaged across all groups, there was a significant difference between slope 1 and slope 2, t (60) = 3.39, $p < 0.001$, and between slope 1 and slope 3, t (54) = 5.38, $p < 0.0001$, such that the left-most slope was steeper than the others, indicating greater errors when people make very fast responses versus slower responses. In contrast, as can be seen in Figure 4, overall, error rates on congruent trials did not differ as a function of response speed. For congruent responses, averaged across all four groups, there was no difference between slope 1 and slope 2, t (67) = 0.10, *ns*, and between slope 1 and slope 3, t (61) = 0.07, *ns.* This analysis confirms that for slower responses on incongruent trials, people respond more accurately to stimulus location, but as they increase in response speed, they also increase in the number of response errors.

When each group was examined separately, these same results were found for incongruent trials for young bilinguals, young monolinguals and older bilinguals. Older monolinguals, however, did not show a difference between slope 1 and 2 or between slope 1 and 3. See Appendix E for a table of values. As shown in Figure 4, the lack of a difference between slope 1 and 2 is due to the fact that the older monolinguals made more errors in the second RT bin compared to the other groups whose accuracy values in the second RT bin had nearly reached the same accuracy values as the slower RT bins. Thus, the second slope for older monolinguals was steadily rising, whereas for the other groups, it was less steep or leveled off. This suggests that the executive control correction that took place when the other groups responded slower (in the second RT bin) took longer for the older monolinguals.

Group differences were examined further. For young and older adults separately, mean accuracy scores were submitted separately to mixed-design 2 x 2 x 3 (trial type x language group x RT bin) ANOVAs for the three fastest RT bins only, with repeated measures on the trial-type and RT-bin factors. For young adults, there was a main effect of trial type, F (1, 33) = 20.63, $p < 0.0001$, such that accuracy was higher on congruent than incongruent trials (97% vs. 93%). There was a significant main effect of RT bin, F (2, 66) = 16.24, $p < 0.0001$, demonstrating higher accuracy on slower than faster responses, and a significant trial type x RT bin interaction, F (2, 66) = 20.60, $p < 0.0001$, demonstrating higher accuracy for congruent versus incongruent trials on fast compared to slow responses. The main effect of language group was marginal, F (1, 33) = 3.39, p = 0.07, suggesting greater accuracy overall for bilinguals, but the trial type x language group interaction was not significant F (1, 33) = 0.003, *ns*.

For older adults, there was also a main effect of trial type, F (1, 25) = 13.14, $p <$ 0.01, such that accuracy was higher on congruent than incongruent trials (99% vs. 96%). As with the young adults, there was a significant main effect of RT bin, F (3, 75) = 6.07, $p < 0.001$, demonstrating higher accuracy on slower responses than faster responses, and a significant trial type x RT bin interaction, F (3, 75) = 11.43, $p < 0.0001$, demonstrating higher accuracy for congruent versus incongruent trials on fast compared to slow responses. The main effect of language group, F (1, 25) = 0.92, *ns*, and the trial type x language group interaction, F (1, 25) = 0.86, *ns*, were not significant, suggesting no overall difference between older bilinguals and monolinguals. There was, however, a trend for a significant trial type x language group x RT bin interaction, F (3, 75) = 2.21, p = 0.09, suggesting a difference between older bilinguals and monolinguals in the second RT bin but not the other RT bins, such that the monolinguals showed a bigger congruent versus incongruent difference than the bilinguals in that bin. This suggests that the older group may be showing the bilingual advantage for the Simon Effect but for accuracy, not RT.

This analysis demonstrates that overall, on very fast responses, people made more errors on incongruent than congruent trials that the traditional overall RT analysis of correct trials did not account for. The slope analyses and RT bin analyses suggest that older monolinguals have less efficient direct response capture, as older monolinguals were slower to activate the executive control correction than the other groups. This suggests that older bilinguals' accuracy increased at faster RTs than their monolingual counterparts. Performance on slow responses is examined more closely in the next section.

3.1.2.2 Selective Response Inhibition. For fast responses, the automatic response facilitates the correct responses on congruent trials but interferes with the correct responses on incongruent trials. With slower responses, however, selective inhibition has time to develop, and incorrect responses are reduced. Simon Effects are lessened by selective response inhibition more in slow responses than in fast responses. Selective inhibition results in a reduction of the congruency effect (the Simon Effect), so the more effective the selective inhibition is, the more pronounced the congruency effects in *slow versus fast* responses are. The following analyses examined whether more effective selective inhibition results in more pronounced reduction of the Simon Effect in slow versus fast responses.

Similar to the direct response capture analyses, first, for each person, the RTs for correct responses were sorted by trial type. Then for each type (congruent and incongruent), RTs were sorted by speed (slowest to fastest). Each trial type was then divided into four 100-ms bins. A mean RT and Simon Effect score was calculated for each bin. Delta plots for RT were constructed by plotting Simon Effect size (mean RT in the incongruent condition minus mean RT in the congruent condition) as a function of RT bin as shown in Figure 5 (young adults: upper graph; older adults: lower graph). If more effective selective inhibition results in more pronounced reduction of the Simon Effect in slow responses, then the down-turning of the delta plot in the right-most bin (the slowest) should be more pronounced in groups that are more proficient in response inhibition than in less proficient groups.

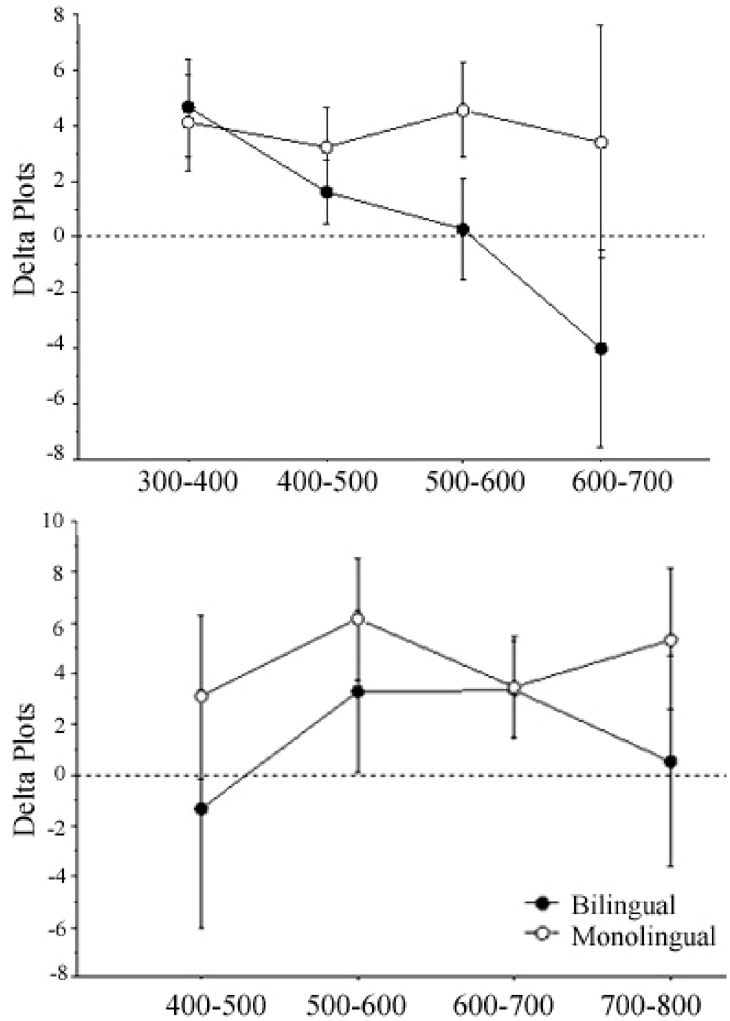

Figure 5. ***Delta plots for reaction time (RT) as a function of RT bin by language group (young adults: upper graph; older adults: lower graph).***

As can be seen in Figure 5, for both young and older bilinguals the delta plot declines between the third and fourth RT bin. (Notice that for the young bilinguals, the decline is steady throughout the entire session.) Conversely, for young and older monolinguals, the delta plot remains relatively stable. Using one-tailed *t*-tests, slope 3 (the right-most, slowest slope) was compared to the other slopes (slopes 2 and 1, right to left, where slope 1 is the fastest). Averaged across all groups, there was a marginal difference between slope 3 and slope 1, t (69) = 1.36, p = 0.09, and no significant difference between slope 3 and slope 2, t (74) = 0.39, *ns*. When each group was examined separately, only the older bilinguals demonstrated a marginal difference between slope 3 and slope 1, t (12) = 1.70, p = 0.06, and none of the groups displayed a difference between slopes 3 and 2. This analysis suggests that older bilinguals may be more proficient in response inhibition than their monolingual counterparts, as their slowest slope is negative and is significantly different from their fastest slope, and there is no difference among slopes for the monolinguals. This also suggests that there is no difference in response inhibition between young bilinguals and monolinguals, as there was no difference among slopes for those groups.

3.1.3 Executive Control Summary

In summary, when the traditional measure for the Simon Effect is used (i.e., overall RT of correct responses on incongruent minus congruent trials), young bilinguals demonstrated a smaller Simon Effect, and thus greater executive control compared to young monolinguals. Older bilinguals and monolinguals, on the other hand, performed equivalently. However, when distributional analyses were carried out, evidence for a bilingual advantage was seen in the older group as well. That is, older bilinguals performed better than their monolingual counterparts, and there was no difference between the young bilinguals and monolinguals for either the direct capture response or the selective response inhibition. Thus, although this study did not replicate earlier findings of reduced Simon Effect in older bilinguals when the traditional measure was used, it did demonstrate enhanced direct response capture and more efficient response inhibition, two key components of executive control, in older bilinguals, compared to older monolinguals. This is a novel finding, as no other study to date that has examined bilingualism and executive control has used the distributional analyses used here. This finding suggests that the executive control difference between older bilinguals and monolinguals that has been demonstrated in previous studies may be more complex than the traditional Simon task overall performance analyses account for.

It is unclear why the young bilinguals and monolinguals in this study demonstrated a significant difference for the traditional analyses but *not* for the distributional analyses. One could assume that the differences in the traditional analyses would be more fine-grained and clarified with the distributional analyses, as they were with the older groups in this study. This issue warrants further investigation.

3.2 Implicit Sequence Learning on the ASRTT

3.2.1 Data Reduction

In the ASRTT, a four-element repeating sequence of pattern stimuli alternate with random stimuli (c.f., Howard & Howard, 1997). Because predictable (pattern) and unpredictable (random) events alternate, some successive runs of three event, or triplets, occur more often than others. For example, for the sequence 2r3r1r4r, the triplets 223 and 134 occur often, whereas the triplets 132 and 312 occur only rarely. The former are referred to as high-frequency triplets and the latter as low-frequency triplets. Previous studies have shown that people learn triplet frequencies implicitly, responding more quickly and accurately to the third event of high- than low-frequency triplets with practice (D. V. Howard et al., 2004).

Two kinds of low-frequency triplets, repetitions (111, 222, 333 and 444) and trills (121, 343, 414, etc.), were excluded from the analyses since they only occurred on random trials for all participants, and as is typical, people revealed pre-existing response tendencies when responding to these triplets (Soetens, Melis, & Notebaert, 2004). In general, people responded exceptionally fast to repetitions and exceptionally slowly to trills. These pre-existing response tendencies did not occur for other triplet types.

To examine each group's sequence-specific learning, performance on the predictable high-frequency trials was compared to performance on the low-frequency trials. A median RT was determined separately for correct high-frequency and low-frequency triplets for each participant for each block. The medians were then averaged across blocks to obtain a mean of the median RT for each epoch. A similar procedure was used for accuracy. Sequence-specific learning is demonstrated by the high- and low-frequency trials diverging across epochs for both RT and accuracy. These differences between high- and low-frequency trials are referred to as trial-type effects, and they provide a measure of learning as well as sensitivity to the sequence structure.

In Figure 6, the overall mean of the median RT (upper graph) and mean accuracy (lower graph) for both high- and low-frequency trials are plotted for all groups. The RT and accuracy data were subjected to separate 8 x 2 x 2 x 2 (epoch x trial type x age group x language group) ANOVAs.

3.2.2 Overall Skill Learning

As shown in Figure 6 and as is typical, people responded faster overall with practice. This was confirmed in the significant main effect of epoch for RT, F (7, 532) =

103.01, $p < 0.0001$, indicating general skill learning. The main effect of age group, F (1, 76) = 157.25, $p < 0.0001$, and the age group x epoch interaction, F (7, 532) = 11.21, $p < 0.0001$, were significant, revealing faster RTs for young adults than older adults overall, but greater overall skill learning for older adults by the end of the session. This significant effect is likely due to the fact that young adults performed much faster than older adults and demonstrated a floor effect (i.e., they could not get any faster).

For accuracy, there was also a significant main effect of epoch, F (7, 532) = 10.60, $p < 0.0001$, demonstrating a decline in accuracy with practice, likely due to the computer feedback guiding participants to an accuracy level of 92%. There was a main effect of age group, such that, as shown in Figure 6, older adults were more accurate than young adults, F (1, 76) = 24.01, $p < 0.0001$. However, there was no age group x epoch interaction.

3.2.3 Sequence-Specific Learning

More important, for assessing implicit sequence learning, low-frequency trials were slower overall than high-frequency trials, and this trial-type effect increased across epochs, as shown in Figure 7 (young adults) and Figure 8 (older adults)[3]. Across all four groups, for RT, the main effect of trial type, F (1, 76) = 74.43, $p < 0.0001$, and the epoch x trial type interaction, F (7, 532) = 7.26, $p < 0.0001$, were significant. The same pattern was found for accuracy: across all four groups, the main effect of trial type, F (1, 76) =

[3] Since there is a large difference between older adults and young adults in reaction time, it is nearly impossible to see the difference between high and low frequency trials when both age groups are plotted on the same graphs. So the age groups are plotted separately to ease viewing.

131.92, $p < 0.0001$, and the epoch x trial type interaction, $F(7, 532) = 7.13$, $p < 0.0001$, were significant, demonstrating sequence-specific learning.

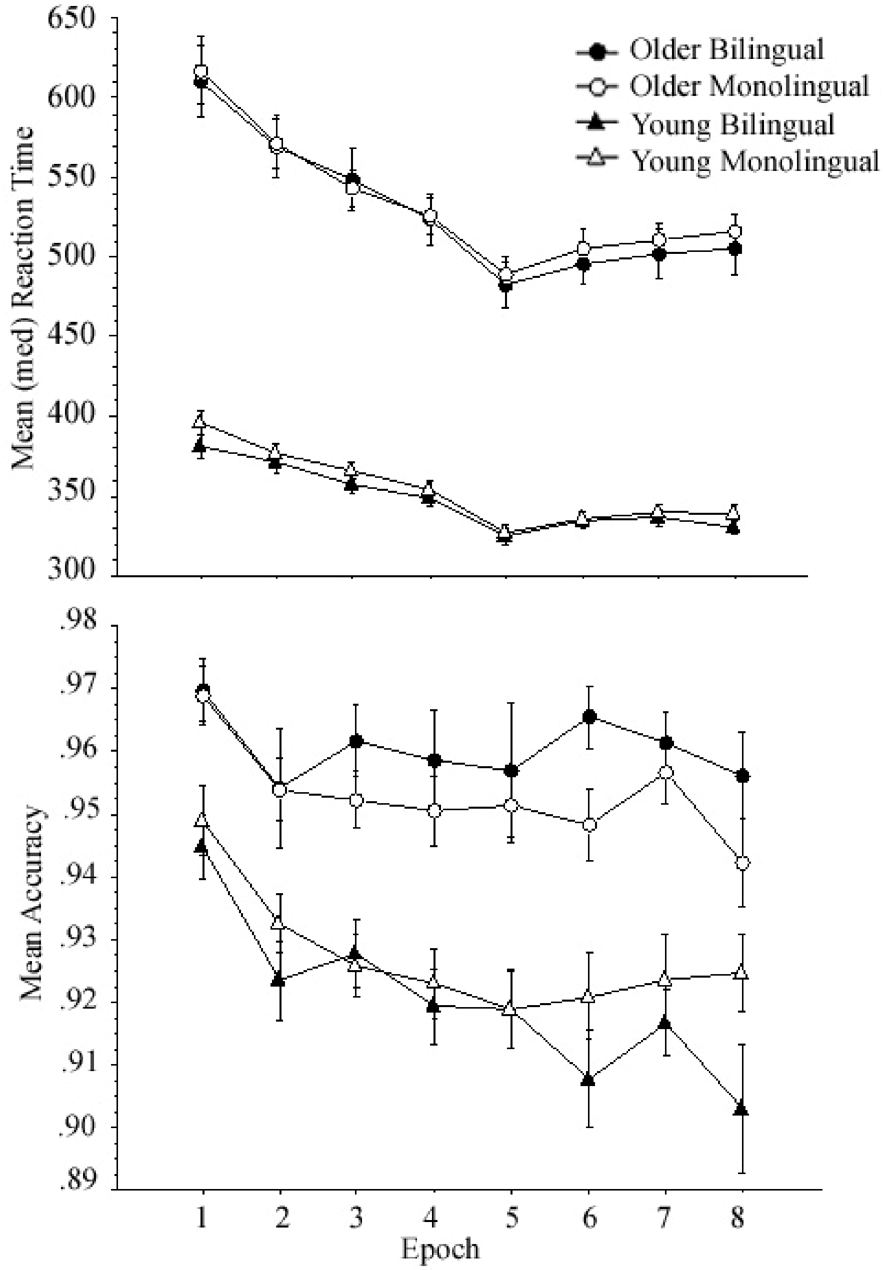

Figure 6. ***ASRTT overall reaction time (RT; upper graph) and overall accuracy (lower graph) by age group and language group.***

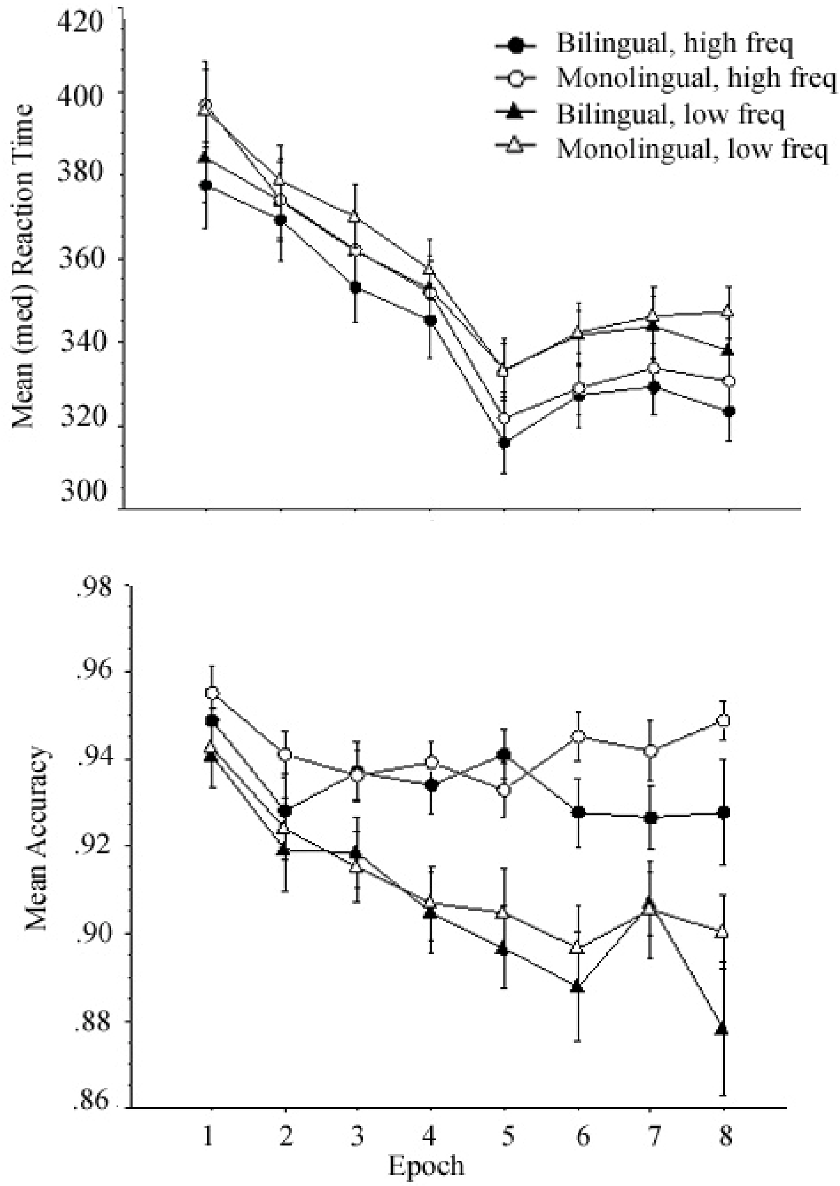

Figure 7. ***ASRTT reaction time (RT; upper graph) and accuracy (lower graph) scores for young adults by language group and trial type.***

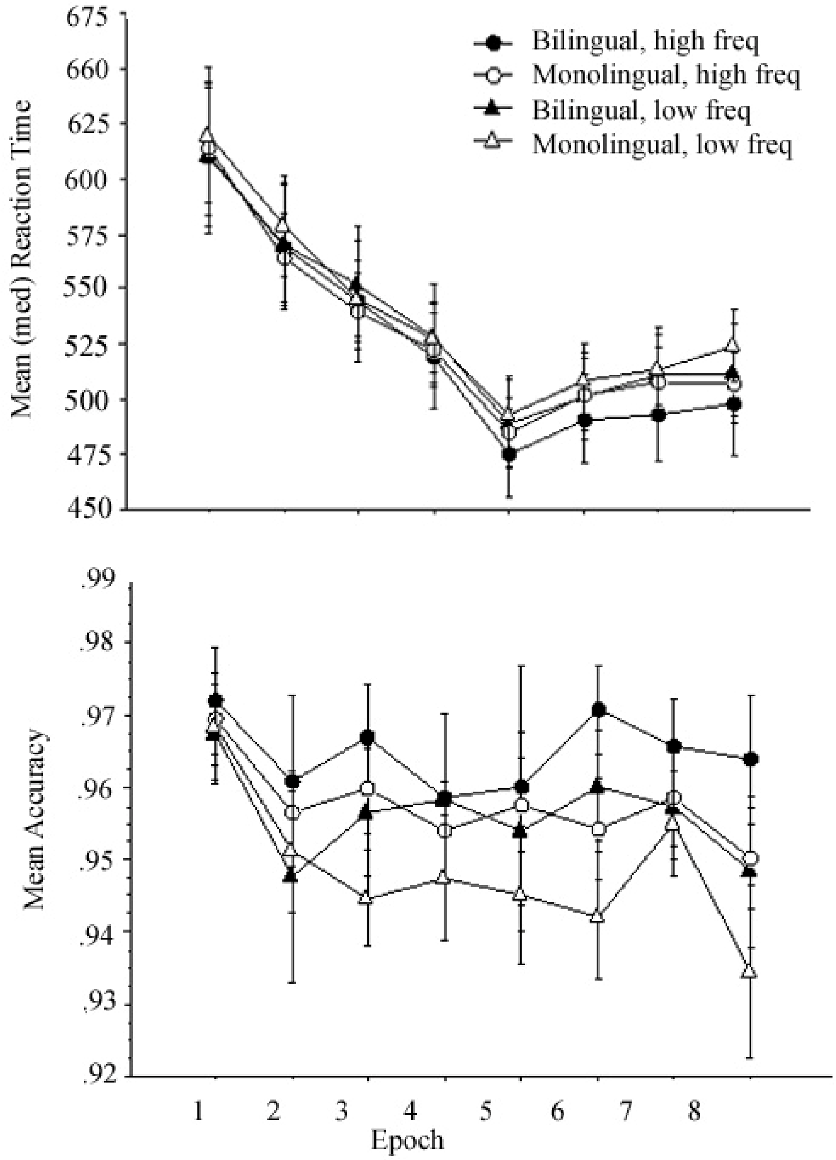

Figure 8. ***ASRTT reaction time (RT; upper graph) and accuracy (lower graph) scores for older adults by language group and trial type.***

As is typical, the magnitude of this trial-type effect differed for young and older adults. For both RT and accuracy, there was an epoch x trial type x age group interaction, F (7, 532) = 2.08, $p < 0.05$; F (7, 532) = 3.70, $p < 0.001$, RT and accuracy, respectively, such that young adults showed greater sequence-specific learning than older adults. There were no effects of language group for either measure, suggesting that bilingualism did not affect implicit sequence learning.

When examined separately, for young adults, there was clear evidence of sequence-specific learning for both bilinguals and monolinguals on both RT and accuracy measures. As shown in Figure 7, the high-frequency trials were faster and more accurate than low-frequency trials, and these trial-type effects increased with practice. The trial-type effects can be more clearly seen in Figure 9. The main effect of trial type and the trial type x epoch interaction were significant for both RT, F (1, 41) = 96.15, $p < 0.0001$; F (7, 287) = 10.59, $p < 0.0001$, respectively, and accuracy, F (1, 41) = 120.54, $p < 0.0001$; F (7, 287) = 8.98, $p < 0.0001$, respectively. There was no main effect or interaction of language group, suggesting that bilingualism did not have a beneficial effect on sequence-specific learning for young adults.

For older adults, there was also evidence of sequence-specific learning, as can be seen in Figure 8. High-frequency trials were faster and more accurate than low-frequency trials overall, and these trial-type effects increased with practice. The trial-type effects can be more clearly seen in Figure 10. As shown in Figure 8, for both RT and accuracy, there was a main effect of epoch, F (7, 245) = 45.33, $p < 0.0001$, F (7, 245) = 3.12, $p < 0.005$, respectively. The main effect of trial type was significant for both RT, F (1, 35) = 18.98, $p = 0.0001$, and accuracy, F (1, 35) = 24.54, $p < 0.0001$, but there was no significant trial type x epoch interaction for either measure, and there was no main effect or interaction of language group. This suggests an overall difference in learning the different trial types that does not increase with practice for older adults. It also suggests that bilingualism did not have a beneficial effect on sequence-specific learning for older adults.

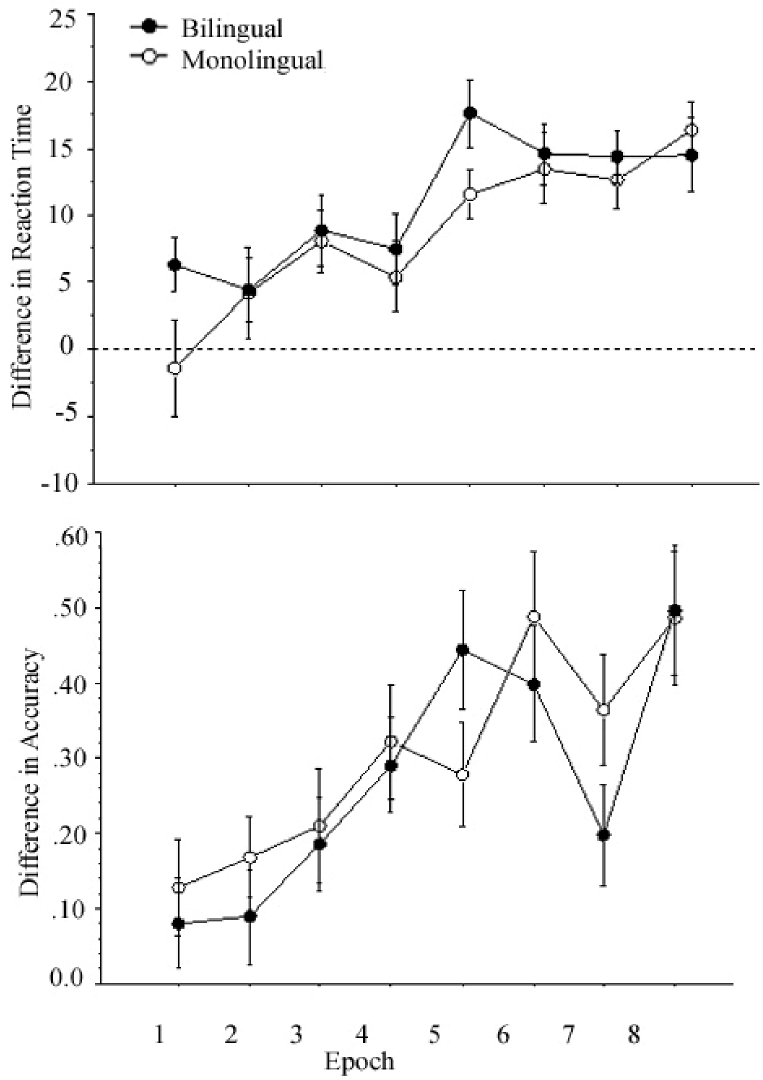

Figure 9. ***ASRTT reaction time (RT) trial-type effects (low-high frequency trials; top graph) and accuracy trial-type effects (high-low frequency trials; lower graph) for young adults by language group.***

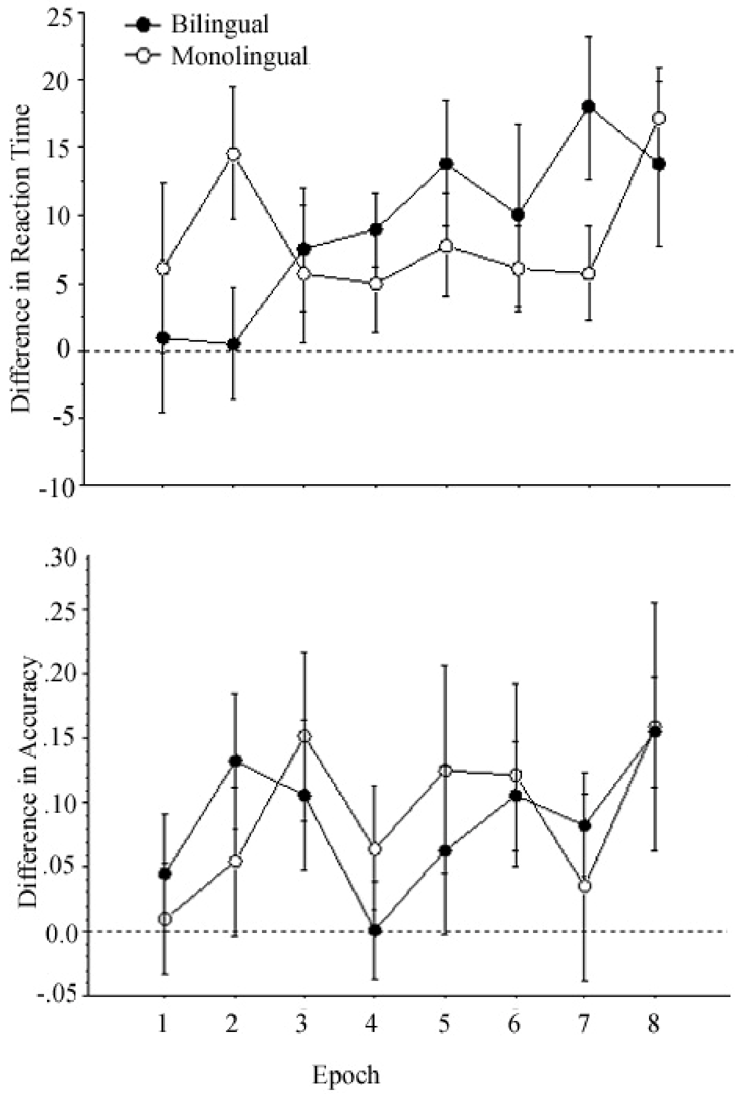

Figure 10. ***ASRTT reaction time (RT) trial-type effects (low-high frequency trials; upper graph) and accuracy trial-type effects (high-low frequency trials; lower graph) for older adults by language group.***

In summary, both young and older adults demonstrated overall skill learning and sequence-specific learning. Older adults demonstrated greater skill learning compared to young adults, but this was likely due to a floor effect for the young adults. Young adults, however, demonstrated greater sequence-specific learning compared to older adults.

There was no effect of language group, such that for both young and older adults, bilinguals and monolinguals performed equivalently.

3.2.4 Is Learning Declarative?

Responses on the post-experimental questionnaire and the card-sorting task provide consistent evidence that participants did not acquire declarative knowledge of the sequence structure. Questionnaire responses were similar for all groups and were consistent with data from previous ASRTT studies (e.g., D.V. Howard et al., 2004). When asked whether they noticed any regularity, none of the participants reported a pattern or described the alternating nature of the sequence. There was no difference among groups in self-reported strategies to complete the task.

For the card-sorting data, to determine if individuals were able to judge explicitly the relative frequency at which each triplet sequence occurred, the mean proportion of times the low- and high-frequency triplets were placed into the *frequent* category was calculated for each group. A difference between high-frequency and low-frequency sorting would indicate that people were able to make declarative judgments about triplet frequency. A group x triplet type ANOVA revealed no significant effects. There was no difference between the overall mean for rare triplets (M = 0.63, SE = 0.02) and frequent triplets (M = 0.62, SE = 0.03), and there were no significant differences among young bilinguals (M = 0.60, SE = 0.02), young monolinguals (M = 0.60, SE = 0.03), older bilinguals (M = 0.59, SE = 0.03) and older monolinguals (M = 0.61, SE = 0.03) indicating that participants were unable to explicitly distinguish low- and high-frequency triplets. Thus, consistent with the questionnaire responses, the card-sorting data confirm that participants in all groups did not have explicit knowledge of the sequence structure they had learned.

3.2.5 Implicit Sequence Learning Summary

In summary, all groups demonstrated both general skill and implicit sequence-specific learning. Young adults responded faster than older adults and demonstrated greater sequence-specific learning, but there were no language group differences. The main hypothesis of this study was that bilingualism would assist in learning sequential regularities and thus, both young and older bilinguals would show greater implicit sequence learning compared to their monolingual counterparts. However, although all groups demonstrated general skill and sequence-specific learning, there was no effect of language group. For both age groups, bilinguals and monolinguals performed equivalently.

3.3 Correlations Between Executive Control and Implicit Learning

As indicated earlier, it was hypothesized that since similar processes (executive control, inhibition, and attentional processes) are used in the Simon task and the ASRTT, performance on the two tasks would correlate. This correlation would imply that the two cognitive processes are related, such that people with good executive control would perform well on both the Simon task and the ASRTT, and people with poor executive control would perform poorly on both tasks. Learning scores for both RT and accuracy for the ASRTT were calculated for each participant by taking the sum of the difference scores (high- minus low-frequency trials for accuracy and low- minus high-frequency trials for RT) across all epochs. Higher scores indicate greater learning. The learning score for the Simon task was the Simon Effect score (incongruent minus congruent trials). Higher scores indicate greater interference, and thus weaker executive control.

Table 6. *Correlations Between the Simon Effect Score and the ASRTT*

Measure	Group			
	Young adults		Older adults	
	Monolingual	Bilingual	Monolingual	Bilingual
1. Simon Effect	-	-	-	-
2. ASRTT sum of mean DRT	.054	.179	.292	-.531*
3. ASRTT sum of mean DACC	-.264	-.022	-.147	.540*

Note * $p < 0.05$. ASRTT = Alternating Serial Reaction Time Task.
DRT = Difference in Reaction Time. DACC = Difference in Accuracy.

Table 6 shows the correlations between the ASRTT and the Simon task for all groups. No correlations were significant for either of the young groups or for the older monolinguals. The only significant correlation that occurred was for the older bilinguals. A significant negative correlation was observed for the ASRTT RT learning score and Simon Effect for older bilinguals, $r = -0.53$, $p < 0.03$, such that the lower the Simon Effect, the greater the ASRTT learning. A significant positive correlation was observed for the ASRTT accuracy learning score and Simon Effect for older bilinguals, $r = 0.54$, $p < 0.03$, such that the greater the Simon Effect, the greater the ASRTT learning. Scatter plots for these correlations are presented in Figure 11.

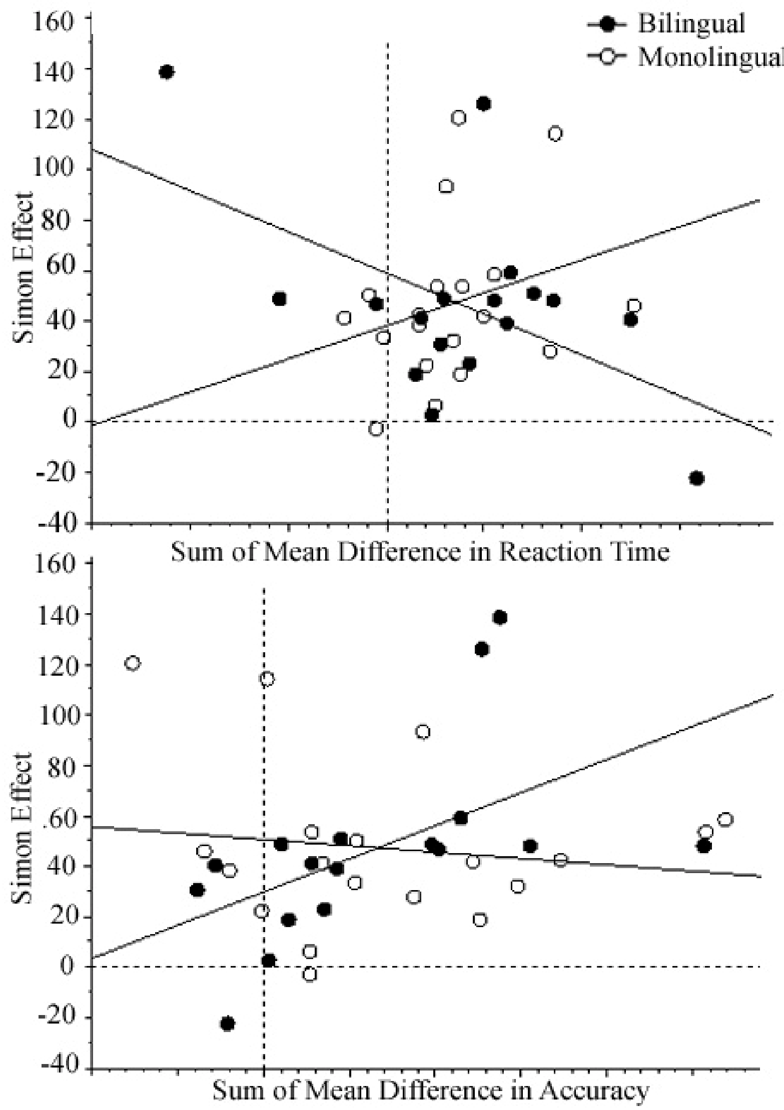

Figure 11. ***Scatter plots comparing ASRTT reaction time (RT; upper graph) and accuracy (lower graph) learning to Simon Effect in older adults.***

The ASRTT accuracy measure correlation is not consistent with expectations set for this study; however, older adults performed with very high accuracy and may have reached a ceiling, in which case, a correlation would not be obtained. The older bilingual group did show a correlation though, so this cannot fully account for the findings. The ASRTT RT measure correlation is consistent with the hypothesis, as higher learning on the ASRTT is related to greater executive control, or less interference, on the Simon task. However, there is great variation in the older adults' performance, as can be seen in Figure 11. As the correlation was only observed in older bilinguals, this implies that managing two competing languages for a lifetime may lead to greater executive control. This suggestion warrants further study as the participants' performance in this study varied greatly and likely cannot be generalized.

3.4 Standardized Neuropsychological Tests

The results for the standardized neuropsychological tests are displayed in Tables 7, 8, and 9. For each task, results were submitted to 2 x 2 (age group x language group) ANOVAs. There was a main effect of age group on the Spatial Span forward and backward tasks, $F\ (1, 76) = 29.24$, $p < 0.0001$; $F\ (1, 76) = 55.97$, $p < 0.0001$, respectively; the Operation Span task, $F\ (1, 76) = 17.15$, $p < 0.0001$; the Letter-Number Sequencing task, $F\ (1, 76) = 10.01$, $p < 0.01$; the Consonant Trigrams task, $F\ (1, 79) = 13.68$, $p < 0.001$; the Digit-Symbol Coding, Pairing and Free-Recall tasks, $F\ (1, 79) = 109.84$, $p < 0.001$; $F\ (1, 79) = 24.38$, $p < .0001$; $F\ (1, 79) = 11.09$, $p < 0.01$, respectively, and the Matrix Reasoning task, $F\ (1, 79) = 37.25$, $p < 0.0001$, such that young adults performed better than older adults. Older adults scored higher on Full-Scale Intelligence, $F\ (1, 79) = 11.80$, $p < 0.001$. There was no main effect of age group on the Digit Span forward and backward tasks or on the Vocabulary task. For all tasks, there was no main effect or interaction with language group, suggesting that bilingualism did not affect these cognitive skills (all ps > 0.05).

In sum, the results of the standardized neuropsychological tasks showed an overall effect of age group, such that young adults performed better than older adults on most of the tasks, and older adults performed better than young adults on Full-Scale Intelligence. These results are consistent with research demonstrating cognitive decline in fluid skills, such as processing speed, working memory and episodic memory, but no (or late) decline in crystallized skills, such as intelligence (Hedden & Gabrieli, 2004; Salthouse, 1996). There were no effects of language group on the standardized neuropsychological tasks, suggesting that bilingualism did not have an effect on these cognitive abilities.

Table 7. *Mean Scores (and Standard Deviation) for Standardized Neuropsychological Tests by Age Group and Language Group*

	Spatial span		Digit span		
Group	Forward	Backward	Forward	Backward	LNS
Young monolingual	8.15 (2.01)	7.85 (1.46)	10.80 (2.07)	6.25 (2.00)	10.80 (2.95)
Young bilingual	9.00 (1.57)	8.65 (1.50)	9.87 (1.94)	6.17 (2.10)	10.57 (2.69)
Older monolingual	5.65 (1.69)	5.25 (1.59)	10.10 (2.22)	5.90 (2.36)	9.15 (1.81)
Older bilingual	6.72 (2.05)	5.83 (1.82)	9.56 (2.36)	6.33 (1.75)	8.56 (2.20)
Young mean	8.61 (1.81)*	8.28 (1.52)*	10.30 (2.03)	6.21 (2.03)	10.67 (2.78)#
Older mean	6.16 (1.93)	5.53 (1.70)	9.84 (2.27)	6.11 (2.08)	8.87 (2.00)

Note: * $p < 0.0001$, for Age group. # $p < 0.01$ for Age group. LNS = Letter-Number Sequencing.

Table 8. ***Mean Scores (and Standard Deviation) for Standardized Neuropsychological Tests by Age Group and Language Group (cont.)***

		Consonant	Digit-symbol		
Group	OSPAN	trigrams	Coding	Pairing	Free recall
Young monolingual	.68 (.13)	6.10 (2.51)	88.20 (14.66)	14.25 (3.39)	7.60 (1.10)
Young bilingual	.65 (.14)	6.78 (1.86)	87.70 (10.38)	15.52 (3.45)	8.13 (1.14)
Older monolingual	.54 (.13)	4.45 (2.67)	56.30 (16.72)	9.75 (5.45)	6.80 (1.44)
Older bilingual	.52 (.20)	4.67 (2.30)	57.22 (11.75)	10.56 (5.08)	7.06 (1.51)
Young mean	.69 (.13)*	6.47 (2.19)**	87.93 (12.40)**	14.93 (3.44)*	7.88 (1.14)#
Older mean	.53 (.17)	4.55 (2.47)	56.74 (14.39)	10.13 (5.22)	6.92 (1.46)

Note: * $p < 0.0001$, for Age group. ** $p < 0.001$ for Age group. # $p < 0.01$ for Age group.
OSPAN = Operation Span.

Table 9. ***Mean Scores (and Standard Deviation) for Intelligence Tasks by Age Group and Language Group***

Group	Vocabulary	Matrix reasoning	FSIQ
Young monolingual	57.70 (7.51)	29.50 (3.83)	109.35 (11.73)
Young bilingual	55.91 (7.47)	27.91 (3.41)	104.00 (11.03)
Older monolingual	58.95 (8.75)	21.95 (5.08)	115.30 (13.35)
Older bilingual	60.67 (9.25)	23.72 (4.78)	116.00 (11.63)
Young adults mean	56.74 (7.45)	28.65 (3.66)*	106.49 (11.54)
Older adults mean	59.76 (8.91)	22.79 (4.96)	115.63 (12.40)**

Note: * $p < 0.0001$, for Age group. ** $p < 0.001$ for Age group. FSIQ = Full-Scale Intelligence Quotient.

4.0 General Discussion

This study revealed three major findings. First, young bilinguals demonstrated greater executive control compared to young monolinguals in traditional overall RT analyses of the Simon task, and older bilinguals and monolinguals performed equivalently. Second, with more sensitive distributional analyses, older bilinguals demonstrated a bilingual advantage for congruency effects, but young bilinguals did not. Third, all groups demonstrated both general skill and implicit sequence-specific learning in the implicit learning ASRT task, and there were no language group differences. Each of these is discussed in detail below.

4.1 Executive Control

In this study, the findings from the traditional overall performance measures used to analyze the Simon task conflict with other studies that have found *greater* differences between older bilinguals and monolinguals compared to young bilinguals and monolinguals. Why didn't the older bilinguals in this study show enhanced executive control compared to monolinguals in the traditional Simon task analyses as demonstrated in other studies while showing a bilingual advantage in the distributional analyses? There are four possible reasons why this study did not replicate other findings. Each possibility is discussed next, and a summary follows.

4.1.1 Bilingualism Does Not Influence Executive Control Skills

First, there is the possibility that bilingualism simply does not influence other cognitive processes, and the findings in other studies are due to extraneous factors that correlate with bilingualism. While Mechelli, Crinion, Noppeney, O'Doherty, Ashburner, Frackowiak & Price (2004) found greater grey matter density in early bilinguals compared to late bilinguals, and others have found changes in brain morphology related to expertise in other specific areas (Elbert, Pantev, Wienbruch, Rockstroh & Taub, 1995; Haslinger, Erhard, Altenmuller, Hennenlotter, Schwaiger, Grafin von Einsiedel, et al., 2004; Koeneke, Lutz, Wusterberg & Jancke, 2004; Maguire, Gadian, Johnsrude, Good, Ashburner, Frackowiak and Frith, 2000; Maguire, Spiers, Good, Hartley, Frackowiak & Burgess, 2003; Pantev, Oostenveld, Engelien, Ross, Roberts & Hoke, 1998), Green and Bavelier (2008) suggest that learning expert tasks or being trained on a certain activity is quite specific to the trained activity and does *not* transfer to other unrelated tasks. As no studies to date have demonstrated far transfer to tasks that are not similar to the trained task, it is impossible to rule this possibility out. It may very well be the case that bilingualism does not influence other cognitive processes, as found in the present study, and that results in other studies showing a correlation between executive control and bilingualism were in fact due to a third variable. However, as other studies have shown that bilinguals perform better than monolinguals on this *particular* task with the traditional analyses, this possibility is unlikely.

4.1.2 Various Aspects of Bilingualism Are Important for Transfer

Another possibility of why this study did not replicate the traditional RT analyses results of previous studies is that the groups in the present study may have been categorized differently than participants in other studies. Although the Bilingualism Questionnaire was administered to each participant at testing time to obtain information about the extent of their second language abilities, some components of bilingualism such as proficiency, language usage, and age of acquisition were not accounted for in the original grouping. These factors vary greatly among bilinguals and may have played a key role in the results.

4.1.2.1 Proficiency. One critical aspect of bilingualism that varies among individuals is proficiency. Language proficiency refers to the level of attainment a person has achieved in a given language and often includes four domains: listening, speaking, writing, and reading (Cummins, 1983; Schrauf, 2008). Generally, people who speak two languages from childhood and who use both languages daily achieve high proficiency. However, second language learners often do not achieve the same level of proficiency as native speakers of a language. Some studies have found a difference in cognition between high-proficiency bilinguals and low-proficiency bilinguals (sometimes also referred to as “un-balanced” bilinguals) and/or monolinguals (Bain & Yu, 1980; Bialystok & Majumber, 1998; Cummins, 1979; Lambert, 1977; Peal & Lambert, 1962; Segalowitz & Frenkiel-Fishman, 2005; Zied, Phillipe, Karine, Harvet-Thompson, Ghsilaine, Arnaud, et al., 2004). For example, Zied at al. (2004) found that both older and young balanced bilinguals had faster reaction times than their un-balanced counterparts who had high proficiency in just one of their two languages.

To examine the effects of proficiency, or the extent to which one is bilingual, bilinguals who had high proficiency in their second language, or “high fluency,” and monolinguals who had very minor second-language experience, or “low fluency,” were examined. This assessment was done as some monolinguals in this study had some prior exposure to a second language (even though they did not consider themselves to be bilingual), and some bilinguals had only a little exposure to a second language (and yet considered themselves to be bilingual). The goal here was to include only the proficient bilinguals and the monolinguals.

To categorize participants as “high fluency” and “low fluency,” the bilingual scores that assessed listening, speaking, writing, and reading reported in Section 2.2.4.2 of this paper were divided such that people with a score less than 10 were considered low-fluency (monolinguals) and people with a score greater than 30 were considered high-fluency (bilinguals). See Table 10 for bilingual and Simon Effect scores by age and language group.

Table 10. ***Bilingual and Simon Effect Scores by Proficiency Groups***

		Bilingual scores				Simon effect	
Group	N	Mean	Std dev	Minimum	Maximum	Mean	Std dev
Young high f	19	34.27	1.94	31.15	37.00	23.24	25.54
Young low f	4	7.61	0.85	7.00	8.80	45.21	27.13
Older high f	14	34.65	2.08	30.25	37.00	46.49	39.24
Older low f	17	7.25	0.69	5.75	8.63	32.16	17.39

Note: f = fluency.

The same analyses carried out in Section 3.1 of this paper were carried out again, but this time only these participants were included. See Appendix F for the full set of results. In summary, like in the original results, older adults were slower than young adults, but there were no effects of language[4]. These results parallel the original results.

[4] Notice the disparity in Simon Effect scores between the older high-fluency bilinguals and the older low-fluency monolinguals in the *opposite* direction than hypothesized. It is unclear why older bilinguals show a greater Simon Effect than monolinguals when the groups are categorized by proficiency. One possible explanation of this disparity is that there are other important aspects of bilingualism that are not taken into account here. See Sections 4.1.2.2 and 4.1.2.3 of this paper. These factors may be playing a key role in the results.

For Simon Effect analyses, unlike the original results, there was *no* effect of age group. The Simon task distributional analyses mirrored the results in Section 3.1.2 of this paper. In summary, although these analyses only examined "high-fluency" bilinguals and "low-fluency" monolinguals, results more or less paralleled the results obtained when the groups were broken down merely as "bilingual" or "monolingual." This suggests that proficiency alone does not account for differences seen between bilinguals and monolinguals in other studies.

4.1.2.2 Regular language use. Another more obvious aspect of bilingualism is language usage. Bilinguals continuously control the language they intend to use while suppressing the other to avoid interference, while monolinguals experience this less frequently. A few studies have suggested that regular language usage affects cognition in bilinguals (Bialystok, 1988; Costa, Roelstraete & Hartsuiker, 2006; Lambert; 1955; Lemmon and Goggin, 1989; Kharkhurin, 2008). For example, Kharkhurin (2008) demonstrated that for Russian-English bilingual Russian immigrants in New York, length of acculturation in the United States was a major factor in determining cognitive benefits.

Although I attempted to obtain a sample that did in fact use both languages regularly, it may be that the participants in the present study did not use them regularly, at least not to the extent of participants in other studies. To examine this notion, additional analyses were run in which only people who answered yes to the three introductory questions on the first page of the Bilingualism Questionnaire were included as "regular bilinguals," and people who answered no to each of the three introductory questions were included as "monolinguals." The three questions were:

Are you able to switch between the languages at will?
Do you speak both languages at home?
Do you use both languages more than two times a week?

See Table 11 for bilingual scores and Simon Effect scores by language and age group. Results paralleled the patterns observed with the original sample and reported in Section 3.1 of this paper. This suggests that the regular-usage factor alone does not fully account for the bilingual advantage reported in other studies.

Table 11. ***Bilingual and Simon Effect Scores by Language Usage Groups***

		Bilingual scores				Simon effect	
Group	N	Mean	Std dev	Minimum	Maximum	Mean	Std dev
Young reg b	18	31.97	5.77	12.70	37.00	23.91	34.19
Young mono	14	14.25	5.52	7.00	22.90	45.21	30.57
Older reg b	8	32.67	7.51	14.60	37.00	35.76	10.59
Older mono	16	8.05	2.45	5.75	16.08	39.48	28.19

Note: Reg b = regular bilinguals. Mono = monolinguals.

4.1.2.3 Age of acquisition. Another important aspect of bilingualism is the age in which the second language was acquired, commonly referred to as “age of acquisition.” Some studies have addressed the importance of age of acquisition in order for bilingualism to have positive effects on other aspects of cognition (Hernandez & Li, 2007; Kharkhurin, 2008; Mechelli et al., 2004; Golestani, Alario, Meriaux, Le Bihan, Dehaene & Pallier, 2006; Wartenburger, Heekeren, Abutalebi, Cappa, Villringer & Perani, 2003). For example, Golestani et al. (2006) found different patterns of brain activation in early versus late learners (of the second language) in grammatical processing but not phonetic or semantic processing. During syntactical production tasks, Golestani et al. (2006) demonstrated activation in the left inferior parietal cortex, an area associated with processing complex syntactic structure and coding and retrieval of verbal working memory. This activation was greater when participants used their second language, which presumably is more cognitively demanding than their first language. They also found a similar pattern in the dorsolateral prefrontal cortex, a region thought to underlie attention and the central executive system. They suggest that the neural systems mediating grammatical processing are more vulnerable to changes in early experiences than those mediating semantic processing. Similarly, Wartenburger et al. (2003) suggested that the age of acquisition affected cortical representations of grammatical processes such that late learners activated inferior frontal regions bilaterally more than early learners. One study suggests that bilinguals have greater grey matter density than monolinguals and that the degree of structural reorganization is correlated to second language performance (Mechelli et al., 2004). Mechelli and colleagues (2004) found that the density difference was greater in early bilinguals compared to late bilinguals. All of these studies suggest that the structure of the brain is altered more by early than late experiences of acquiring a second language.

The aforementioned frontal regions are associated with higher order executive processing, such as cognitive control, inhibition, and working memory. Thus, one would expect there to be a difference in performance in executive control tasks for early bilinguals, but not for individuals who acquire their second language later in life. The indirect evidence for this assumption lies in the notion that certain abilities, such as processing speed, attention, encoding new information, recalling information, paired associations, and implicit learning, decline with age (Craik & Jennings, 1992; Hedden &

Gabrieli, 2004; Howard & Howard, 2001; Hultsch & Dixon, 1983; Kharkhurin, 2008; Kemper, 1991; Salthouse, 1996). If acquisition of a new language results in cognitive changes, as suggested by the abovementioned work, then the age of acquisition likely determines the specificity of these age-related changes. If one acquires both languages at an early age, there will be greater organization and functionally-specific connections, and the conceptual representations will be stronger than in monolinguals (Kharkhurin, 2008; Trainor, 2005). [See also Salthouse (1988) for a hypothetical network structure.] If age of acquisition plays an important role in transfer to other skills, and it was not taken into account in the present study, it may be the case that the performance of late learners interfered with the excelling performance of the early learners. This early-learner advantage may be the bilingual advantage that has been demonstrated in other studies.

For the present study, many of the older bilinguals acquired their second language later in life compared to the young bilinguals. In fact, only six of the 18 older bilinguals began speaking their second language at age seven or younger, while 17 of the 23 young bilinguals began before speaking their second language before the age of seven. To test the notion that the age of acquisition is a determining factor of enhanced cognitive processing in bilinguals, additional analyses were run in which only the 17 young and six older bilinguals were included in the bilingual groups. Age seven was the cutoff used here as it has been identified in the bilingualism literature as "a critical period[5]."

To examine the effects of age of acquisition, participants were regrouped based on the age that they learned their second language. Individuals who learned before the

[5] The *critical-period hypothesis* is a developmentally-based hypothesis that the ability to learn a language well is limited to years before puberty, and that adults are limited in their ability to acquire a second language (Gianico & Altarriba, 2008; Hakuta, Bialystok, & Wiley, 2003).

age of seven were considered “early bilinguals,” people who learned after the age of seven were considered “late bilinguals,” and the monolinguals remained “monolinguals.” See Table 12 for mean bilingual and Simon Effect scores by age and language group.

The same analyses carried out in Section 3.1 of this paper were carried out again but with the participants categorized by age of acquisition. See Appendix G for the full results.

With this regrouping, there was a difference among the early bilinguals, late bilinguals and monolinguals with the traditional overall RT analyses. When the Simon Effect was examined, there was a marginal effect of language group, such that older early and late bilinguals performed differently, but there was no difference for the young bilinguals. See Figure 12 for Simon Effect scores by age and language group. Based on these findings, it seems that age of acquisition plays a role in lessening age-related decline in executive control in older adults but not in accelerating its development in young adults.

Table 12. ***Bilingual and Simon Effect Scores by Age of Acquisition Groups***

		Bilingual scores				Simon effect	
Group	N	Mean	Std dev	Minimum	Maximum	Mean	Std dev
Young early	17	33.56	3.22	26.00	37.00	18.17	22.12
Young late	6	31.86	2.83	27.60	34.93	18.05	50.24
Young mono	20	15.64	6.08	7.00	28.65	42.02	27.91
Older early	6	36.27	0.79	35.00	37.00	29.29	28.74
Older late	12	33.25	2.61	27.70	37.00	55.90	40.54
Older mono	20	9.31	3.50	5.75	17.03	47.06	32.20

Note: Early = early bilingual. Late = late bilingual. Mono = monolingual.

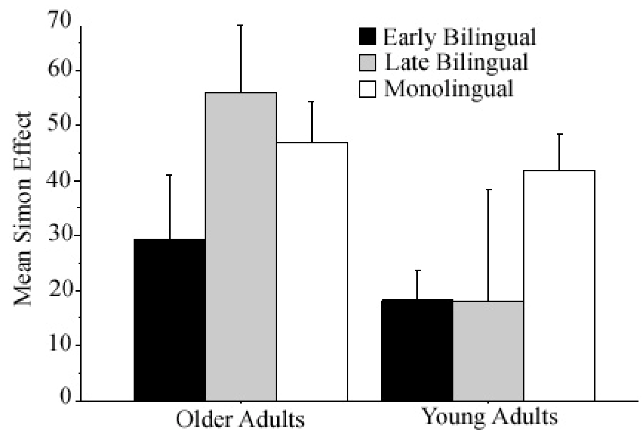

Figure 12. ***Simon Effect scores by age group and age of acquisition group.***

When distributional analyses were carried out, there were no overall language group differences in direct response capture. See Appendix G for the full results. However when young and older adults were examined separately, older late bilinguals made more errors on incongruent trials in the second RT bin compared to older early bilinguals, as shown in Figure 13. This suggests that the executive control correction that took place when the early bilinguals responded slower (i.e., in the second RT bin), took longer for the late bilinguals.

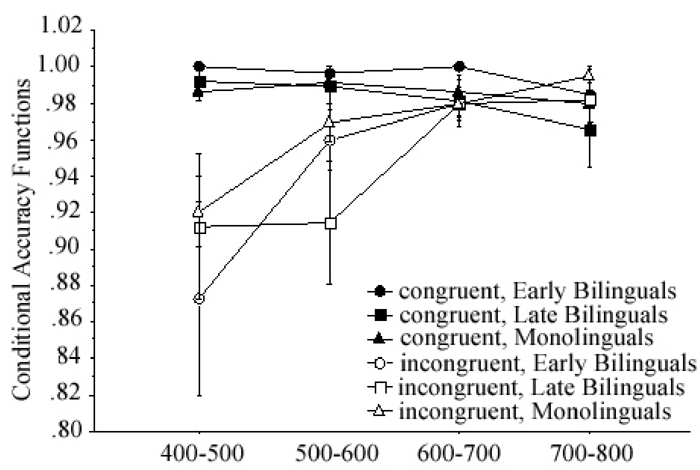

Figure 13. ***CAFs: Mean percentage correct in the Simon task as a function of RT bin by age of acquisition group and congruence in older adults.***

There were no language group differences in selective response inhibition. This suggests that age of acquisition plays a role in lessening decline of direct response capture, a *specific aspect* of executive control, in older bilinguals, but it does not have a global effect on executive control in that it does not affect selective response inhibition.

4.2 Implicit Learning

4.2.1 Bilingualism Does Not Influence Implicit Learning

Like previously mentioned in Section 4.1.1 regarding executive control, there is the possibility that bilingualism simply does not influence implicit learning. It may be the case that different neural substrates underlie executive control and implicit sequence learning, and so while other researchers have found bilingual benefits in executive control tasks, no benefits are found in implicit learning tasks. However, based on the finding in the previous section that age of acquisition plays an important role in cognitive benefits in executive control, one must wonder if the various aspects of bilingualism also play a key role in implicit learning.

4.2.2 Various Aspects of Bilingualism Are Important for Transfer

When the groups in this study were broken down by proficiency and regular language usage, the ASRTT results mirrored the original results reported in Section 3.2 of this paper. However, when the bilingual groups were broken down by age of acquisition, language group differences were revealed. See Appendix G for the full results.

Age of Acquisition. In summary, when the groups were broken down by age of acquisition, there were significant effects of language group, such that for older adults, early bilinguals performed better than late bilinguals and monolinguals on the ASRTT. As can be seen in Figure 14, early bilinguals show the greatest amount of sequence-specific learning as assessed by the RT trial-type effect, followed by the late bilinguals and monolinguals. The trial type x language group interaction was marginal, F (2, 34) = 2.92, $p = 0.07$, and post-hoc ANOVAs revealed a significant difference between early bilinguals and monolinguals, F (1, 23) = 4.32, $p < 0.05$, and a marginal difference between early and late bilinguals, F (1, 16) = 4.00, $p = 0.09$, but no difference between late bilinguals and monolinguals. The young adults showed minor effects, suggesting that early acquisition of a second language has beneficial effects in protecting against cognitive decline of implicit learning but not in accelerating it.

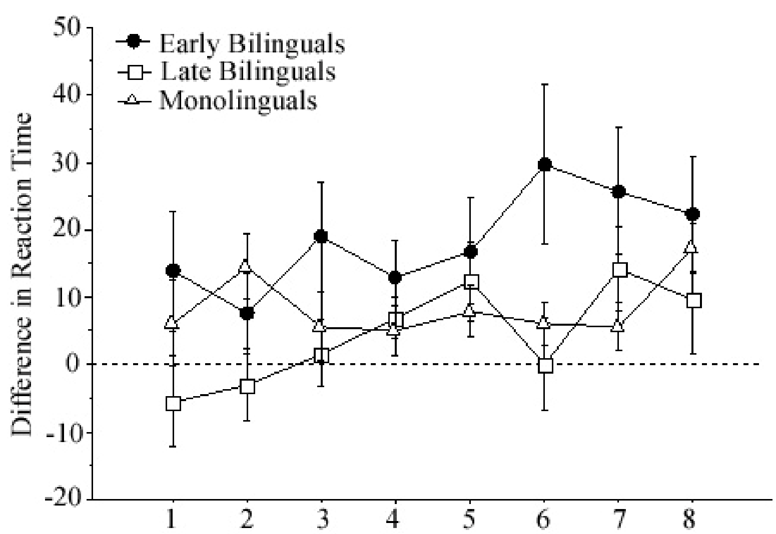

Figure 14. ***ASRTT reaction time (RT) trial-type effect (low-high frequency trials) scores for older adults by age of acquisition group.***

4.3 Summary

Based on these findings, it seems that age of acquisition affects performance on an executive control task and an implicit sequence learning task. This is consistent with theories of neural development and specifically with the aforementioned frontal regions associated with these tasks. However, these findings are not clear-cut in this study, and they contradict neuroimaging research that finds that proficiency seems more important than age of acquisition (Hernandez & Li, 2007) and thus warrant further study. These findings are consistent, however, with the view that early learning of a skill leads to dedicated neural circuitry that affects the form of cognitive and neural structures and later stages of development (Hernandez & Li, 2007; Kuhl, 2004). While this dissertation was not specifically designed to test age of acquisition, it was possible to explore the variable as the information was collected in the Bilingualism Questionnaire. Future research examining age of acquisition of a second language, while controlling for other bilingual variables, and cognitive functioning in old age would prove useful in assessing this possibility.

5.0 Limitations

A fundamental problem in bilingualism research is that there is no consistent assessment of bilingualism. There is a lack of uniformity of reported degree of second language proficiency, age of second language acquisition, how often both languages are used, and the circumstance under which the second language was acquired. Although questionnaires were administered in this study to better understand the bilinguals' second-language abilities and backgrounds, when the groups were sub-grouped by the different variables, the number of people in each group was reduced in size and the comparisons were made with small, uneven sample sizes. Furthermore, these comparisons were made based on self-reported bilingualism abilities. Although the Bilingualism Questionnaire correlated with a well-known test of second language ability, it may not have accurately captured the bilinguals' skills. Future researchers should aim to have a common way to identify and quantify bilingualism so that studies can be accurately compared to one another. Measuring and controlling for these variables is critically important in the study of cognition and bilingualism.

In this study, participants were recruited either through an introductory psychology students participant pool at the university or through advertisements in a local newspaper. In a sense, these participants were selected for the study, and thus these results cannot be generalized to the entire population. However, the chances are very small that people who would perform in a certain way on these tasks (i.e., fast responders) would take an introductory psychology class or opt to participate in a psychology research study. It is very common in psychology research studies such as this one and most of the aforementioned studies, to recruit in the same manner used here.

Similarly, the older participants in this study were recruited from the Washington, DC metro area (including areas of northern Virginia and Maryland that border Washington DC) by newspaper advertisements. By default, this excluded people who did not read the newspapers used to recruit and people who did not live in the area. Furthermore, as this study called for only Spanish-English bilinguals and English monolinguals, results cannot be generalized to bilinguals of different languages. Spanish and English are similar in many ways, and results may differ when examining languages that are very different from each other. Future studies should examine languages that are very different from each other, for example, languages in which words are made with symbols or in which people read from right to left. Having such studies would prove useful in exploring whether cognition is different for different languages and in identifying explanations for enhanced cognition in some languages and not others.

6.0 Conclusion

This dissertation aimed to replicate previous findings of greater executive control in bilinguals versus monolinguals. Furthermore, it aimed to examine the effects of bilingualism on implicit sequence learning, specifically in older adults. It also aimed to explore the importance of variables related to bilingualism that lead to cognitive benefits. Specifically, this dissertation aimed to answer the following questions:

1. Does bilingualism affect performance in an implicit sequence learning task and an executive control task?

2. Do older bilinguals perform better than older monolinguals in an implicit sequence learning task and an executive control task?

3. Are second language proficiency, language usage, and age of acquisition important factors in obtaining cognitive benefits?

The findings of traditional analyses in this study did not replicate existing studies which indicate that older bilinguals have greater executive control than older monolinguals. Young bilinguals in this study demonstrated greater executive control compared to young monolinguals. Older bilinguals and monolinguals, however, performed equivalently. Distributional analyses that examined direct response capture in slow responses and response inhibition in fast responses were utilized in this study, a novel approach for examining the effects of bilingualism on executive control. With these distributional analyses, older bilinguals demonstrated enhanced direct response capture and more efficient response inhibition than older monolinguals, but the young groups performed the same. This suggests that researchers who examine bilingualism and executive control should use distributional analyses, which are more sensitive to response speed variations across the entire session and to congruency effects on accuracy (Forstmann et al., 2008; Ridderinkhof et al., 2005; Stins et al., 2007; Wiegand & Wascher, 2007) rather than the traditional analysis that examines mean response speed for correct responses (Bialystok et al., 2004; Van der Lubbe & Verleger, 2002). For the ASRTT implicit learning task, all groups demonstrated both general skill and implicit sequence-specific learning. Young adults had faster reaction times than older adults, but there were no language group differences. Additional analyses demonstrating a difference in executive control and implicit sequence learning between older early bilinguals and older late bilinguals but not between the young groups suggest that age of acquisition is an important factor in lessening cognitive decline inherent with aging. Although second language proficiency and language usage were not found to be important factors in acquiring cognitive benefits, more studies are needed that include a multitude of bilinguals with differing levels of second-language abilities, including level of second language proficiency and how often the second language is used, as well as differing ages of acquisition.

Research on bilingualism and cognitive aging is very sparse. Such research is made more difficult with the necessity of controlling for many language acquisition and language usage variables. This dissertation adds to the small body of knowledge that is already present and raises many more questions. Future controlled, empirical research should aim to identify variables associated with preserved cognitive aging in bilinguals.

Appendix A: Bilingualism and Cognition

Previous research has shown that while bilinguals may only use one language at a time, both languages are always active, resulting in a mechanism that manages the two competing systems to avoid intrusion from the unwanted language while the chosen language is used (Gollan & Kroll, 2001). This mechanism directs attention to the chosen language while suppressing and inhibiting attention to the unwanted language, and also monitors context to switch to the unwanted language when it is required. Perhaps due to the constant experience of using this mechanism, bilingualism has been shown to alter certain aspects of cognition early on in children and young adults, and also serves to protect against the natural age-related decline in cognition across many domains, such as memory (Kormi-Nouri et al., 2003), cognitive control (Bialystok et al., 2008; Costa et al., 2008; Segalowitz & Frankiel-Fishman, 2005), planning and monitoring (Craik & Bialystok, 2006). While certain aspects of cognition (i.e. verbal abilities and general knowledge) have been shown to increase or remain stable in old age, other aspects (i.e. problem solving, pattern recognition, learning, abstract reasoning) have been shown to decline early, around age 25, and steadily throughout adulthood (Hultsch & Dixon, 1983; Salthouse, 1996). However, it appears that bilingualism may offset this decline.

Bilingualism and Development

An early study by Ianco-Worall (1972) found that bilingual children are able to perceive relationships between words in terms of symbolic rather than acoustic properties at a younger age than monolinguals due to experiencing two different symbols for almost every object in their environment. In the study, nursery and elementary school bilingual and monolingual children performed several verbal tasks. In the first task, they judged the similarity of object names, some of which were phonetically similar and semantically different, and some of which were semantically similar but phonetically different. Bilinguals were better able to interpret the similarity between words in terms of semantics compared to monolinguals. In the second task, participants interchanged names of objects, which required children to ignore semantic meanings and rules that govern the usual relationship among words. Bilinguals excelled over monolinguals in interchanging names when interchanging required formulating the concept that names are arbitrarily assigned to things. In summary, bilingual children displayed a greater ability to realize basic arbitrary relationships between words and the objects they denote, suggesting greater semantic development, compared to monolinguals.

Similarly, Bialystok (1988) investigated meta-linguistic abilities in children. Like the tasks used in Ianco-Worall (1972), children interchanged names of objects, which requires the ignoring of semantic meanings and rules that govern the usual relationship among words. The primary demands of the task were on control of processing since children had to ignore their usual experiences with the words in order to manipulate their usage of them. As in Ianco-Worall (1972), bilingual children were better able to interchange names of objects compared to monolinguals. Children also defined words, a task that relies upon analyzed knowledge of the concept of a word. Bilinguals were better able to formally define words, compared to monolinguals, demonstrating enhanced meta-linguistic performance. The difference, the author argues, lies in the control that bilingual children can exert over their processing of language, which enhances meta-linguistic skills.

Ben-Zeev (1977) and Cromdal (1999) also found that greater control of attention allows bilinguals to ignore semantic meanings and rules that govern the usual relationship among words, enabling them to swap arbitrary names for objects and have a better understanding of syntactic structure than monolinguals. 7-year old children performed a number of verbal tasks (Ben-Zeev, 1977). In the first, a verbal transformation task, a nonsense word was repeated over and over on a loop and participants reported transformations. Bilinguals reported more transformations and began hearing them earlier, compared to monolinguals. The author argues that this is due to bilinguals having to interpret speech of two different structural types, which likely results in a strategy to quickly interpret auditory patterns until a satisfactory interpretation is found. In the second task, a symbol-substitution task, participants substituted one meaning for another, as in Ianco-Worall (1972) and Bialystok (1988). Similar to those studies, bilinguals were better at interchanging names of objects than monolinguals. The bilinguals were better able to "treat words as 'desemanticized' units within a larger syntactic code system and to change the rules of the system as the test required" (Ben-Zeev, 1977, p. 1016). Participants also performed a non-verbal task, a matrix transposition and naming of dimensions task. Children were shown various sized matrices and were asked questions about the "sameness" or "different-ness" of the items in the matrices. They were also asked to transpose the items in the matrices to make sense and complete the system. Bilinguals were significantly better at isolating and specifying underlying dimensions of the matrices and identifying matrix patterns, compared to monolinguals. The bilinguals were better able to reorganize perceptions to identify structure in an arbitrary environment, resulting in a more analytical orientation to structures, compared to monolinguals. These findings lend support to the notion that bilingualism is related to greater control of attention and inhibition skills.

Further support comes from Cromdal (1999), who also found that bilingualism enhances concept formation and meta-linguistic analysis. Monolingual and bilingual children aged 6 and 7 who attended bilingual schools participated in the study. Similar to previous studies (i.e., Ben-Zeev, 1977; Bialystok, 1988; Ianco-Worall, 1972), children performed a symbol substitution task (interchanged names of objects, which required children to ignore semantic meanings and rules that govern the usual relationship among words). Furthermore, these participants performed a sentence judgment and correction task, in which they judged grammar rather than semantics, of the sentences. This task measures meta-linguistic knowledge because knowledge of grammar, as well as the ability to concentrate on language form, is required to perform well. Once again, bilinguals out-performed the monolinguals in fluid tasks requiring symbol substitution (a.k.a. control of processing), such that they produced more successful substitutions than their monolingual peers. Also, bilingual children were better able to make correct judgments of grammar, compared to monolinguals. This study offers additional support for the positive influence of bilingualism on children’s ability to control processing of linguistic information.

Bochner (1996) examined another aspect of cognition: learning styles, specifically motives and strategies in how students approach the task of learning. 14 and 16-year olds filled out questionnaires examining motives and strategies as well as questionnaires about language usage. Questionnaire responses revealed that individuals who are bilingual are more inherently interested in what they learn and are more inclined to regard learning and education as a mode to compete and achieve and as a source of positive self-esteem, compared to monolinguals. They also use more appropriate strategies to attain their goals of acquiring new knowledge than monolinguals. This is similar to the results of Ben Zeev (1977), who found that bilinguals have an inclination to search for structure in perceptual situations and to reorganize perceptions in response to feedback.

Diaz (1983) and Bialystok and Majumber (1998) found that children's control of processing, an aspect of selective attention, is different for bilinguals and monolinguals. They compared bilingual and monolingual children on tasks that depended more on analysis of representational structure or on control of attentional processing. Bilingual children excelled on tasks involving control of processing but not on tasks of analysis, compared to monolinguals. This enhanced component of cognition, the authors argue, is likely due to extended practice in switching between languages, and thus shifting attention.

Further support for enhanced cognition lies in studies of semantic and episodic memory (Kormi-Nouri et al., 2003) and sociolinguistic awareness, which enhances theory of mind (Goetz, 2003). Kormi-Nouri et al., (2003) found that bilingual children recall more in both semantic and episodic memory tasks, as well as in both free recall and cued recall conditions. Monolingual and bilingual 3 and 4-year olds participated in a study examining theory-of-mind (Goetz, 2003). Children were given tasks measuring appearance-reality, perspective, false beliefs with unexpected contents (i.e., a crayon box containing a toy car) and false beliefs with unexpected transfer (i.e., a story about a boy placing an item in one place; his mother moves it while the boy is playing; where will the boy look for the item?). Bilingual children performed better than monolingual children in the tasks, demonstrating enhanced theory-of-mind. Goetz (2003) suggests that because bilingual children use different languages with different groups, they better understand that others have their own mental states, and thus they have enhanced sociolinguistic interactions.

Bilingualism and Age-Related Cognitive Decline

While much earlier research has focused on children and developmental differences between bilinguals and monolinguals, more recent studies have examined differences in adults and the relation between bilingualism and cognitive decline. Evidence has emerged for bilingualism as a defense against decline of executive processes. Cognitive aging research has consistently demonstrated decline in executive processes with age, including cognitive control (Bialystok, Craik & Ryan, 2006), inhibition (Hasher, Stoltzfus, Zacks, & Rypma, 1991), planning and monitoring (Craik & Bialystok, 2006), attention (Salthouse & Miles, 2002; Bialystok, Craik & Ruocco, 2006), dual-task processing (Craik, 1977; Verhaeghen & Cerella, 2002) and certain kinds of implicit learning (Howard & Howard, 1997). Three studies have examined the effects of bilingualism on cognitive control in older adults (Bialystok, Craik, Grady, Chau, Ishii, Gunji and Pantev, 2005; Bialystok et al., 2004; Bialystok, Craik & Ryan, 2006). In one (Bialystok et al., 2004), participants ranged in age from 30 to 88 and participated in the

Simon Task, a computer-based task examining cognitive control. In the Simon Task, colored stimuli are presented on either the right or left side of the screen and each color is associated with a response key: one on the right side of the keyboard and one on the left. On congruent trials, the response key side is the same as the side the associated colored square, and on incongruent trials, the colored square appears on the opposite side of the screen as the associated response key. Irrelevant location information typically results in longer reaction times for incongruent trials. This longer reaction time for incongruent trials is referred to as the "Simon Effect." Bilinguals responded faster overall than monolinguals and experienced a smaller Simon Effect, indicating less interference from incongruent trials, regardless of speed. Furthermore, bilinguals demonstrated a reduction in the age-related increase in the Simon Effect, compared to monolinguals, suggesting that the lifelong experience of managing two competing languages compensates for natural age-related decline such that bilinguals may be somewhat protected against some executive function decline.

In another study (Bialystok et al., 2005), 29-year old bilinguals and monolinguals participated in the Simon Task while undergoing magneto-encephalography (MEG). Bilinguals had faster response times compared to monolinguals, as well as better cognitive control (see also Bialystok, 2006). Furthermore, faster reaction times were associated with increased frontal activation for all groups, but there were activation differences between the bilinguals and the monolinguals. Fast responding in bilinguals was associated with greater activation in the cingulate, superior frontal, and inferior frontal regions, while faster responding in the monolinguals was associated with only left middle frontal activation. Many of the regions associated with faster responding in the bilinguals are regions bordering regions associated with language. The authors suggest that bilingualism enhances those language areas in the brain, and thus leads to advantages in bordering areas. These enhancements ultimately lead to a lesser decline in cognitive abilities, specifically control of attention and inhibition, with advancing age.

Craik and Bialystok (2006) examined another aspect of cognition: planning and monitoring. Older (mean age = 69.6 years) and younger (mean age = 20.2 years) bilinguals and monolinguals participated in a computerized task designed to replicate cooking breakfast while setting a table (as a distracter task). Good planning in the task required many high-level cognitive skills, such as abstract reasoning, problem solving and looking ahead, all previously shown to decline with age. They found that although older adults in general showed deficits in planning and monitoring compared to young, the older bilinguals out-performed older monolinguals, such that they were more efficient and made better use of time to perform the breakfast tasks compared to older monolinguals. Both older and young bilinguals demonstrated better planning and monitoring skills over their monolingual counterparts. This study demonstrated that not only does bilingualism lead to better planning and monitoring compared to monolinguals, but also, the use of a task so similar to real life demonstrates the importance of such benefits.

More recently, Bialystok et al. (2007) examined whether bilingualism protects against dementia symptoms. Medical files of 184 older individuals (mean age = 77) who had been admitted into a memory clinic were examined. Bilinguals were classified as individuals who were fluent in two languages and had used both languages regularly for most of their lives. They found that the bilinguals exhibited a delay of four years in the onset of dementia symptoms, compared to their monolingual peers. This study demonstrates that not only does bilingualism enhance various aspects of cognition throughout a lifetime, but it also seems to be a protective factor against cognitive decline into old age, a finding that has tremendous implications for health care, mental wellness and future research.

Fluency

Studies have examined specific aspects of bilingualism that lead to cognitive benefits. Some studies report fluency or proficiency, that is how *well* people speak both languages, some report length of exposure to both languages, some report language usage (i.e., regular use of both languages versus occasional use of one and regular use of the other), and yet others report age of acquisition of the second language. It is unclear if one aspect of bilingualism is more important than another or if all factors are equally important in order to experience cognitive benefits.

A detailed look at the bilingualism research lends support to the notion that proficiency plays a role in the cognitive benefits associated with bilingualism. Cummins (1979) argues for a threshold theory such that two thresholds of language proficiency must be reached before a bilingual child receives cognitive benefits. The first is needed to avoid cognitive deficits and the second is needed to gain cognitive benefits. Thus, different degrees of bilingualism result in different effects on cognitive abilities. Studies have consistently shown that higher proficiency in *both* languages yields greater benefits than high proficiency in only one language and a low proficiency in the other (i.e., Bialystok & Majumber, 1998; Segalowitz & Frenkiel-Fishman, 2005) or than low proficiency in both languages (i.e., Andreou & Karapetsas, 2004; Ricciardelli, 1992). In the previous mentioned study by Cromdal (1999), it was found that the highly bilingual children performed better than their less proficient bilingual peers, producing the highest number of successful substitutions, compared to both monolinguals and partial bilinguals. Andreou and Karapetsas (2004) found that highly proficient balanced bilingual adolescents performed better at various verbal ability tasks compared to low proficient bilinguals.

Bialystok & Majumber (1998) found that fully bilingual children showed an advantage over the partial bilinguals and monolinguals in the analysis task previously mentioned. Higher degrees of balanced bilingualism were associated with higher scores on the analysis tasks. Diaz (1983) also demonstrated higher degrees of bilingualism relating to higher levels of cognition. Similar to previously mentioned studies (ie. Cromdal, 1999), more proficient bilinguals performed better than less proficient bilinguals in tasks measuring concept formation, meta-linguistic awareness, and cognitive flexibility.

In addition, Ricciardelli (1992) found that only balanced bilinguals, those who were highly proficient in *both* languages, demonstrated cognitive advantages. In tasks measuring meta-linguistic awareness, children who were five and six-years old performed a word discrimination task, a word length task, a word print task, a symbol substitution task, and a word order correction task. Those who had low proficiency in both languages experienced negative cognitive effects, while those who had high proficiency in both languages experienced beneficial effects and scored higher in specific areas, specifically divergent thinking, imagination, grammatical awareness, perceptual organization and reading achievement. Consistent with Bialystok and Majumber (1998), this study demonstrates that proficiency does indeed play a role in cognitive advantages associated with bilingualism, such that individuals must be highly proficient in *both* languages in order to benefit.

Some studies have addressed the importance of age of acquisition in order for bilingualism to have positive effects on other aspects of cognition (Hernandez & Li, 2007; Kharkhurin, 2008; Mechelli et al., 2004; Golestani et al., 2006; Wartenburger et al., 2003). For example, Golestani et al. (2006) found different patterns of brain activation in early versus late learners in grammatical processing. During syntactical production tasks, Golestani et al. (2006) demonstrated activation in the left inferior parietal cortex, an area associated with processing complex syntactic structure and coding and retrieval of verbal working memory. This activation was greater when participants used their second language, which presumably is more cognitively demanding than their first language. They also found a similar pattern in the dorsolateral prefrontal cortex, a region thought to underlie attention and the central executive system. They suggest that the neural systems mediating grammatical processing are more vulnerable to changes in early experiences than those mediating semantic processing. Similarly, Wartenburger et al. (2003) suggested that the age of acquisition affected cortical representations of grammatical processes such that late learners activated inferior frontal regions bilaterally more than early learners. One study suggests that bilinguals have greater grey matter density than monolinguals and that the degree of structural reorganization is correlated to second language performance (Mechelli et al., 2004). Mechelli and colleagues(2004) found that the density difference was greater in early bilinguals compared to late bilinguals and suggests that the structure of the brain is altered by early experiences when acquiring a second language.

Of all the previous studies that have examined cognitive effects of bilingualism, one stands out as the most thorough. In 2008, Kharkhurin identified three major factors in bilingual development that relate to bilinguals' cross-linguistic and cross-cultural experience. First, the bilingual must be proficient in the two languages; second, the bilingual must have acquired the second language at a very young age, and third, the bilingual must have had extensive exposure to the cultural setting in which the languages were acquired. In other words, in order for a bilingual to experience cognitive transfer, or cognitive benefits in other areas, a person must acquire the second language at a very young age, must immerse themselves into an environment where the language is spoken (and the culture associated with the new language is learned), and must gain proficiency in the second language to the extent that they can speak, read, write and listen to it just as well as their first language.

All in all, studies on bilingualism and cognition have shown that bilingualism is associated with enhanced cognitive abilities. It appears that the constant exercising of control and managing of two languages leads to an advantage in non-language related tasks. Bilingualism produces processing differences in both young and old, enhances control of attention and inhibition, as well as offsets age deficits in tasks unrelated to language. Fluency and age of acquisition also appear to play roles, such that individuals who are more balanced and fluent in both languages and who begin speaking at a young age reap larger benefits compared to individuals who only partially know a second language or who learn later in life. Although many areas of cognition have been examined, many others, such as implicit learning, still need further exploration.

Appendix B: Implicit Sequence Learning

Implicit learning refers to the unintentional, automatic acquisition of knowledge about the structural relations between (usually more than two) objects or events (Stadler & Frensch, 1998). Knowledge acquisition is incidental, that is, participants are not informed that there are regularities, nor are they instructed to search for regularities. There are a number of different ways to examine implicit learning. One major paradigm, and the one we will focus on here, is implicit sequence learning.

Typically in an implicit sequence learning task, participants respond as fast as possible to event sequences that follow a subtle pattern (Nissen & Bullemer, 1987; Howard & Howard, 1989). One well-known implicit sequence learning task is the serial reaction time (SRT) task (Nissen & Bullemer, 1987). In the SRT task, events, such as asterisks, appear in one of four different locations on a computer screen. Participants are instructed to press the key below the stimulus when it appears, as quickly as possible while maintaining a high level of accuracy. The positions at which the stimuli appear on the screen occur in a specific repeating pattern unbeknownst to the participant. Learning is assessed by comparing performance on the pattern trial blocks to performance on random event blocks, which occur either within or at the end of the session. Learning is said to occur when individuals are faster on pattern blocks compared to random blocks.

Early studies revealed that young and older adults perform similarly on implicit sequence learning tasks. That is, unlike explicit tasks, there are few age-related differences associated with implicit sequence learning (Cherry & Stadler, 1995; Frensch & Miner, 1994; Howard & Howard, 1989; Knopman & Nissen, 1987; Nissen, Willingham, & Hartman, 1989). In one study by Howard and Howard (1989), both young and older adults implicitly learned the sequence. Older individuals learned as much as the young, even though their reaction time was significantly slower.

One major problem with the SRT task is that oftentimes there is explicit awareness of the learned pattern (Howard & Howard, 1992; Knopman, 1991; Willingham & Dumas, 1997). To address this, Howard and Howard (1997) introduced a more complex version of the SRT task, the Alternating SRT (ASRT) task. In the ASRT task, alternate stimuli follow a predetermined pattern while the remaining stimuli are selected randomly. For example, for the pattern 1234, where 1 represents the leftmost position on the screen and 4 represents the rightmost position, the pattern would be 1r2r3r4r, where "r" represents random chosen stimuli. Learning is again measured by comparing performance on the pattern versus random trials. People are unable to explicitly describe the pattern they implicitly learn in the ASRT task.

Another problem associated with the SRT task is that there is not a continuous measure of learning. Learning assessment depends on random test blocks that take place after learning has occurred. However, the ASRT task provides a continuous measure of learning, and so learning can be assessed with ongoing practice.

Furthermore, whereas in the SRT task, older adults do not show a deficit in learning, in the ASRT task, they do. In an early paper by Howard and Howard (1997), young, young-old and old-old all demonstrated learning on the ASRT task. However, age-related deficits were found in the magnitude of learning, such that young-old and old-old did not learn as much as young. Furthermore, only the young showed sensitivity to higher order statistical structure. Since this first paper demonstrating age-related differences in the magnitude of learning on the ASRT task, others have emerged, replicated these findings (Dennis, Howard & Howard, 2003; Feeney, Howard & Howard, 2002; Howard, Howard, Dennis & Yankovich, 2007; Howard, Howard, Japikse, DiYanni, Thompson & Somberg, 2004).

While previous research has found age-related deficits on the ASRT task, none to date have examined the effects of bilingualism on implicit learning. This type of learning is also involved in acquiring a new language, learning motor skills and other tasks that require shifts of attention (Conway & Christensen, 2001; Jimenez & Mendez, 1999; Stadler, 1995). Therefore, one can expect that bilingualism will also offer some advantage on the ASRT task since it is a motor task that requires shifts of attention. For example, research on older adults has shown that bilinguals experience better executive control than monolinguals (Bialystok et al., 2004). Executive control may play a role in the ASRT task, in that greater executive control may lead to less impulsive responses. If this is the case, then bilinguals, who have better executive control, should perform better on this task and make fewer impulsive responses, compared to monolinguals. Furthermore, bilinguals experience a four-year delay in dementia symptoms (Bialystok et al., 2007). This enhanced cognition may compensate for the effects of age-related cognitive decline on implicit learning. However, more research is needed to verify the advantages and to examine links between bilingualism and enhanced cognition, particularly in older adults. Although many lifestyle factors, such as physical exercise, social activities, diet, intellectual engagement, and memory training have been shown to improve cognition and compensate for cognitive aging (Baltes & Baltes, 1993; Brenes, 2003; Buell, Scott, Dawson-Hughes, Dallal, Rosenberg, Folstein & Tucker, 2009; Buchman, Boyle, Wilson, Fleischman, Leurgans & Bennett, 2009; Bunce & Muren, 2006; Buschkuehl, Jaeggi, Hutchison, Perrig-Chiello, Dapp, Muller, et al., 2008; Camp, Foss, Stevens, Reichard, McKitrick & O'Hanlon, 1993; Caprio-Prevette & Fry, 1996; Cassavaugh & Kramer, 2009; Cavallini, Pagnin & Vecchi, 2003; Colcombe, Kramer, Erickson, Scalf, McAuley, Cohen, et al., 2004; Connor, 2001; Cotman & Berchtold, 2002; Dahlin, Nyberg, Backman & Neely, 2008; Del Parigi, Panza, Capurso, & Solfrizzi, 2006; Dellefield & McDougall, 1996; De Vreese, Belloi, Iacono, Finelli & Neri, 1998; Gunther, Schafer, Holzner & Kemmler, 2003; Hogan, 2005; Hultsch, Hertzog, Small & Dixon, 1999; Jobe, Smith, Ball, Tennstedt, Marsiske, Willis, et al., 2001; Koustaal, Schacter, Johnson, Angell & Gross, 1998; Kramer, Colcombe, McAuley, Eriksen, Scalf, Jerome, et al., 2003; Kramer, Hahn, Cohen, Banich, McAuley, Harrison, et al., 1999; Lachman, Weaver, Bandura, Elliot & Lewkowicz, 1992; Lindenberger, Marsiske & Baltes, 2000; Logsdon, McCurry, Pike & Teri, 2009; Lopez,-Crespo, Plaza, Fuentes & Estevez, 2009; McAuley, Elavsky, Jerome, Konopack & Marquez, 2005, McDaniel, Ryan & Cunningham, 1998; Rowe & Kahn, 1998; Snowden, 2001; Weil, 2005; Wight, Aneshensel & Seeman, 2002), little research has focused on lifelong bilingualism. This study will add to what we already know about aging gracefully by examining the link between being fluent in two languages throughout a lifetime and cognition into old age.

Appendix C: Bilingualism Questionnaire

Language #1					Language #2				
________________________					________________________				
Which?	Level of competence?				Which?	Level of competence?			
_____Speak	1	2	3	4	_____Speak	1	2	3	4
_____Write	1	2	3	4	_____Write	1	2	3	4
_____Listen	1	2	3	4	_____Listen	1	2	3	4
_____Read	1	2	3	4	_____Read	1	2	3	4
	Not at all	Not well	Well	Very well		Not at all	Not well	Well	Very well

Have you worked or lived in countries where this language is spoken? Please give details of the length of time in each case:

_______________________________ _______________________________
_______________________________ _______________________________
_______________________________ _______________________________
_______________________________ _______________________________
_______________________________ _______________________________
_______________________________ _______________________________
_______________________________ _______________________________

If more than one language is spoken in your home, please list them according to how often they are used.

Most often used language: __________________________
2nd most-often used language: __________________________
3rd most-often used language: __________________________

Are both languages spoken simultaneously? _____ OR Do you use one in one scenario and the other in another scenario? ______ (check ONLY one)

Explain ____
____

At what age did you begin to speak your second language? _______________

How did you learn your second language? For example, some people grow up learning two languages simultaneously, while others learn when they move to a new country, and others learn in class. How did you learn? ____

Are you able to switch between the languages at will? Yes No

Do you speak both languages at home? Yes No

Do you use both languages more than two times a week? Yes No

Explain ____
____

Part 1: Please read each of the descriptive statements regarding oral proficiency of LANGUAGE #1 (________________) in the following sections. The statements represent a wide range of abilities. Place a check in the line preceding the statement that best represents your present level of ability in each of these sections.

1. Listening Comprehension
_____ I can understand a limited number of high frequency words and common conversational set expressions such as "How are you?" or "My name is –".
_____ I can understand simple questions and statements in short dialogues or passages if it is repeated at slower-than-normal speed.
_____ I can understand the main points of a short dialogue or passage if spoken at slower-than-normal speed. I may need some repetition.
_____ I can understand most of what is said (all main points and most details) at near normal speed.
_____ I can understand nearly everything at normal speed, although occasional repetition may be necessary.
_____ I can understand everything at normal speed like a native speaker.

2. Fluency
_____ I can speak using only short question-answer patterns such as "How are you? I am fine, thank you."
_____ I can participate in a simple conversation on familiar everyday topics at slower-than-normal speed. I must frequently pause during conversation.
_____ I can express myself using simple language, but make mistakes and pause a lot when I try to express complex ideas.
_____ I can effortlessly express myself at near normal speed. Occasionally, I have to slow down when expressing complex ideas and less-common expressions.
_____ I am generally fluent, but occasionally have minor pauses when I search for the correct manner of expression.
_____ I have native-like fluency.

3. Vocabulary in Speech
_____ I know a limited number of high frequency words and common conversational set expressions (e.g., How are you? My name is…)
_____ I have enough vocabulary to make simple statements and ask questions in a simplified conversation.
_____ I have an adequate working vocabulary. I know some synonyms and can express simple ideas in a limited number of different ways.
_____ I have enough vocabulary to participate in everyday conversations and know many alternative ways of expressing simple ideas.
_____ I have enough vocabulary to participate in more extended discussions on various topics. I also know some connotations and nuances of certain words and expressions.
_____ I have an extensive native-like vocabulary.

4. Pronunciation
_____ I have difficulty in accurately producing the sounds and sound patterns of the language.
_____ I am beginning to master some sounds and sound patterns, but still have difficulty with some of the sounds.
_____ I can produce most of the sounds and sound patterns, but sometimes need to repeat myself to make the utterance more clear.
_____ My speech is always intelligible, but a definite accent and/or awkward intonation patterns are apparent.
_____ My pronunciation and intonation are near native-like.
_____ My pronunciation and intonation are *exactly* like those of a native speaker.

5. Grammar in Speech
_____ I can only use common conversational set expressions.
_____ I can produce very basic sentence patterns but with frequent grammatical errors.
_____I can produce a few complex sentence constructions but with noticeable grammatical errors.
_____ I can speak using a good range of complex patterns and grammatical rules. However, occasional errors are still present.
_____ I have a good command over a large range of complex grammar and errors are infrequent.
_____ I can speak with a native-like command of complex grammatical patterns.

Part 2: Please read the following statements in each of the four areas. Rate how well you can perform the various activities in LANGUAGE #1 (___________________) on a scale of 1 (cannot do it at all) to 5 (can do it comfortably). Circle the appropriate level.

1: I cannot do it at all.
2: I can do it but with great difficulty.
3: I can do it but with some difficulty.
4: I can do it fairly well but with occasional difficulty.
5: I can do it comfortably.

1. Listening Comprehension

1	2	3	4	5	I can understand a short message on the answering machine/voicemail.
1	2	3	4	5	I can watch and understand a television program.
1	2	3	4	5	I can understand a lecture given by a native speaker on a topic that interests me.
1	2	3	4	5	I can play BINGO.
1	2	3	4	5	I can understand directions to my friend's house.
1	2	3	4	5	I can understand a native speaker describe his/her favorite hobby.
1	2	3	4	5	I can understand a story that the teacher reads to us in class.
1	2	3	4	5	I can understand my teacher's directions in class.
1	2	3	4	5	I can understand the explanation of the rules of a game.
1	2	3	4	5	I can understand general questions about myself and my family.

2. Speaking

1	2	3	4	5	I can greet someone.
1	2	3	4	5	I can tell someone my summer vacation plans.
1	2	3	4	5	I can tell a friend about a television program I recently saw.
1	2	3	4	5	I can leave a message on an answering machine/voice mail (e.g., name, phone number, time, date, reason for calling).
1	2	3	4	5	I can converse with a native speaker on any general topic using the appropriate language forms.
1	2	3	4	5	I can describe my best friend.
1	2	3	4	5	I can introduce myself to other people.
1	2	3	4	5	I can explain the rules of my favorite game to someone.
1	2	3	4	5	I can answer general questions about my family.
1	2	3	4	5	I can give someone directions to my house.

3. Reading Comprehension

1	2	3	4	5	I can read instructions on a test.
1	2	3	4	5	I can read the names of simple objects.
1	2	3	4	5	I can read a newspaper.
1	2	3	4	5	I can read the instructions for a board game.
1	2	3	4	5	I can read some or all of a popular novel.
1	2	3	4	5	I can read a letter from a pen-pal.
1	2	3	4	5	I can read magazines with minimal use of a dictionary.
1	2	3	4	5	I can read simple sentences in a textbook.
1	2	3	4	5	I can read a short children's story.
1	2	3	4	5	I can read a note from my teacher.

4. Writing

1	2	3	4	5	I can list the things in my school bag.
1	2	3	4	5	I can write a review of my favorite movie/book.
1	2	3	4	5	I can write a note to my friend.
1	2	3	4	5	I can write a report on the history of a foreign country.
1	2	3	4	5	I can keep a journal.
1	2	3	4	5	I can describe the characteristics of my best friend.
1	2	3	4	5	I can write a letter to my pen-pal.
1	2	3	4	5	I can write about my future plans and the reasons for them.
1	2	3	4	5	I can take a simple telephone message.
1	2	3	4	5	I can write an essay expressing my thoughts on learning a foreign language in high school.

Part 3: Please read each of the descriptive statements regarding oral proficiency of LANGUAGE #2 (_________________) in the following sections. The statements represent a wide range of abilities. Place a check in the line preceding the statement that best represents your present level of ability in each of these sections.

1. Listening Comprehension

_____ I can understand a limited number of high frequency words and common conversational set expressions such as "How are you?" or "My name is –".

_____ I can understand simple questions and statements in short dialogues or passages if it is repeated at slower-than-normal speed.

_____ I can understand the main points of a short dialogue or passage if spoken at slower-than-normal speed. I may need some repetition.

_____ I can understand most of what is said (all main points and most details) at near normal speed.

_____ I can understand nearly everything at normal speed, although occasional repetition may be necessary.

_____ I can understand everything at normal speed like a native speaker.

2. Fluency

_____ I can speak using only short question-answer patterns such as "How are you? I am fine, thank you."

_____ I can participate in a simple conversation on familiar everyday topics at slower-than-normal speed. I must frequently pause during conversation.

_____ I can express myself using simple language, but make mistakes and pause a lot when I try to express complex ideas.

_____ I can effortlessly express myself at near normal speed. Occasionally, I have to slow down when expressing complex ideas and less-common expressions.

_____ I am generally fluent, but occasionally have minor pauses when I search for the correct manner of expression.

_____ I have native-like fluency.

3. Vocabulary in Speech

_____ I know a limited number of high frequency words and common conversational set expressions (e.g., How are you? My name is…)

_____ I have enough vocabulary to make simple statements and ask questions in a simplified conversation.

_____ I have an adequate working vocabulary. I know some synonyms and can express simple ideas in a limited number of different ways.

_____ I have enough vocabulary to participate in everyday conversations and know many alternative ways of expressing simple ideas.

_____ I have enough vocabulary to participate in more extended discussions on various topics. I also know some connotations and nuances of certain words and expressions.

_____ I have an extensive native-like vocabulary.

4. Pronunciation
_____ I have difficulty in accurately producing the sounds and sound patterns of the language.
_____ I am beginning to master some sounds and sound patterns, but still have difficulty with some of the sounds.
_____ I can produce most of the sounds and sound patterns, but sometimes need to repeat myself to make the utterance more clear.
_____ My speech is always intelligible, but a definite accent and/or awkward intonation patterns are apparent.
_____ My pronunciation and intonation are near native-like.
_____ My pronunciation and intonation are exactly like those of a native speaker.

5. Grammar in Speech
_____ I can only use common conversational set expressions.
_____ I can produce very basic sentence patterns but with frequent grammatical errors.
_____I can produce a few complex sentence constructions but with noticeable grammatical errors.
_____ I can speak using a good range of complex patterns and grammatical rules. However, occasional errors are still present.
_____ I have a good command over a large range of complex grammar and errors are infrequent.
_____ I can speak with a native-like command of complex grammatical patterns.

Part 4: Please read the following statements in each of the four areas. Rate how well you can perform the various activities in LANGUAGE #2 (___________________) on a scale of 1 (cannot do it at all) to 5 (can do it comfortably). Circle the appropriate level.

1: I cannot do it at all.
2: I can do it but with great difficulty.
3: I can do it but with some difficulty.
4: I can do it fairly well but with occasional difficulty.
5: I can do it comfortably.

1. Listening Comprehension

1	2	3	4	5	I can understand a short message on the answering machine/voicemail.
1	2	3	4	5	I can watch and understand a television program.
1	2	3	4	5	I can understand a lecture given by a native speaker on a topic that interests me.
1	2	3	4	5	I can play BINGO.
1	2	3	4	5	I can understand directions to my friend's house.
1	2	3	4	5	I can understand a native speaker describe his/her favorite hobby.
1	2	3	4	5	I can understand a story that the teacher reads to us in class.
1	2	3	4	5	I can understand my teacher's directions in class.
1	2	3	4	5	I can understand the explanation of the rules of a game.
1	2	3	4	5	I can understand general questions about myself and my family.

2. Speaking

1	2	3	4	5	I can greet someone.
1	2	3	4	5	I can tell someone my summer vacation plans.
1	2	3	4	5	I can tell a friend about a television program I recently saw.
1	2	3	4	5	I can leave a message on an answering machine/voicemail (e.g., name, phone number, time, date, reason for calling).
1	2	3	4	5	I can converse with a native speaker on any general topic using the appropriate language forms.
1	2	3	4	5	I can describe my best friend.
1	2	3	4	5	I can introduce myself to other people.
1	2	3	4	5	I can explain the rules of my favorite game to someone.
1	2	3	4	5	I can answer general questions about my family.
1	2	3	4	5	I can give someone directions to my house.

3. Reading Comprehension

1	2	3	4	5	I can read instructions on a test.
1	2	3	4	5	I can read the names of simple objects.
1	2	3	4	5	I can read a newspaper.
1	2	3	4	5	I can read the instructions for a board game.
1	2	3	4	5	I can read some or all of a popular novel.
1	2	3	4	5	I can read a letter from a pen-pal.
1	2	3	4	5	I can read magazines with minimal use of a dictionary.
1	2	3	4	5	I can read simple sentences in a textbook.
1	2	3	4	5	I can read a short children’s story.
1	2	3	4	5	I can read a note from my teacher.

4. Writing

1	2	3	4	5	I can list the things in my school bag.
1	2	3	4	5	I can write a review of my favorite movie/book.
1	2	3	4	5	I can write a note to my friend.
1	2	3	4	5	I can write a report on the history of a foreign country.
1	2	3	4	5	I can keep a journal.
1	2	3	4	5	I can describe the characteristics of my best friend.
1	2	3	4	5	I can write a letter to my pen-pal.
1	2	3	4	5	I can write about my future plans and the reasons for them.
1	2	3	4	5	I can take a simple telephone message.
1	2	3	4	5	I can write an essay expressing my thoughts on learning a foreign language in high school.

Appendix D: Tables of Frequencies for CAF RT Bins

	Young adults		Older adults	
RT bin	Monolinguals	Bilinguals	Monolinguals	Bilinguals
< 300	97	117	14	12
300-399	1283	1280	81	126
400-499	1635	2377	812	669
500-599	1041	1227	1545	916
600-699	497	503	1062	790
> 699	571	596		
700-799			486	473
> 799			636	674

Appendix E. One-Tailed T-Test Values for CAF Slope Comparisons

	Young adults				Older adults			
Slopes	Monolinguals		Bilinguals		Monolinguals		Bilinguals	
	t value	*p* value	*t* value	*p* value	*t* value	*p* value	*t* value	*p* value
1 vs. 2	2.02	0.03	1.86	0.04	.49	0.32	4.18	0.00
1 vs. 3	4.69	0.00	3.87	0.00	1.03	0.16	2.61	0.01

Note. Slope 1 is the left-most, steepest slope, followed by slope 2, then slope 3, the right-most, shallowest slope.

Appendix F. Proficiency Analyses

Simon Task

Traditional analyses. For the Simon task, there was a main effect of age group, such that older adults were slower than young adults, F (1, 48) = 16.27, $p < 0.001$, but there was no main effect of language group F (1, 48) = 0.55, *ns*, indicating that overall, bilingualism did not influence RT, and there was no age group x language group interaction, F (1, 48) = 0.10, *ns*, indicating that older high-fluency bilinguals and low-fluency monolinguals were slower than their young counterparts with no effects of language. There was a main effect of trial type, F (1, 48) = 57.47, $p < 0.0001$, such that the incongruent trials were slower than congruent trials when averaged over the four groups, indicating that overall, people revealed a Simon Effect. These results mirror the original results obtained.

For the Simon Effect analyses, unlike in the original results, a 2 x 2 (age group x language group) ANOVA revealed *no* main effect of age group, F (1, 48) = 0.28, *ns*, or language group, F (1, 48) = 0.16, *ns*, and no age group x language group interaction, F (1, 48) = 3.50, *ns.*

Distributional analyses. For the distributional analyses, the CAFs for each RT bin by trial type (congruent and incongruent) and language group are plotted in Figure 15 (young adults: upper graph; older adults: lower graph).

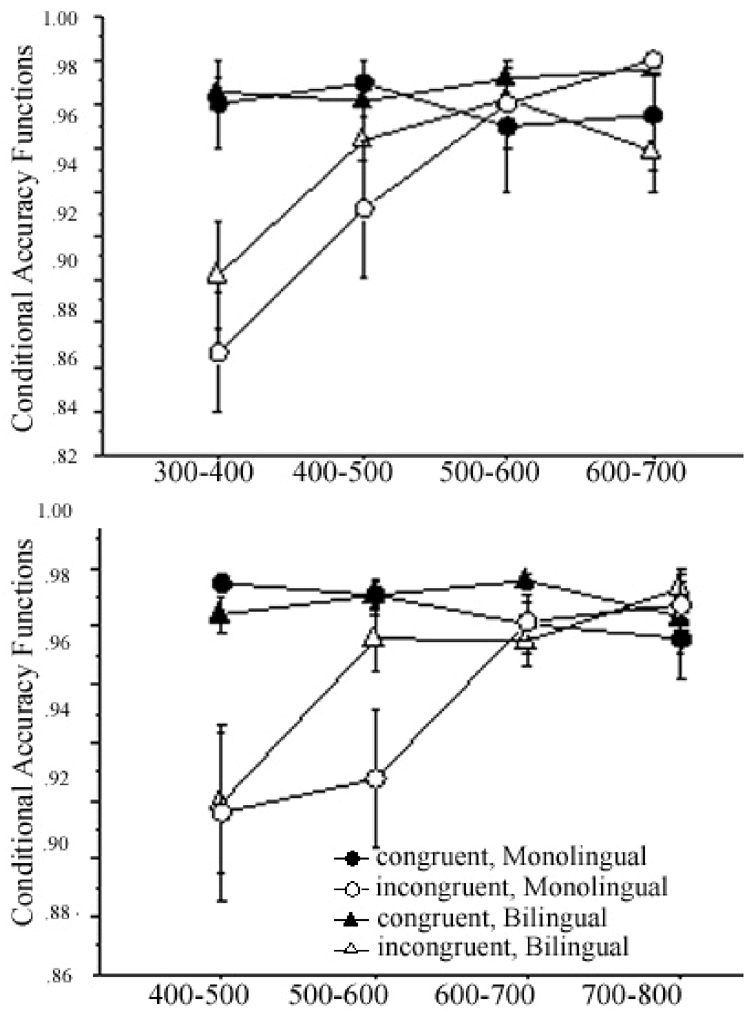

Figure 15. ***CAFs: Mean percentage correct in the Simon task as a function of RT bin by language group and congruence (young adults: upper graph; older adults: lower graph).***

As shown in Figure 15 and consistent with the original results, for all groups, very fast incongruent responses were more error prone than slow incongruent responses. For incongruent responses, averaged across all groups, there was a significant difference between slope 1 and slope 2, t (40) = 3.20, and between slope 1 and slope 3, $p = 0.001$, t (37) = 3.18, $p < 0.01$, such that the left-most slope was steeper than the others, indicating greater errors when people make very fast responses versus slower responses. Alternatively, as can be seen in Figure 15 and consistent with the original results, overall, error rates on congruent trials did not differ as a function of response speed. For congruent responses, averaged across all four groups, there was no difference between slope 1 and slope 2, t (43) = -0.13, *ns*, and between slope 1 and slope 3, t (40) = 0.14, *ns.*

When each group was examined separately, the same results were found for young high-fluency bilinguals, young high-fluency monolinguals and older high-fluency bilinguals. However, consistent with the original results, older low-fluency monolinguals, did not show a difference between slope 1 and 2 or between slope 1 and 3. As shown in Figure 15, the lack of a difference between slope 1 and 2 is likely is due to the fact that the older low-fluency monolinguals made more errors in the second RT bin compared to the other groups whose accuracy values in the second RT bin had nearly reached the same accuracy values as the slower RT bins.

Group differences were examined further. For young and older adults, results were submitted separately to mixed-design 2 x 2 x 3 (trial type x language group x RT bin) ANOVAs for the three fastest RT bins only, with repeated measures on the trial-type and RT-bin factors. For young adults, there was a main effect of trial type, F (1, 16) = 9.07, $p < 0.01$, such that accuracy was higher on congruent than incongruent trials (99% vs. 95%). There was a significant main effect of RT bin, F (2, 32) = 6.16, $p < 0.01$, demonstrating higher accuracy on slower than faster responses, and a significant trial type x RT bin interaction, F (2, 32) = 6.84, $p < 0.01$, demonstrating higher accuracy for congruent versus incongruent trials on fast compared to slow responses. The main effect of language group was not significant, F (1, 16) = 1.33, *ns*, and the trial type x language group interaction was not significant F (1, 16) = 0.05, *ns*, suggesting no difference in accuracy between young high-fluency bilinguals and low-fluency monolinguals.

For older adults, there was also a main effect of trial type, F (1, 20) = 19.21, $p <$ 0.001, such that accuracy was higher on congruent than incongruent trials (99% vs. 95%). As with the young adults, there was a significant main effect of RT bin, F (2, 40) = 4.83, p = 0.01, demonstrating higher accuracy on slower responses than faster responses, and a significant trial type x RT bin interaction, F (2, 40) = 6.16, p < 0.01, demonstrating higher accuracy for congruent versus incongruent trials on fast compared to slow responses. The main effect of language group, F (1, 20) = 1.43, *ns*, and the trial type x language group interaction, F (1, 20) = 1.15, *ns*, were not significant, suggesting no overall difference between older high-fluency bilinguals and low-fluency monolinguals. There was also no significant trial type x language group x RT bin interaction, F (2, 40) = 2.16, *ns*.

Delta plots for RT were constructed by plotting Simon Effect size (mean RT in the incongruent condition minus mean RT in the congruent condition) as a function of RT bin as shown in Figure 16 (young adults: upper graph; older adults: lower graph) for the new groups.

As can be seen in Figure 16 and consistent with the original results, for both young and older high-fluency bilinguals, the delta plot slope turns negative between the third and fourth RT bin. Conversely, for young low-fluency monolinguals, the delta plot remains stable, and for older low-fluency monolinguals, the delta plot turns positive. Using one-tailed *t*-tests, slope 3 (the right-most, slowest slope) was compared to the other slopes (slopes 2 and 1, right to left, where slope 1 is the fastest). Averaged across all groups, there was no significant difference between slope 3 and slope 1, *t* (44) = 0.75, *ns*, and no significant difference between slope 3 and slope 2, *t* (47) = 0.13, *ns*. When each groups was examined separately, none of the groups demonstrated a difference between slope 3 and slope 1 or between slopes 3 and 2.

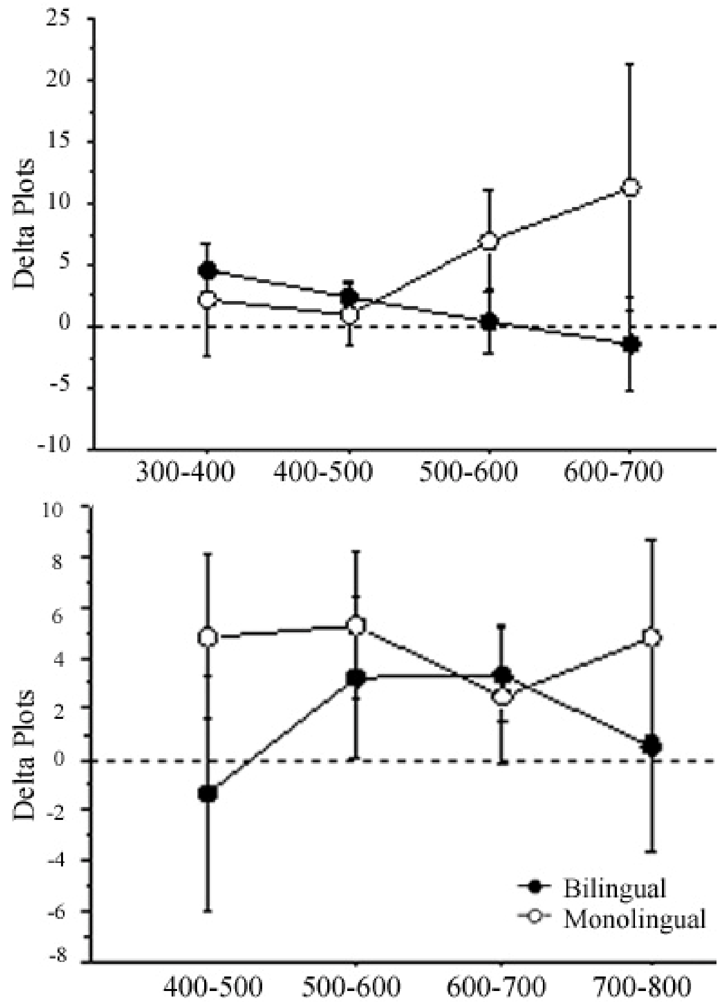

Figure 16. ***Delta plots for reaction time (RT) as a function of RT bin by language group (young adults: upper graph; older adults: lower graph).***

Implicit Sequence Learning

Overall skill learning. For overall skill learning, Figure 17 displays the overall mean of the median RT (upper graph) and mean accuracy (lower graph) for both high-and low-frequency trials. The RT and accuracy data were subjected to separate 8 x 2 x 2 x 2 (epoch x trial type x age group x language group) ANOVAs. As shown in Figure 17 and as is typical, people responded faster overall with practice. This was confirmed in the significant main effect of epoch for RT, F (7, 343) = 39.26, $p < 0.0001$, indicating general skill learning. As with the original result, the main effect of age group, F (1, 49) = 54.13, $p < 0.0001$, and the age group x epoch interaction, F (7, 343) = 5.35, $p < 0.0001$, were significant, revealing faster RTs for young adults than older adults overall, but greater overall skill learning for older adults by the end of the session. This significant effect is likely due to the fact that young adults performed much faster than older adults and likely demonstrated a floor effect.

For accuracy, there was also a significant main effect of epoch, F (7, 343) = 5.48, $p < 0.0001$, demonstrating a decline in accuracy with practice, likely due to the computer feedback guiding participants to an accuracy level of 92%. There was a main effect of age group, such that, as shown in Figure 17, older adults were more accurate than young adults, F (1, 49) = 9.99, $p < 0.01$. However, there was no age group x epoch interaction.

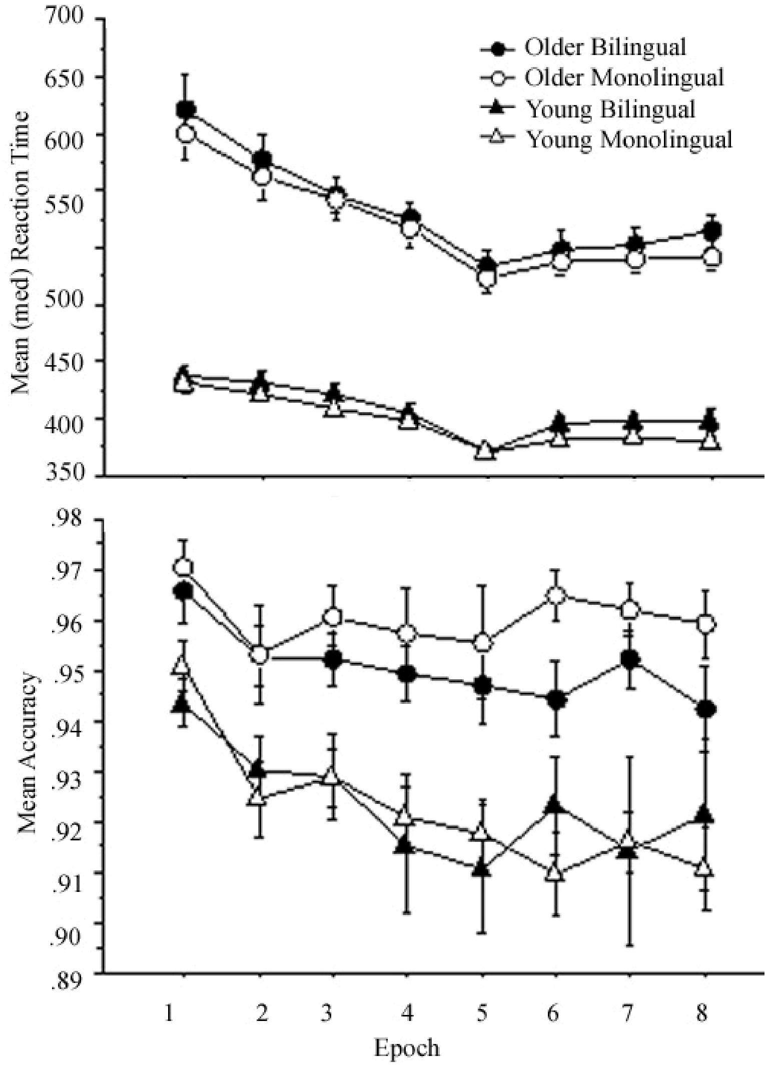

Figure 17. ***ASRTT overall reaction time (RT; upper graph) and overall accuracy (lower graph) by age group and language group.***

Sequence-specific learning. In assessing implicit sequence learning, low-frequency trials were slower overall than high-frequency trials, and this trial-type effect increased across epochs, as shown in Figure 18 (young adults) and Figure 19 (older adults)[6]. Across all four groups, for RT, the main effect of trial type, F (1, 49) = 28.99, p < 0.0001, and the epoch x trial type interaction, F (7, 343) = 3.85, p < 0.001, were

[6] Since there is a vast difference between older adults and young adults in reaction time, it is near impossible to see the difference between high and low frequency trials when both age groups are plotted on the same graphs. So the age groups are plotted separately to ease viewing.

significant. The same pattern was found for accuracy: across all four groups, the main effect of trial type, F (1, 49) = 69.66, $p < 0.0001$, and the epoch x trial type interaction, F (7, 343) = 5.25, $p < 0.0001$, were significant, demonstrating sequence-specific learning for all groups on both measures. There were no effects of language group for either measure, suggesting that proficiency did not have a beneficial effect on implicit sequence learning in bilinguals.

When examined separately, for young adults, there was clear evidence of sequence-specific learning for both bilinguals and monolinguals on both RT and accuracy measures. As shown in Figure 18, the high-frequency trials were faster and more accurate than low-frequency trials, and these trial-type effects increased with practice. The trial-type effects can be more clearly seen in Figure 20. The main effect of trial type and the trial type x epoch interaction were significant for both RT, F (1, 21) = 35.84, $p <$ 0.0001; F (7, 147) = 4.83, $p < 0.0001$, respectively, and accuracy, F (1, 21) = 37.42, $p <$ 0.0001; F (7, 147) = 4.87, $p < 0.0001$, respectively. There was no main effect or interaction of language group, suggesting that proficiency did not have a beneficial effect on sequence-specific learning for young bilingual adults.

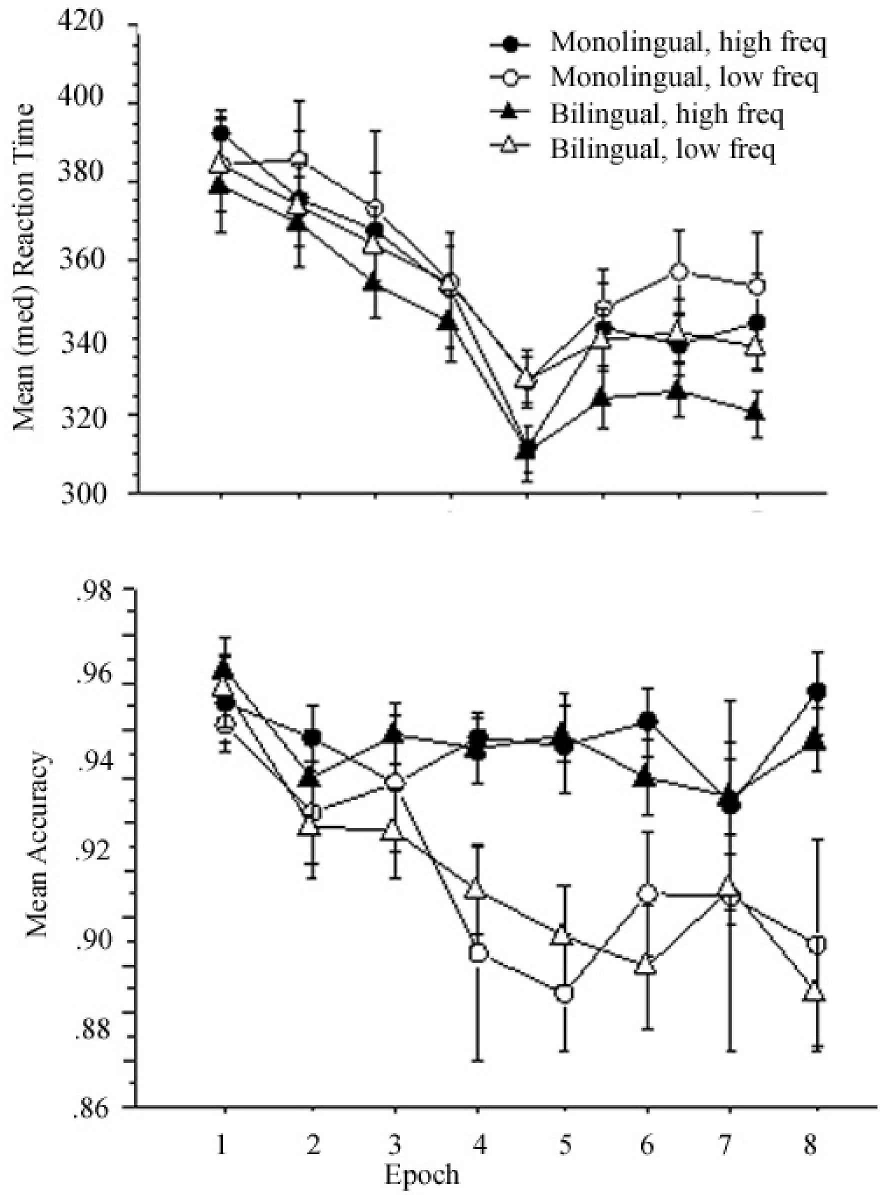

Figure 18. ***ASRTT reaction time (RT; upper graph) and accuracy (lower graph) scores for young adults by language group and trial type.***

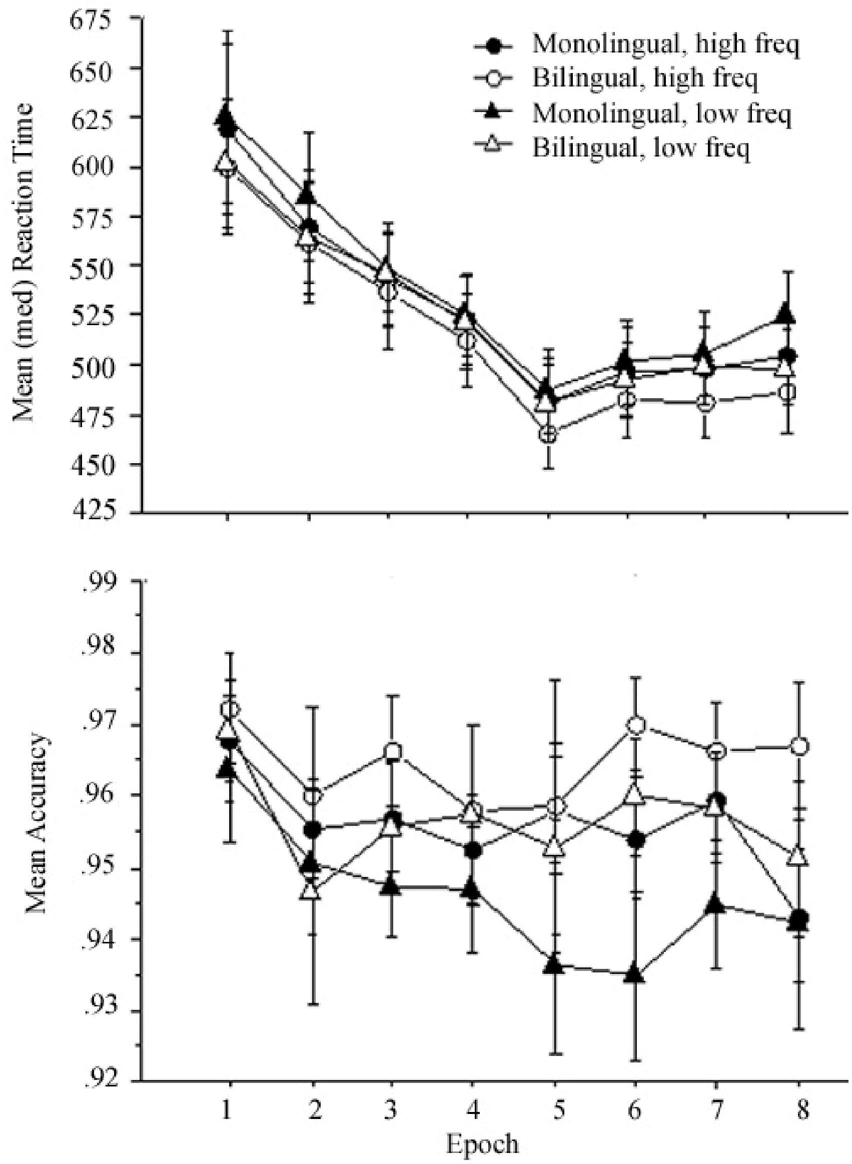

Figure 19. ***ASRTT reaction time (RT; upper graph) and accuracy (lower graph) scores for older adults by language group and trial type.***

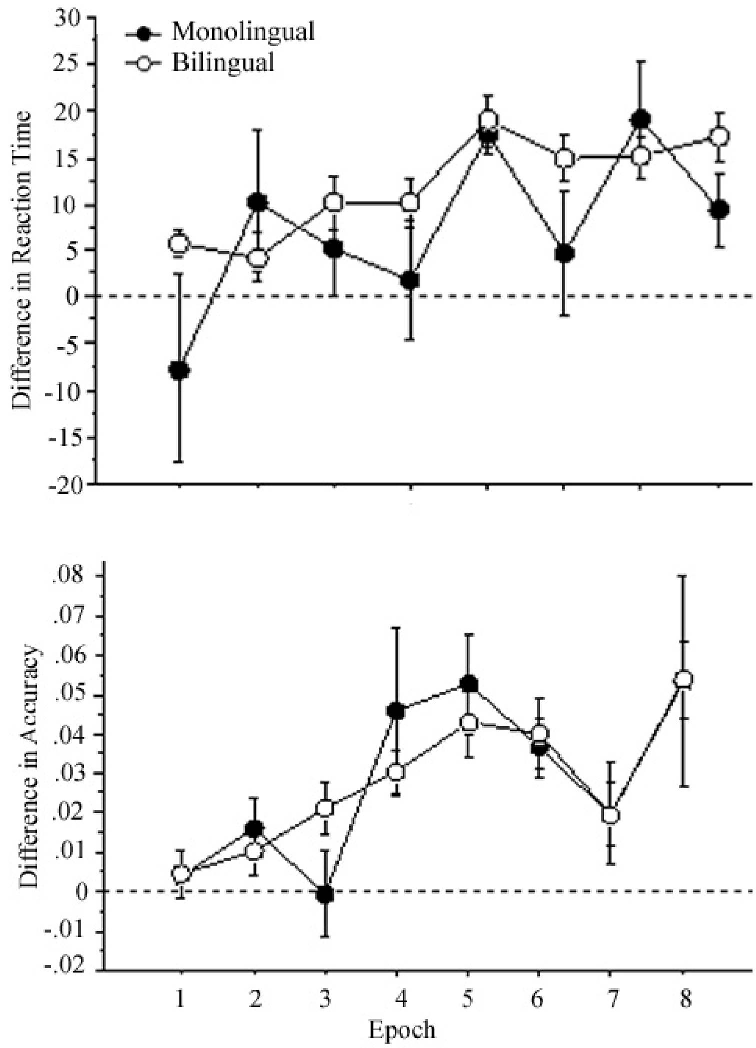

Figure 20. ***ASRTT reaction time (RT) trial-type effects (low-high frequency trials; top graph) and accuracy trial-type effects (high-low frequency trials; lower graph) for young adults by language group.***

For older adults, there was also evidence of sequence-specific learning, as can be seen in Figure 19. High-frequency trials were faster and more accurate than low-frequency trials overall, and these trial-type effects increased with practice. The trial-type effects can be more clearly seen in Figure 21. The main effect of trial type was significant for both RT, F (1, 28) = 14.50, p = 0.001, and accuracy, F (1, 28) = 22.59, $p <$ 0.0001, but there was no significant trial type x epoch interaction for either measure, and there was no main effect or interaction of language group. This suggests an overall difference in learning the different trial types that does not increase with practice for older adults. It also suggests that proficiency does not have a beneficial effect on sequence-specific learning for older bilingual adults.

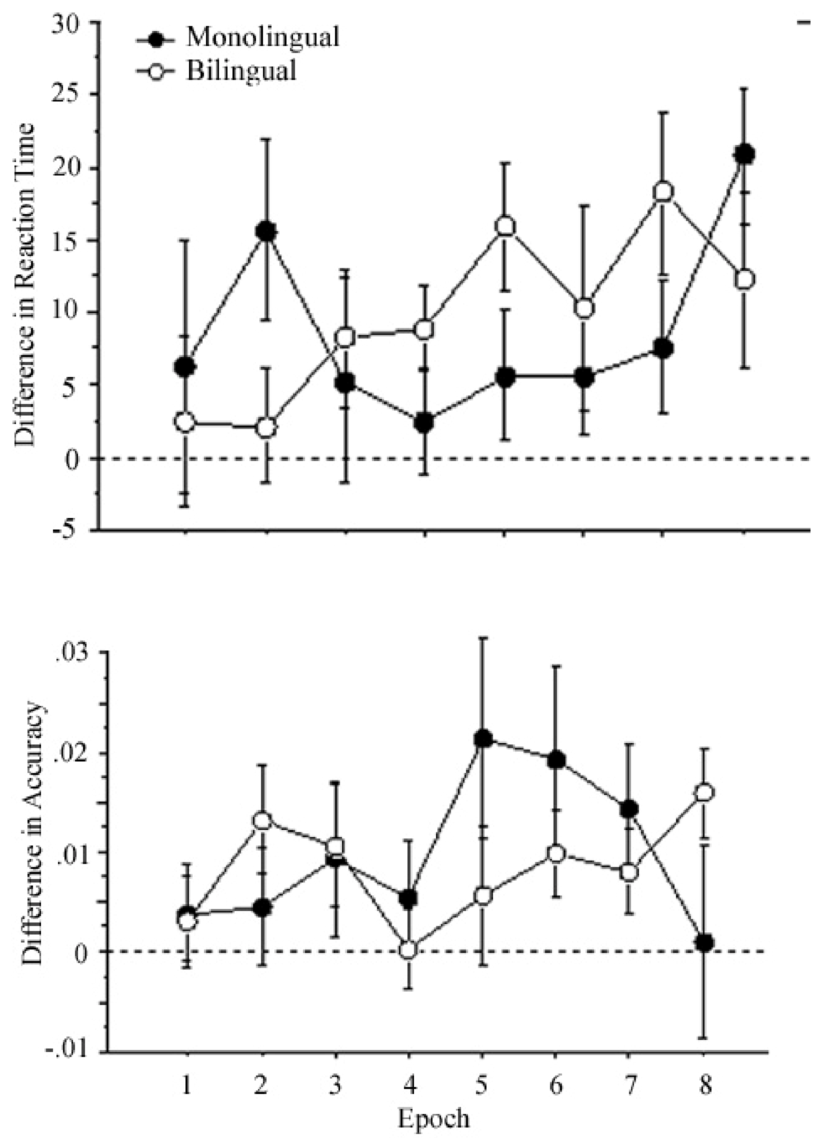

Figure 21. ***ASRTT reaction time (RT) trial-type effects (low-high frequency trials; upper graph) and accuracy trial-type effects (high-low frequency trials; lower graph) for older adults by language group.***

In summary, both young and older adults demonstrated overall skill learning and sequence-specific learning. Older adults demonstrated greater skill learning compared to young adults, but this was likely due to a floor effect for the young adults. Young adults demonstrated greater sequence-specific learning compared to older adults. There was no effect of language group, such that for both young and older adults, high-fluency bilinguals and low-fluency monolinguals performed equivalently.

As with the original results, participants did not acquire declarative knowledge of the sequence structure they learned.

Appendix G. Age of Acquisition Analyses

Simon Task

Overall performance. The mean reaction times (RTs) for correct trials by age group (young vs. older adults) and language group (early bilinguals vs. late bilinguals vs. monolinguals) are shown in Figure 22. Results were submitted to a 2 x 3 x 2 (age group x language group x trial type) ANOVA. As with the previous results, there was a main effect of age group, such that older adults were slower than young adults, F (1, 142) = 52.23, $p < 0.0001$. There was also a main effect of language group, F (1, 142) = 0.21, $p < 0.05$, indicating a difference among the early bilinguals, late bilinguals, and monolinguals, but there was no age group x language group interaction.

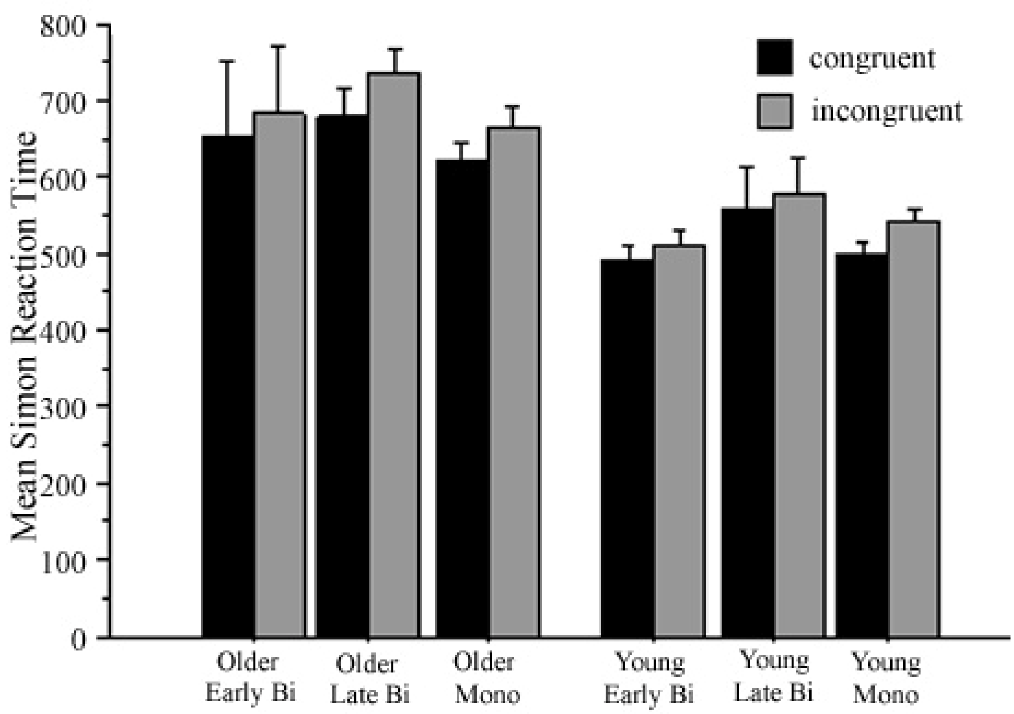

Figure 22. ***Simon reaction time (RT) scores by age group and age of acquisition group.***

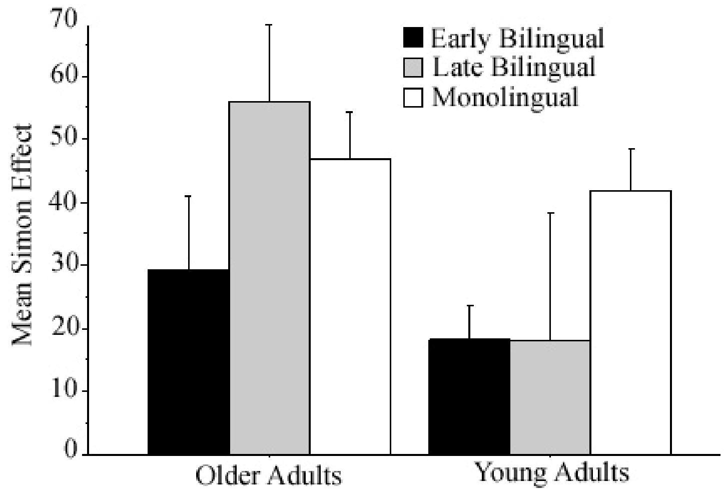

Figure 23. ***Simon Effect scores by age group and age of acquisition group.***

The Simon Effect (incongruent – congruent trials) can be more clearly seen in Figure 23. The mean Simon Effect was 18.17 milliseconds (*SD* = 22.12 ms) for young early bilinguals, 18.05 milliseconds (*SD* = 50.24 ms) for young late bilinguals, 42.02 milliseconds (*SD* = 27.91 ms) for young monolinguals, 29.29 milliseconds (*SD* = 28.74 ms) for older early bilinguals, 55.90 milliseconds (*SD* = 40.54 ms) for older late bilinguals, and 47.06 milliseconds (*SD* = 32.20 ms) for older monolinguals. A 2 x 3 (age group x language group) ANOVA revealed a significant main effect of age group, F (1, 71) = 4.81, $p < 0.05$, a marginal main effect of language group, F (2, 71) = 2.53, $p = 0.09$, and no interaction, F (1, 71) = 1.45, *ns*. One-tailed post-hoc *t*-tests confirmed a marginal significant difference between early and late bilinguals for the older adults, t (15) = -1.42, $p = 0.09$, and no difference between early and late bilinguals for the young adults, t (21) = 0.008, *ns*.

When the young and older adults were examined separately, there was no significant difference for language group. The marginal significance and lack of significance across some of these tests (e.g., early vs. late bilinguals differences) is likely a reflection of insufficient power to detect the effect, due to the size of the bilingual groups becoming significantly smaller when separated into early and late learners.

Distributional analyses. For the distributional analyses, the CAFs for each RT bin by trial type (congruent and incongruent) and language group (early bilinguals, late bilinguals, and monolinguals) are plotted in Figure 24 (young adults: upper graph; older adults: lower graph).

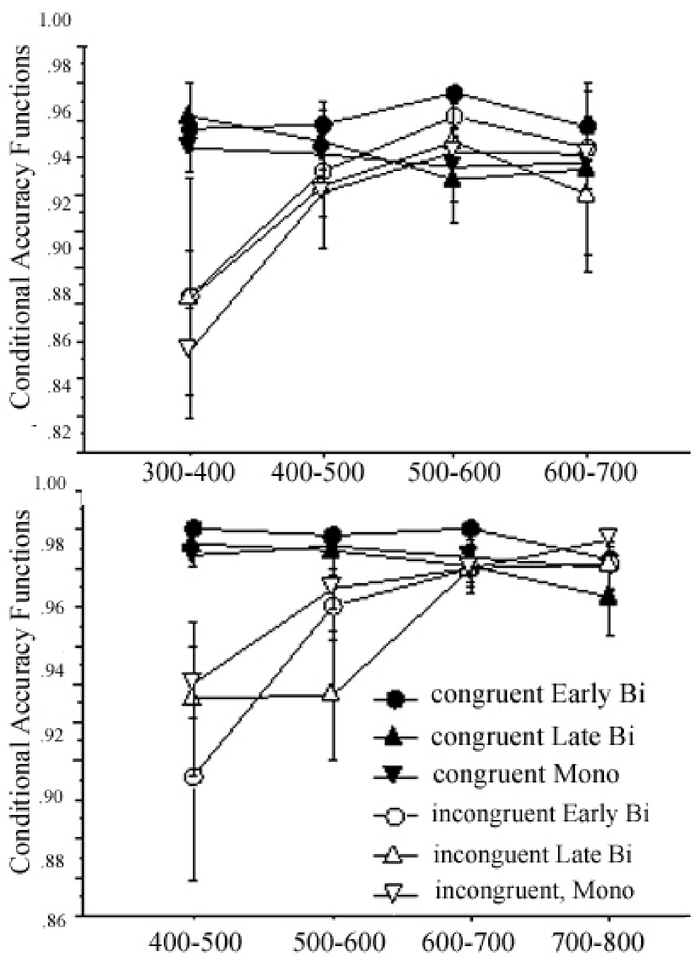

Figure 24. ***CAFs: Mean percentage correct in the Simon task as a function of RT bin by language group and congruence (young adults: upper graph; older adults: lower graph).***

As shown in Figure 24 and consistent with the original results, for all groups, very fast incongruent responses were more error prone than slow incongruent responses. For incongruent responses, averaged across all groups, there was a significant difference between slope 1 and slope 2, t (61) = 3.36, $p < 0.001$, and between slope 1 and slope 3, t (56) = 5.17, $p < 0.0001$, such that the left-most slope was steeper than the others, indicating greater errors when people make very fast responses versus slower responses. Alternatively, as can be seen in Figure 24 and consistent with the original results, overall, error rates on congruent trials did not differ as a function of response speed. For congruent responses, averaged across all six groups, there was no difference between slope 1 and slope 2, t (66) = -0.06, *ns*, and between slope 1 and slope 3, t (60) = 0.18, *ns*.

When each group was examined separately, the same results were found for young early bilinguals, young late bilinguals, young monolinguals, older early bilinguals, and older monolinguals. However, older late bilinguals did not show a difference between slope 1 and 2 or between slope 1 and 3. As shown in Figure 24, the lack of a difference between slope 1 and 2 is likely is due to the fact that the older late bilinguals made more errors in the second RT bin compared to the other groups whose accuracy values in the second RT bin had nearly reached the same accuracy values as the slower RT bins.

Group differences were examined further. For young and older adults, results were submitted separately to mixed-design 2 x 3 x 3 (trial type x language group x RT bin) ANOVAs for the three fastest RT bins only, with repeated measures on the trial-type and RT-bin factors. For young adults, there was a main effect of trial type, F (1, 31) =

14.92, $p < 0.001$, such that accuracy was higher on congruent than incongruent trials (99% vs. 95%). There was a significant main effect of RT bin, F (2, 62) = 10.80, $p < 0.0001$, demonstrating higher accuracy on slower than faster responses, and a significant trial type x RT bin interaction, F (2, 62) = 14.73, $p < 0.0001$, demonstrating higher accuracy for congruent versus incongruent trials on fast compared to slow responses. The main effect of language group was not significant, F (2, 31) = 1.78, *ns*, and the trial type x language group interaction was not significant F (2, 31) = 0.03, *ns*, suggesting no difference in accuracy between young early bilinguals, late bilinguals, and monolinguals.

For older adults, there was also a main effect of trial type, F (1, 24) = 25.35, $p < 0.0001$, such that accuracy was higher on congruent than incongruent trials (99% vs. 95%). As with the young adults, there was a significant main effect of RT bin, F (2, 48) = 7.82, $p < 0.01$, demonstrating higher accuracy on slower responses than faster responses, and a significant trial type x RT bin interaction, F (2, 48) = 10.75, $p = 0.0001$, demonstrating higher accuracy for congruent versus incongruent trials on fast compared to slow responses. The main effect of language group, F (2, 24) = 0.50, *ns*, and the trial type x language group interaction, F (2, 24) = 1.51, *ns*, were not significant, suggesting no overall difference between older early bilinguals, late bilinguals, and monolinguals. There was also no trial type x language group x RT bin interaction, F (2, 48) = 0.75, *ns*.

Delta plots for RT were constructed by plotting Simon Effect size (mean RT in the incongruent condition minus mean RT in the congruent condition) as a function of RT bin as shown in Figure 25 (young adults: upper graph; older adults: lower graph) for the new groups.

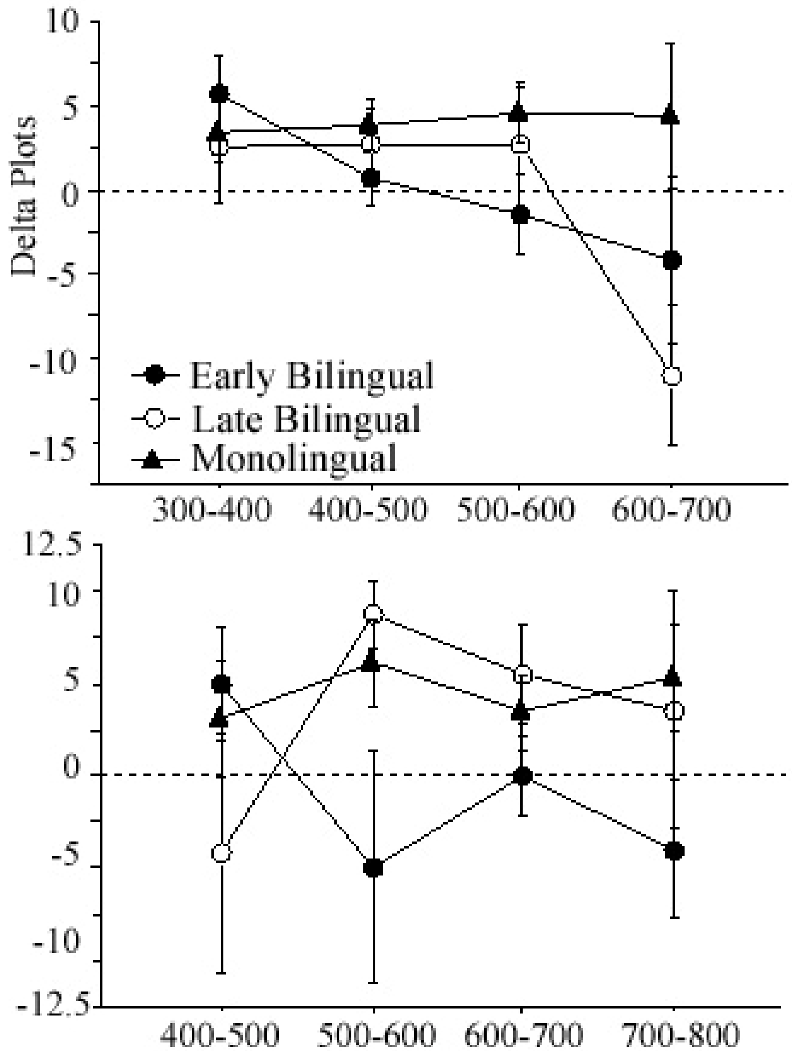

Figure 25. ***Delta plots for reaction time (RT) as a function of RT bin by language group (young adults: upper graph; older adults: lower graph).***

As shown in the upper graph of Figure 25, for young late bilinguals, the delta plot slope turns negative between the third and fourth RT bin. For young early bilinguals, the slope continuously declines across the RT bins. For young monolinguals, the delta plot remains stable across all RT bins. Using one-tailed *t*-tests, slope 3 (the right-most, slowest slope) was compared to the other slopes (slopes 2 and 1, right to left, where slope 1 is the fastest). Averaged across all groups, for young adults, there was no significant difference between slope 3 and slope 1, t (35) = 0.53, *ns*, and no significant difference between slope 3 and slope 2, t (36) = 0.73, *ns*. When each groups was examined separately, only lat bilinguals showed a marginal difference between slope 3 and slope 1, t (4) = 1.58, $p = 0.09$, and between slopes 3 and 2, t (4) = 1.60, $p = 0.09$. This difference is likely marginal due to the small number of people in the group when broken-down by proficiency. Similarly, for older adults, there is great variance in performance, likely due to the small sample size when regrouped in this manner, making this information uninformative.

Implicit Sequence Learning on the ASRTT

Overall skill learning. In Figure 26, the overall mean of the median RT (upper graph) and mean accuracy (lower graph) for both high- and low-frequency trials are plotted for all groups. The RT and accuracy data were subjected to separate 8 x 2 x 2 x 3 (epoch x trial type x age group x language group) ANOVAs. As shown in Figure 26, people responded faster overall with practice. This was confirmed in the significant main effect of epoch for RT, F (7, 546) = 104.66, $p < 0.0001$, indicating overall skill learning. As with the original results, the main effect of age group, F (1, 78) = 161.99, $p < 0.0001$, and the epoch x age group interaction, F (7, 546) = 11.58, $p < 0.0001$, were significant, revealing faster RTs for the young adults than older adults, and greater overall skill learning for older adults. As stated previously in this paper, this significant effect is likely due to the fact that young adults performed much faster than older adults and likely demonstrated a floor effect.

For accuracy, there was also a significant main effect of epoch, F (7, 546) =

10.86, $p < 0.0001$, demonstrating a decline in accuracy with practice, likely due to the computer feedback guiding participants to an accuracy level of 92%. There was a main effect of age group, F (1, 78) = 24.55, $p < 0.0001$, such that older adults were more accurate than young adults, however, there was no age group x epoch interaction.

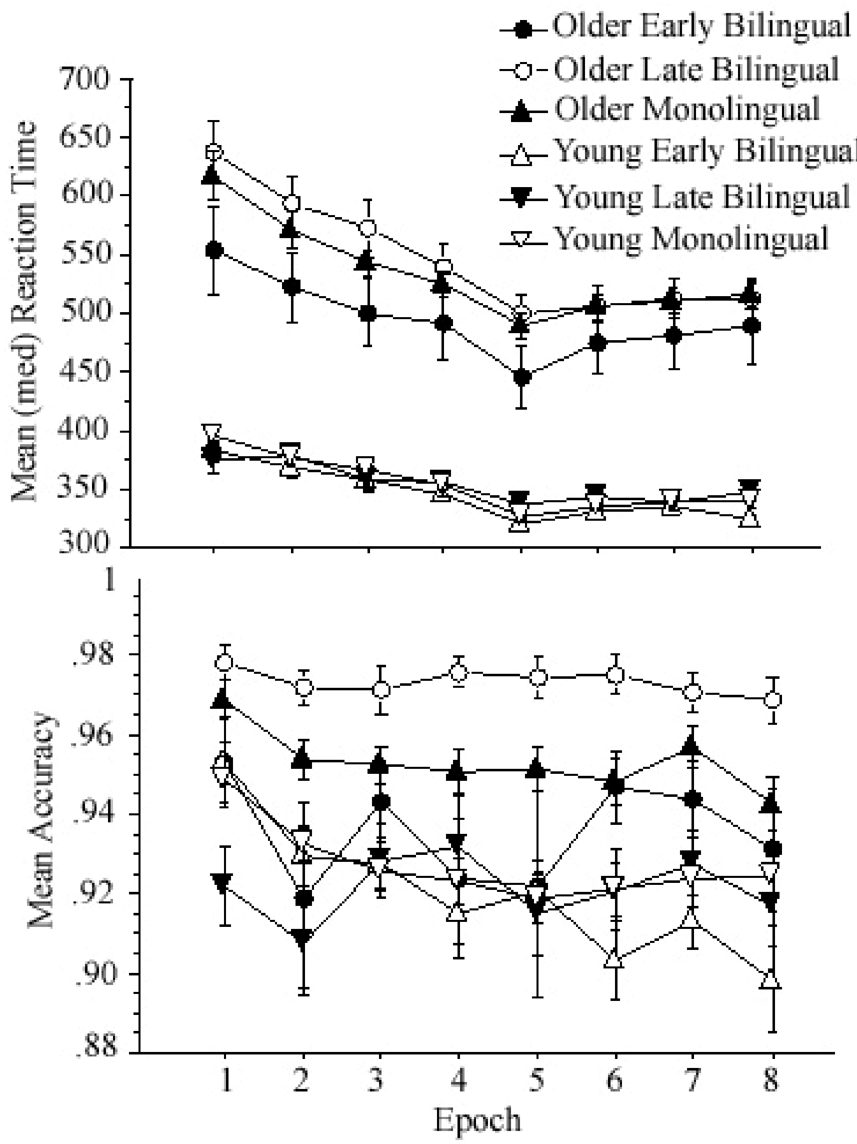

Figure 26. ***ASRTT overall reaction time (RT; upper graph) and overall accuracy (lower graph) by age group and language group.***

Sequence-specific learning. More important, for assessing implicit sequence learning, low-frequency trials were slower overall than high-frequency trials, and this trial-type effect increased across epochs, as shown in Figure 27 (young adults) and Figure 28 (older adults). Across all six groups, for RT, the main effect of trial type, F (1, 74) = 79.55, $p < 0.0001$, and the epoch x trial type interaction, F (7, 518) = 6.72, $p < 0.0001$, were significant. The same pattern was found for accuracy. Across all six groups, the main effect of trial type, F (1, 74) = 88.31, $p < 0.0001$, and the epoch x trial type interaction, F (7, 518) = 5.52, $p < 0.0001$, were significant, demonstrating sequence-specific learning on both measures.

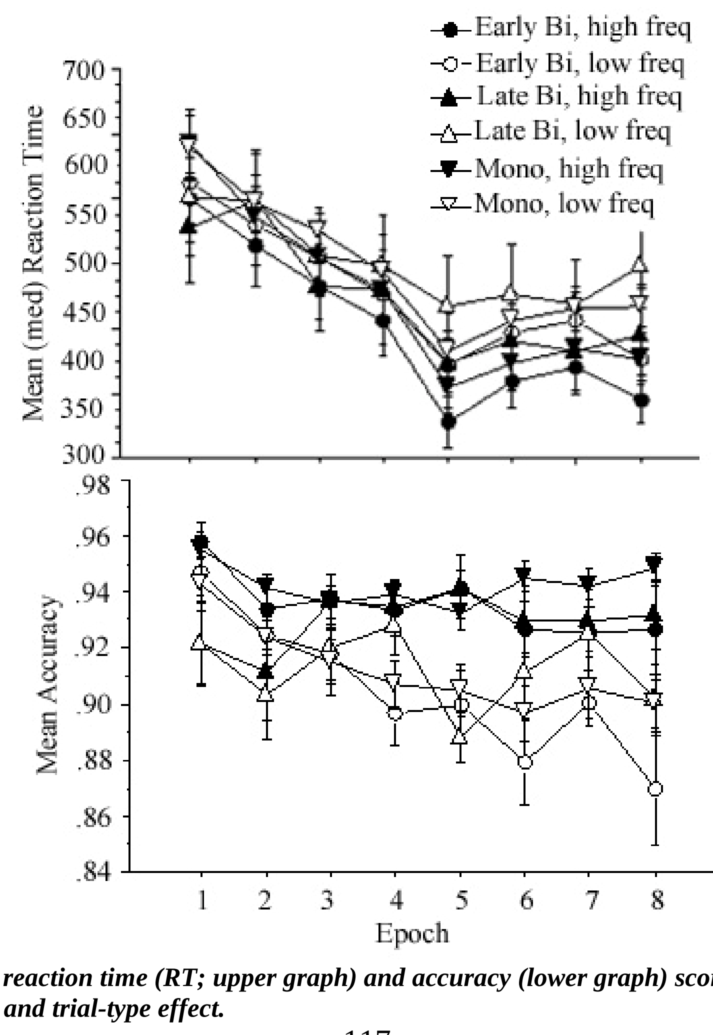

Figure 27. ***ASRTT reaction time (RT; upper graph) and accuracy (lower graph) scores for young adults by language group and trial-type effect.***

As before, the magnitude of this trial-type effect differed for young and older adults, as shown in an epoch x trial type x age group interaction for accuracy, F (7, 518) = 2.751, $p < 0.01$, indicating that young adults showed greater sequence-specific learning than older adults. The interaction for the RT measure did not reach significance.

For RT, the trial type x language group interaction was marginal, F (2, 74) = 2.98, $p = 0.06$, and the trial type x language group x age group interaction, F (2, 74) = 2.72, $p = 0.07$, was marginal, suggesting a difference among the language groups in learning sensitivity to the sequential structure. For accuracy, the epoch x language group interaction, F (14, 518) = 1.61, $p = 0.07$, was marginal, and the epoch x language group x age group interaction, F (14, 518) = 1.857, $p < 0.05$, was marginal, suggesting a difference among the language groups in accuracy over time.

When examined separately, for young adults, there was clear evidence of sequence-specific learning for early and late bilinguals and monolinguals on both RT and accuracy measures, as can be seen in Figure 27. As is apparent, the high-frequency trials were faster and more accurate than low-frequency trials, and these trial-type effects increased with practice. The trial-type effects can be more clearly seen in Figure 29. The main effect of trial type and the trial type x epoch interaction were significant for both RT, F (1, 40) = 79.30, $p < 0.0001$; F (7, 280) = 8.39, $p < 0.0001$, respectively, and accuracy, F (1, 40) = 79.09, $p < 0.0001$; F (7, 280) = 6.64, $p < 0.0001$, respectively. For accuracy, there was a significant epoch x language group interaction, and as can be seen in Figure 29, this is likely due to the variability in the late bilinguals.

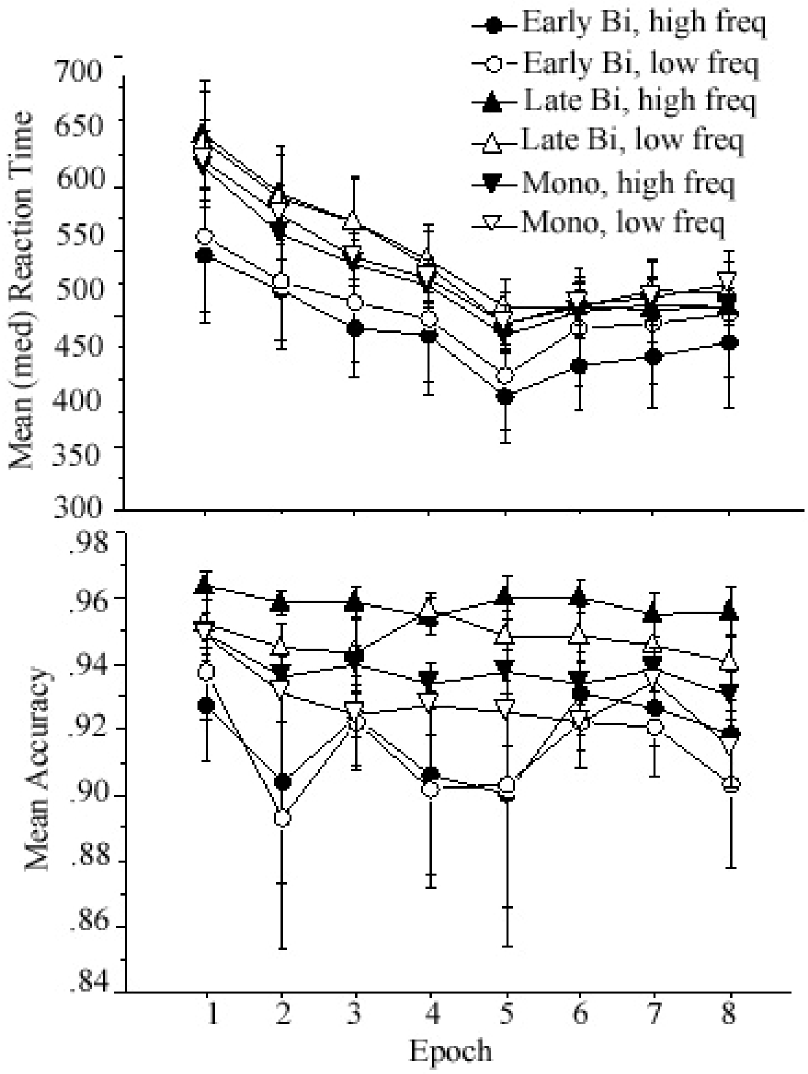

Figure 28. ***ASRTT reaction time (RT; upper graph) and accuracy (lower graph) scores for older adults by language group and trial type.***

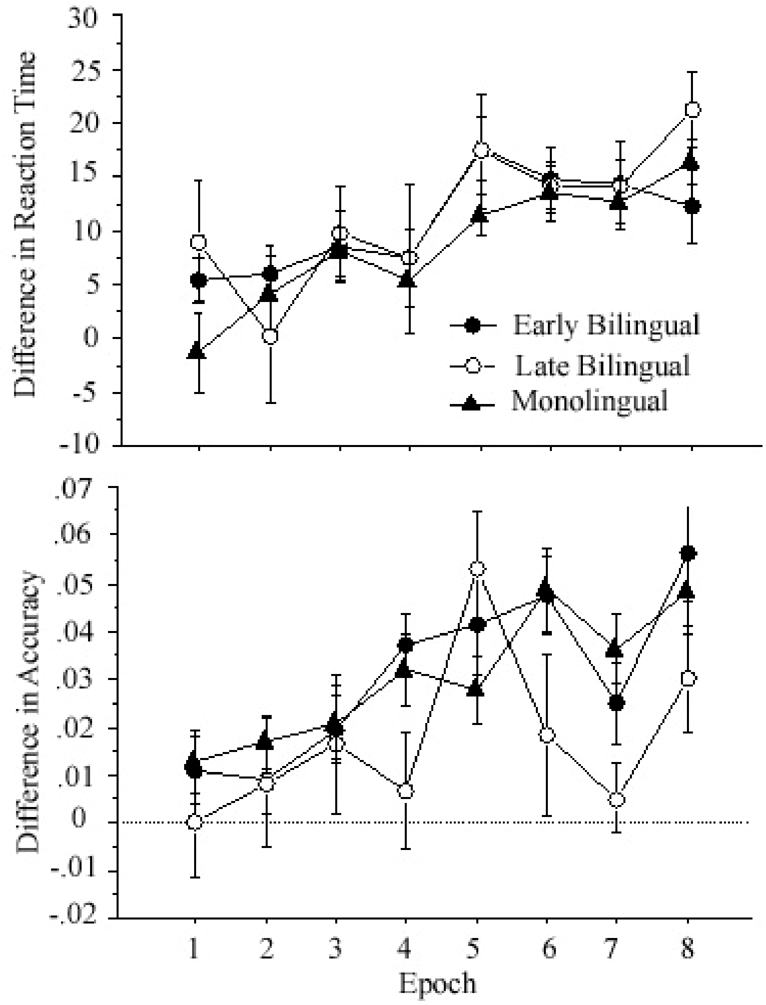

Figure 29. ***ASRTT reaction time (RT) trial-type effects (low-high frequency trials; top graph) and accuracy trial-type effects (high-low frequency trials; lower graph) for young adults by language group.***

Post-hoc ANOVAs revealed no significant main effect or interactions of language group for RT between the early bilinguals and monolinguals and between the early bilinguals and the late bilinguals. However, there was a significant epoch x language group interaction, F (7, 168) = 3.09, $p < 0.01$, when late bilinguals were compared to monolinguals. As can be seen in Figure 29, it appears that late bilinguals showed greater skill learning compared to monolinguals.

For accuracy, post-hoc ANOVAs revealed a significant epoch x language group interaction when early bilinguals were compared to monolinguals, F (7, 245) = 2.17, $p <$ 0.05, when early bilinguals were compared to late bilinguals, F (7, 147) = 2.68, p = 0.01, and a marginal difference when late bilinguals were compared to monolinguals, F (7, 168) = 1.78, p = 0.09. The trial type x language group interaction was marginal, F (1, 21) = 3.18, p = 0.09, when early and late bilinguals were compared. Although these findings are not straight-forward and yield no certain conclusions, it is clear that there are some bilingual differences. Likely due to power issues, the results are not clear.

For older adults, there is also evidence of sequence-specific learning, as can be seen in Figure 28. High-frequency trials were faster and more accurate than low-frequency trials, overall, and these trial-type effects increased with practice. The trial-type effects can be more clearly seen in Figure 30. The main effect of trial type was significant for both RT, F (1, 34) = 24.51, p = 0.0001, and accuracy, F (1, 34) = 16.52, p < 0.001. For RT, the trial type x language group interaction was marginal, F (2, 34) = 2.92, p = 0.07, and for accuracy, there was a significant main effect of language group, F (2, 34) = 3.63, p < 0.05.

Post-hoc ANOVAs on the RT data revealed a significant trial type x language group interaction when early bilinguals and monolinguals were compared, F (1, 23) = 4.32, p < 0.05, and a marginal interaction when early and late bilinguals were compared, F (1, 16) = 4.00, p = 0.09, but no interaction when late bilinguals and monolinguals were compared. As can be seen in Figure 30, early bilinguals show the greatest amount of learning, followed by late bilinguals, who are followed by monolinguals.

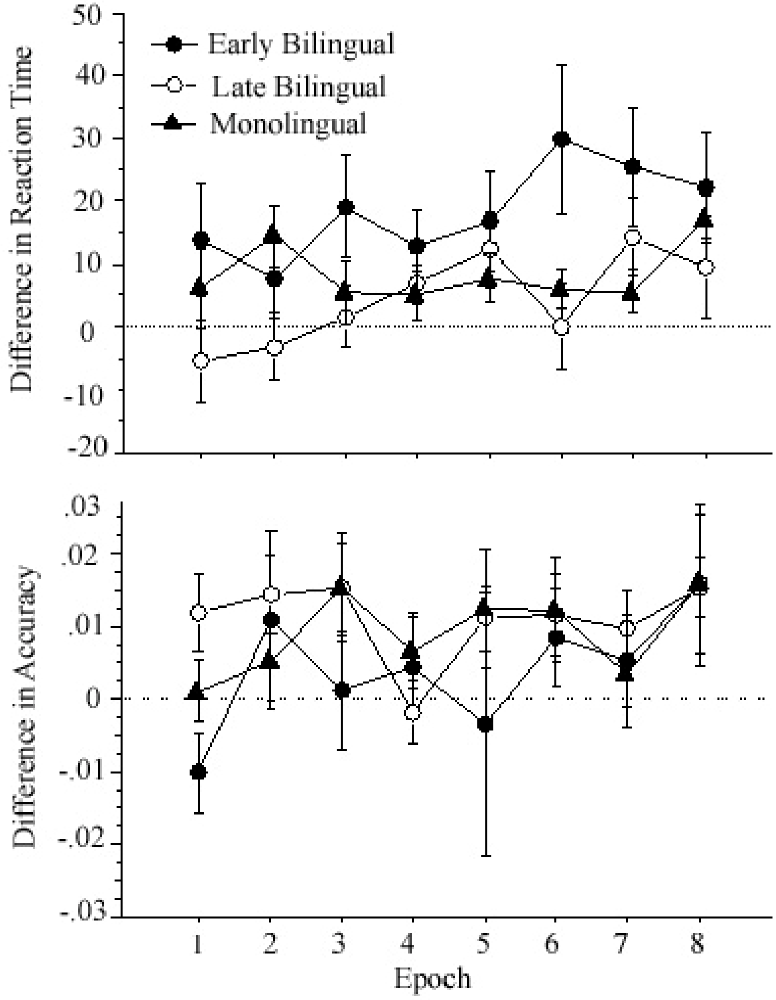

Figure 30. ***ASRTT reaction time (RT) trial-type effects (low-high frequency trials; upper graph) and accuracy trial-type effects (high-low frequency trials; lower graph) for older adults by language group.***

For accuracy, post-hoc ANOVAs revealed no significant effects of language group between early bilinguals and monolinguals and between the late bilinguals and monolinguals. However, there was a significant main effect of language group between early and late bilinguals, F (1, 16) = 5.13, $p < 0.05$, suggesting that early bilinguals make more errors overall than late bilinguals. As with the young group comparisons, although these findings are not completely straight-forward, it is clear that there are some bilingual differences. The older adult groups display more effects than the young groups, suggesting that, for older adults, there is an effect of age of acquisition on overall skill learning, such that early bilinguals learn more than both late bilinguals and monolinguals.

In summary, both young and older adults demonstrated overall skill learning and sequence-specific learning. Older adults demonstrated greater skill learning compared to young adults, but this was likely due to a floor effect for the young adults. Young adults, however, demonstrated greater sequence-specific learning compared to older adults. There were effects of language group, such that in general, early bilinguals demonstrated greater sensitivity to the sequence structure than late bilinguals and monolinguals. These effects were stronger for older adults, suggesting that early acquisition of a second language has beneficial effects into old age. These effects would likely not be seen in the young adults as they have not been using the two languages for as long as the older adults.

Standardized Neuropsychological Tasks

Next the standardized neuropsychological tasks were examined to investigate if age of acquisition plays a role in these processes. Results from the standardized neuropsychological tasks were submitted to 2 x 3 (age group x language group: early bilingual vs. late bilingual vs. monolingual) ANOVAs. There was a main effect of language group on the Spatial Span forward and backward tasks, F (2, 72) = 5.13, $p < 0.01$; F (2, 72) = 4.81, $p = 0.01$, respectively; the Digit Span forward and backward tasks, F (2, 72) = 5.64, $p < 0.01$; F (1, 76) = 4.82, $p < 0.05$, and Digit-Symbol Pairing task, F (2, 72) = 3.73, $p < 0.05$, demonstrating differences among the groups. There was not an age group x language group interaction for any of the measures.

When young adults were examined separately, the main effect of language group on the Digit Span forward task was marginal, F (2, 40) = 2.76, $p = 0.08$, and there was a significant main effect on the Digit Span backward task, F (2, 40) = 3.79, $p < 0.05$. The main effect of language group on the Consonant Trigrams task was also marginal, F (2, 40) = 2.47, $p = 0.10$, such that early bilinguals scored higher than late bilinguals and monolinguals.

Older adults revealed a significant main effect of language group for the Spatial Span forward task, F (2, 35) = 4.02, $p < 0.05$, and a marginal effect on the Spatial Span backward task, F (2, 35) = 2.94, $p = 0.07$. The main effect of language group on the Digit Span forward task was also marginal, F (2, 35) = 2.78, $p = 0.08$.

The mean scores for these tasks by age group and language group are displayed in Table 13. These results, although not completely straight-forward, suggest differences among the early bilinguals, late bilinguals, and monolinguals. The difference seems to be for older adults who learned a second language at a young age and have been using two languages longer than young bilinguals, who even though they learned young, have not been speaking two languages as long as the older people, by default.

Table 13. ***Mean Scores (and Standard Deviation) for Standardized Neuropsychological Tests by Age Group and Language Group: Age of Acquisition***

Group	N	Spatial span Forward*[##]	Spatial span Backward*	Digit span Forward*	Digit span Backward*[#]	Digit symbol pairing**	Consonant trigrams*
Y mono	20	8.15 (2.01)	7.85 (1.46)	10.80 (2.07)	6.25 (2.00)	14.25 (3.39)	6.10 (2.51)
Y early b	17	9.29 (1.69)	8.82 (1.63)	10.29 (2.05)	6.82 (1.78)	16.07 (2.56)	7.29 (1.69)
Y late b	6	8.17 (0.75)	8.17 (0.98)	8.67 (0.82)	4.33 (1.97)	14.00 (5.25)	5.33 (1.63)
O mono	20	5.65 (1.69)	5.25 (1.59)	10.10 (2.22)	5.90 (2.36)	9.75 (5.45)	4.45 (2.67)
O early b	6	8.00 (1.67)	7.00 (2.10)	11.17 (2.14)	7.50 (1.64)	14.00 (4.15)	5.00 (1.90)
O late b	12	6.08 (1.98)	5.25 (1.42)	8.75 (2.09)	5.75 (1.55)	8.83 (4.73)	4.50 (2.54)

Note: * $p < .01$, for language group, overall. ** $p < .05$ for language group, overall.
[#] *p* significant for language group: young adults. [##] *p* significant for language group: older adults.
Y = young adults. O = older adults. Mono = monolingual. B = bilingual.

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