BILINGUALISM AND COGNITION: EXPLORING THE BILINGUAL COGNITIVE ADVANTAGE ACROSS THE LIFESPAN

BY

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DISSERTATION

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Abstract

Research has demonstrated that bilingual children who constantly juggle two languages have better controlled processing and enhanced executive function (Bialystok, 2001; Bialystok & Martin, 2004). These findings have also been extended to adults whereby bilingual adults across the lifespan were found to have smaller interference effects than monolingual adults on a number of measures thought to involve cognitive and/or word-level linguistic control, for instance the Simon, Flanker, and Stroop tasks (see e.g., Bialystok et al., 2004). The claims of this hypothesis are controversial, however, with several recent studies finding no evidence of the advantage (Hilchey & Klein, 2011; Kousaie & Phillips,2012, Kousaie et al., 2012, Paap & Greenberg, 2013, Paap et al., 2014) and of the calls for more research (Abutalebi & Clahsen, 2015; Bialystok & Kroll, 2013; Titone & Baum, 2014; Valian, 2015), especially with older adults, the present study examines how bilingual language experiences can impact cognitive-linguistic processing across the lifespan. This study further investigates the Bilingual Cognitive Advantage (BCA) hypothesis, which holds that bilinguals can show evidence of having certain cognitive advantages relative to monolinguals (Bialystok et al., 2004, 2006, 2008 a,b; Costa et al., 2008; Hernandez et al., 2010; Salvatierra & Rosselli, 2011; Bialystok et al., 2014; Blumenfeld & Marian, 2014). Participants included French-English and English-French bilinguals and both English and French monolinguals between 18-80 years of age (n=131). Tasks which served as proxy measures of executive function included English- and French-language versions of the Simon, Stroop, Corsi block task, Verbal fluency test, and Aospan. Results from these tasks considered together with language-related experiential variables are interpreted as supporting the BCA hypothesis. Findings are discussed with respect to possible future avenues of research.

Keywords: bilingualism, cognitive and linguistic processing, cognitive control, aging

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Chapter 1: Overview and Rationale for Research

This project was undertaken as an exploration of a phenomenon that appears to be somewhat ephemeral. It is perhaps the ephemeral nature of the bilingual cognitive advantage (henceforth BCA), a hypothesis according to which speakers of two languages enjoy certain attentional and processing abilities that are incrementally yet reliably superior to those of monolinguals, that makes it such a pertinent topic with far reaching scope. Its span reaches beyond the boundaries of academic disciplines to where it has regularly been discussed in the mainstream press (e.g., *The New York Times*, *The Atlantic*, and *The Economist*).

There is some question however as to whether a BCA exists. This is in part the case because while many studies have reported results that support its existence (Bialystok et al. 2004, 2005, 2008a,b, 2014), many others that have not (Kousaie & Phillips, 2012; Kousaie et al., 2014; Paap & Greenberg, 2013; see Hilchey & Klein, 2011 for review). There is little question that further exploration of the BCA is both timely and necessary; today more than ever, additional data are needed to inform academics and policy makers about the far-reaching consequences of bilingualism. It is also perhaps no coincidence that bilingualism as a field has reached a point of maturity that allows for reflection about what has come before, and consideration of the legacy that it will create as the basis for the much-needed additional research that will follow. The renaissance of the field of bilingualism coincides with the seminal work by Peal and Lambert (1963), who found that bilingual French-speaking children outperformed their monolingual peers on various tasks requiring mental flexibility. Prior to the 1960s, being bilingual had become almost a stigma and a condition to be avoided, as it was claimed that it might potentially retard cognitive development and attainment of superior monolingual language performance.

Since the 1960s, numerous studies have been conducted (e.g. for review see Adesope, Lavin, Thompson & Ungerleider, 2010; Bialystok & Martin, 2004; Carlson & Meltzoff, 2008, Bialystok, 2007b) to explore the possibility of a BCA in children. The present study situates itself in adulthood (18-80yrs) and seeks to build upon the findings of the seminal work of Bialystok et al. (2004) who found evidence for a BCA in adults. The academic relevance of this topic is undisputed, as it comes at a time when the field of bilingualism is able to stand alone as a discipline in order to explore relevant questions independently, while drawing upon knowledge from other fields. In fact, a key goal of this study is to address bilingualism in a more systematic manner in order to observe and clarify its role in the observation of a BCA. One might wonder how it might be possible to ignore bilingualism while investigating the "bilingual" cognitive advantage. While it has not been ignored, many researchers have paid less than rigorous attention to the complexity of bilingualism within the context of experimental settings (Bialystok et al., 2004; 2008a,b; Paap & Greenberg, 2013). It is beyond the scope of one dissertation to provide a definite answer about the nature and impact of bilingualism on the manifestation and observation of a BCA. What is clear is that there is empirical evidence to support the contention that a BCA exists, that brain-based changes can result from being bilingual (Bialystok et al. 2004, 2008a,b, 2014, Bialystok, Craik & Freedman, 2007), and that there is empirical evidence to allow for skepticism (for review, see Hilchey & Klein, 2011). The present project situates itself at this juncture and heeds calls to pay more attention to bilingualism in a systematic way, especially with older adults who might potentially derive the greatest benefit from such an advantage (Kroll & Bialystok, 2013; Valian, 2015).

One of the aims of this study was to explore the ephemeral nature of the phenomenon in question by trying to observe it in a group of bilinguals and monolinguals between 18 and 80

years of age and using tasks that have been previously used far more frequently with younger populations than with older ones; another aim of the present study is to examine whether there is evidence for a more widespread reach of the BCA, one that extends beyond inhibitory control; and lastly and perhaps most importantly, a key aim of this study is to be able to more fully explore the impact of bilingualism on the observation of the BCA.

In the spirit of full disclosure, this work was undertaken in the belief that a BCA in fact exists; however, the data will be objectively presented and the reasonable conclusions that might be derived from them will be shared. It will then be for future research to continue the exploration of this most fascinating and pertinent phenomenon.

In addition, the timeliness of this finding could not be more relevant to individuals and to policy makers, as baby boomers reach their twilight years by the millions and seek to maintain a high level quality of life, which means maintaining their independence and high levels of physical and intellectual functioning. Also interested are policy makers who wrangle about how to support this goal for the population at large with limited resources. Evidence that bilingualism can provide neurocognitive benefits and slow normal age-related cognitive declines (Stern, 2002, Bialystok et al. 2004), and that bilingualism may stave off dementia symptoms for up to four years (Bialystok, Craik & Freedman, 2007), both provide compelling reasons to continue the work to explore the potential benefits of bilingualism.

This dissertation examines cognitive-linguistic processing in bilingual adults, and further investigates the BCA hypothesis, which to reiterate holds that bilinguals can show evidence of having certain cognitive advantages relative to monolinguals (Bialystok, 2004, 2006, 2008a,b, 2007a, Costa et al., 2008; Hernandez et al., 2010; Salvatierra & Rosselli, 2011; Bialystok et al., 2014; Blumenfeld & Marian, 2014). In particular, this study investigates a claim of the BCA

hypothesis, according to which adult bilinguals across the lifespan will manifest a cognitive processing advantage and less interference relative to their monolingual peers on certain timed executive function tasks because they are bilingual. In light of the controversy surrounding the claims of this hypothesis (Hilchey & Klein, 2011; Kousaie & Phillips, 2012, Kousaie et al., 2012, Paap & Greenberg, 2013, Paap et al., 2014) and of the calls for more research especially with older adults (Bialystok & Kroll, 2013; Titone & Baum, 2014; Valian, 2015; Abutalebi & Clahsen, 2015), this study promises to shed needed light upon how bilingual language experience can impact linguistic and cognitive processing across the lifespan.

It appears that the BCA might be more robust in older adults who acquired their L2 before 12 years of age and who use both languages regularly and consistently in the context of performing relatively challenging executive function tasks (Bialystok et al., 2004, 2005, 2007a, 2008a,b). The studies that have not found robust evidence for the BCA have been completed predominantly with younger bilinguals, often undergraduates in a university setting (Paap & Greenberg, 2013; Kousaie & Phillips, 2012a). However, younger bilinguals have also been included in some of the Bialystok et al. studies cited above, and with BCAs observed for the younger bilinguals. In a study with older and younger adults, Kousaie et al. (2014) found evidence of a BCA on the Stroop task, but not on the other executive function tasks used in that study (Simon task, SART).

Recent work suggests that bilingualism and one's bilingual language experience must be carefully addressed in research that explores the BCA hypothesis. In particular, variables such as the age of active bilingualism (AoAB), profiles of use for both of a bilingual's languages, culture-related features of language use, and where the languages are used must be documented and considered in order to further examine which bilingual experiences allow for cognitive processing advantages. In addition to looking at performance differences between monolinguals and

bilinguals, it is also important to consider bilingualism as a non-categorical variable. In other words, it is not the case that someone is or is not bilingual, but rather that someone is to some degree bilingual (Luk & Bialystok, 2013; Kroll & Bialystok, 2013). It is important to try to understand the nature of bilingualism in and of itself, and what about the nature of bilingualism, or someone's bilingual language experience might contribute to the BCA. The BCA claims that bilingualism alters and improves brain function.

This hypothesis does not hold the opposite view, namely that while any person could potentially become bilingual to some degree, a person possessing certain preexisting cognitive advantages could be predisposed to becoming bilingual to a degree greater than people who did not possess any such preexisting advantages. Also according to this latter view, there could be monolinguals possessing the necessary cognitive advantages to predispose them to becoming bilinguals, yet whose life experience had never put them in a position where they could become bilingual. Were they to exist, such monolinguals would manifest the same cognitive processing advantages as any bilingual who possessed those same preexisting cognitive advantages. Likewise, in this latter view that same monolingual could be expected to demonstrate greater cognitive processing advantages relative to a bilingual who did not possess the same preexisting cognitive advantages. Finally, this view would hold that the results appearing to support the BCA hypothesis are due to sampling error/bias, data handling decisions, etc. such that in published studies, the subset of bilinguals with the necessary cognitive advantages have tended to be tested against the subset of monolinguals without those same necessary advantages. As there currently does not seem to be published evidence that would exclusively support this alternate view, and in light of the studies that have been interpreted as supporting the BCA hypothesis, this study will

proceed under the assumption that it is bilingualism that leads to improved brain function, and not vice versa.

It is beyond the scope of this project to provide an answer to the question of whether brain function comes first, such that only those with sufficient cognitive capacity become bilingual, or whether everyone has the potential to become bilingual. The goal of this project is to better understand bilingualism and how differences in bilingualism may modulate or impact differences in cognitive performance. As we know there many variables that can impact cognitive performance, age being one of them. In this project we will consider age, and also look more closely at the experience of bilingualism to identify what aspects of bilingualism most impact cognitive performance. The goal is to go beyond the questions of whether bilinguals perform better than monolinguals on cognitive tasks to better understand what aspects of the bilingual experience have the most impact and potential to modulate performance on cognitive tasks and alter brain function.

To investigate the nature of a BCA across the lifespan, in the present study monolingual English and French speakers and bilingual English-French and French-English speakers were grouped according to specific age ranges (18-29 yrs, 30-59 yrs, and 60-80 yrs). These age ranges were adopted because they correspond closely to age groupings in other studies in this area (Bialystok et al., 2004, 2008a,b; Kousaie et al., 2014). Participants completed a protocol consisting of linguistic and non-linguistic tasks thought to involve executive function, specifically the Stroop, Simon, Corsi Block Span, Verbal Fluency, and Aospan tasks. Extensive information on language acquisition and use experience and biographical information was obtained for all participants. The study was designed in light of the questions surrounding the existence of the BCA and recommendations for key factors to consider in future research. The

goal was to provide an additional data driven perspective in the midst of the present debate on how cognitive processing differences resulting from bilingual language experience impact cognitive performance across the lifespan with younger and older adults.

Chapter 2: Review of Literature

Bilingualism is a complex and multifaceted phenomenon. In order to better understand how bilingual language experience might impact executive function and cognitive processing in bilinguals, a review of literature looking at bilingual lexical processing and bilingual sentence processing will be summarized. It is this ongoing processing of two (or more) languages that is thought to change the brain and thus cognition, such that bilinguals demonstrate differences on cognitive processing tasks associated with executive function. Two bilingual language processing models which have considerable empirical support and which address the interrelationship between language and cognition are Green's Inhibitory Control model, and the Bilingual Interactive Plus (BIA+) model. Both models will be presented here. In addition, a brief overview of the neural correlates of bilingualism will be included.

After a review of bilingual language processing, a discussion and review of literature addressing cognitive control and bilingual cognitive control will follow. First, research providing support for a bilingual cognitive advantage will be summarized, followed by a review of research which calls the BCA into question. Once the research that supports and questions the BCA hypothesis has been reviewed, a summary of key considerations and questions to be addressed in future research will follow in order to provide a rationale for the present study. Important considerations pertaining to bilingualism and bilingual language experience, and cognitive processing and cognitive tasks indexing executive function will be summarized with the aim of addressing elements that need further exploration and may provide further insight into the how, when and with whom the BCA may be observed. As will become apparent, these considerations informed the participant selection and experimental design of the present dissertation.

The dynamic nature of bilingualism and the complexity of cognitive processing do not allow for simple conclusions about the BCA, but rather invite ongoing research to better understand the interaction between language and cognition that allows for the BCA to be observed. The field is also reaching a level of maturity which invites delving into bilingualism and examining bilinguals as compared to other bilinguals, versus comparison only to monolingual groups, in order to better understand the aspects of a bilingual language experience which might result in the presence and observation of a cognitive processing advantage.

The terms cognitive processing, cognitive control and executive function are often used interchangeably. Executive function can be viewed as an umbrella term which refers to a range of cognitive processes including problem solving, attention, inhibitory control and task switching, working memory and cognitive flexibility. It is also referred to as the cognitive control and supervisory attentional system (SAS) (Diamond, 2013). Executive function as it relates to bilingualism will be addressed later.

Bilingual Language Processing:

Cognitive Models of Bilingual Language Processing:

It is beyond the scope of this project to provide an in-depth discussion of all language processing models. However, two cognitive models of bilingual language processing, the Inhibitory Control Model and the BIA+ Model, will be briefly described here as they are the ones most frequently cited in the literature, and seem to provide the best frameworks for conceptualizing what might be occurring with bilingual language processing.

Inhibitory Control Model:

Much of the research on bilingual language processing has referenced or expanded upon Green's cognitive processing model (Green,1998). In Green's Inhibitory Control (henceforth IC)

model, which addresses bilingual language control, it is stipulated that there is simultaneous activation of a bilingual's two languages, such that when one language is in use, the other is suppressed. It is thought that the executive function processes used to suppress one language are the same ones involved in controlling attention and inhibition. There is competition between the two languages which requires inhibition of one so that the other can be produced.

In the IC model, a language is viewed as a task schema which competes with the task schema of another language in order to control the output of the lexico-semantic system. Overarching is the supervisory attentional system (SAS) which in a sense guides and oversees lexical selection. There are inhibitory links within and between the language task schemas which implement the goals of the SAS. In production models, lemmas are conceptual representations associated with word forms and syntactic properties. In bilingual language production, words are selected by language tags at the lemma level, such that lemmas in both languages are activated and all lemmas without a target language tag are inhibited.

In Green's IC model, language control occurs between two languages when the L2 language task schema exerts control to inhibit the L1 schema. There is also self-inhibition that occurs within the L1 task schema in order to allow for the production of L2. The SAS system can exert control and stronger inhibition if the non-target language is activated strongly. If we assume that the L1 or non-target language is the stronger language, then speaking in the L2 will require stronger inhibitory control. In the IC model, when both languages are activated or selected, reactive inhibition at the lemma level is required for language control over non-target access.

Experimental evidence of inhibitory control in bilingual language processing comes from research which requires speakers to switch between L1 and L2 during naming tasks which include stay trials and switch trials. Stay trials involve staying within one language, whereas

switch trials involve switching from one language to another. Research has revealed that switching from the L2 into the L1 elicits larger switch costs, as observed by longer reaction times, than switching from the L1 to the L2 (Meuter & Allport, 1999). In line with the IC, it is thought that the larger switch costs occur in L2 to L1 switches as a consequence of the stronger inhibition that the SAS exerts over the L1, which is typically more dominant. However, these asymmetries do not always exist, and more research is needed to understand asymmetries in switch costs because not all bilinguals demonstrate switch costs. There is evidence to support that language selection occurs not by exerting inhibitory control, but rather by facilitating language activation; that is, once a concept is activated, language selection is facilitated at the lexical level (Bloem & La Heij, 2003; Bobb & Wodniecka, 2013).

BIA + Model:

Dijkstra & Van Heuven (2002) have proposed the Bilingual Interactive Activation plus model (henceforth BIA+) which posits that lexical information from a bilingual's two languages is represented in a shared and integrated lexicon where there is language non-selective activation, that is, the item or concept is activated for the lexical item, but not in a language specific way.

In the BIA + model, language selection is achieved by incorporating evidence from bottom-up word identification processes. The model includes a word identification system, and a task-decision system. In the word identification system, the orthographic inputs activate associated phonological and semantic representations. The orthographic input also activates associated language nodes which serve as tags to indicate the language to which a word belongs. Language nodes are connected directly to representations of lexical form, such that the activation of language nodes stems from the activation of other linguistic representations. The word identification system incorporates activated representations from different languages. Then the

task-decision system weighs the relative activation of language node information, and then responds by making a decision based on the specific task The BIA + model can be applied to comprehension and production.

Neurolinguistic Overview-Neural Correlates of Bilingualism:

Neurolinguistic studies address the neural correlates of language, and try to answer questions about where and how the brain stores language. With respect to bilingualism, a longstanding question in the field has been whether an individual's two languages are represented in the same brain areas or in different ones. Historically, language organization in the brain was discussed in terms of the compound-coordinate distinction. It was believed that the compound bilingual had a single language system which consisted of the two languages of the bilingual, whereas the coordinate bilingual had two separate language systems which did not interfere with each other but interacted only at the level of cognition. Weinreich (1953) was one of the first linguists to systematically describe differences in types of bilingualism, although Roberts (1939) had previously discussed the concept of "subordinative" language. Weinreich (1953) identified three types of bilingualism: 'Type A', in which the signs (a sign refers to the combination of a unit of expression and a unit of content) of each language are separate; 'Type B', in which the signs combine one unit of content with one unit of expression in each language; and 'Type C', in which the meaning unit is in the native language, with a corresponding unit of expression that has an equivalent unit of expression in the second language. 'Type A' was eventually referred to as a 'coordinate system'; 'Type B' as 'compound' and 'Type C' as subordinate.

Weinreich (1953) believed that these different types of bilingualism could be reflected at the various linguistic levels of phonology, morphology, syntax and semantics. The compound

system was viewed as one compound or merged lexical sign at the conceptual level with two different phonetic realizations, one for each language. In a coordinate system, the bilingual was conceptualized as having two separate signs, each of which had its own specific meaning in each language and which would not be used in the same context (e.g., the English word “bread” and its French equivalent “pain”). In a subordinate system, a bilingual would process or produce one language through the other language. Weinreich (1953) did not believe that a bilingual had to fall into one type of bilingualism, but rather that the languages could be compounded, coordinated or subordinated to varying degrees.

Neurolinguistics has drawn heavily on research with bilingual aphasics to explore neural correlates of bilingualism. Historically, to understand how two languages are represented in the brain of a bilingual, researchers have studied the recovery patterns in the languages of bilingual individuals with aphasia. Paradis (1987, 1988, 1997) proposed several hypotheses to account for the neurofunctional and neuroanatomical organization of two languages in one brain.

The Extended System Hypothesis: This hypothesis maintained that the two languages of a bilingual are represented in the same cortical language areas. The two languages of a bilingual are a part of one bilingual language system which simply contains more linguistic elements (phonemes, morphemes, syntactic rules) than the language system of a monolingual, but which is not represented any differently than the language of the monolingual would be. A bilingual has more linguistic elements to choose from; use of the different linguistic elements is dictated by the environment, where the L1 is used in the L1 context and the L2 is used in the L2 context. In this hypothesis, a bilingual switching between two languages is viewed in the same way as a monolingual switching between two different registers (Paradis, 1987, 1988).

The Dual System Hypothesis: This hypothesis held that the two languages of a bilingual are stored separately in systems which are independent of one another. In this system, the different linguistic elements of each language are subserved by different networks of neural connections. Thus, in the brain of a bilingual are found two separate representations; one set of linguistic elements (phonemes, morphemes, syntactic rules) for each language, with each set being mutually independent (Paradis, 1987, 1997).

The Tripartate System Hypothesis: This hypothesis holds that the linguistic elements which both languages have in common are stored in one neural substrate, or cortical area, of the brain. In cases where the linguistic elements differ at the phonemic, phonological, morphological, syntactic or semantic level, there will be a separate neural substrate to account for the different elements. In this way, there is one system for all the common elements and two separate representations for the different linguistic elements of each language (Paradis, 1987, 1997).

The Subset Hypothesis: This hypothesis can be viewed as a combination of the Dual System Hypothesis and the Extended System Hypothesis, in that it posits there is one cognitive system which is responsible for language competence, which is viewed as distinct from other cognitive systems. The different linguistic elements of each language are organized into two separate subsystems of the larger language system. Thus, bilinguals have one large language system which is divided into two subsystems, one for each language, with each subsystem being comprised of its own neural representation (Paradis, 1987, 1997).

Paradis argues that the languages of a bilingual can be subdivided into independent components in the same way that memory and intelligence are subdivided. Evidence to support this assertion of a neurofunctional independence in the languages of a bilingual comes from

research which has documented nonparallel recovery patterns in the languages of bilingual aphasic patients. A neurofunctional separation of two languages does not necessarily imply that the two languages have a separate neuroanatomical organization; a lesion in one specific anatomical portion of the brain can result in a differential recovery of the two languages (Paradis, 1997).

Many of the questions in the field of neurolinguistics overlap with the questions in the field of psycholinguistics which addresses real-time language processing using various methodologies. The research which will be reviewed includes primarily psycholinguistic studies but also many neurolinguistic studies. Methodologies include a number of online processing measures such as reaction times, ERPs, eye-tracking, EEG and other neuroimaging methods such as fMRI. All of these have been used to explore similar questions about bilingual language organization and processing. Some neuroimaging methods such as EEG are focused on the timing of linguistic processes at the neural level, whereas others such as fMRI can provide information on spatial representations of language within the brain's structure.

In monolinguals, a left-lateralized fronto-temporal network has been identified in which there is overlap in brain areas for language processing at various levels. The left inferior frontal gyrus (LIGF), middle frontal gyrus (MFG), insula, precentral sulcus and supplementary motor area (SMA) have been identified as a neural network involved in orthographic, phonological and semantic processing (Gitelman et al., 2005). There is ongoing debate whether L1 and L2 have common or distinct neural representations, but Abutalebi & Green (2007) concluded that similar neural networks are activated for L1 and L2. Many studies have documented differences in neural networks as a result of managing two languages, and the way the L1 and L2 are differentially represented in the brain (Abutalebi, 2008; Abutalebi & Green, 2007; van Heuven &

Dijkstra, 2010). Often there are studies which incorporate both the cognitive and neurological aspects of bilingual language processing and the associated brain areas involved. These studies serve as an example of how using neural based measures/methodologies can complement, or provide additional or different evidence of the phenomenon in question. The fact that there is neural evidence of differences in bilingual language processing complements cognitive evidence of bilingual language processing. Studies addressing neural networks associated with linguistic processing, especially for bilinguals, will be reviewed throughout to complement psycholinguistic studies. The fact that there are often different findings using different methodologies highlights that comparisons with studies using different methodologies must proceed with a clear understanding of what each methodology is targeting in the context of the complexity of bilingualism. The field is still in its infancy, and much more research with different methodologies targeting similar questions is needed. The field is moving beyond categorical yes/no conclusions about the existence of the bilingual processing advantage and focusing on deepening the understanding of well-established differences between monolingual and bilingual minds and brains.

Bilingual Lexical Processing:

There is evidence that for bilingual lexical processing, there is non-selective language activation (Dijkstra & Van Heuven, 2002) at the conceptual level and that this activation continues until competing information constrains the choice of one vs. the other language; another way of expressing this would be to say that one language is suppressed or inhibited, so that the other might be produced. This is model can be compared to Weinreich's (1953) compound system where there is one compound or merged lexical sign at the conceptual level with two different phonetic realizations, that eventually emerge, one for each language. Although

not completely understood, both behavioral and ERP studies have shown that cognates are processed more quickly than matched control words (Dijkstra, T., et al. 1999; Midgley, K. et al., 2011; Peeters, D., et al., 2013). Therefore, there seems to be a facilitating effect for cognates in a bilingual's two languages.

Marian, Spivey & Hirsch (2003) explored the neurological and cognitive aspects of bilingual language processing with eye-tracking and functional neuroimaging methodologies with Russian-English bilinguals. They found that at early stages of word recognition, bilinguals can activate both languages in parallel, even when they were presented with sentences in only one language. Their findings in additional studies using functional neuroimaging suggest that the same general brain structures activate for both languages, but that there are also differences in the cortical structures activated by the two languages and by phonetic versus lexical processing. They conclude that this may support the idea of parallel/language non-selective processing in earlier stages of language processing and separate processing at later stages.

Other studies conclude that there is a general bilingual lexical access disadvantage for non-cognate lexical items (Cordere et. al., 2013; Bialystok 2008, 2009), as compared to monolinguals, which may be because of the initial non-selective activation of both languages.

For lexical processing, there seems to be general agreement for an initial preference for parallel, non-selective activation of a bilingual's two languages. However, there is evidence to suggest that this non-selective activation may not be absolute or constant under different conditions. Lexical access in sentence contexts seems to suggest that context may constrain the activation of one of the bilingual's languages, such that the activation of the other language has no effect, or only a limited effect (Schwartz & Kroll, 2006).

Much of the research on bilingual language processing has been at the word level, but many studies also address the activation of language items in sentence contexts and in the course of sentence processing. There are studies (Schwartz & Kroll, 2006; Dijkstra et al., 2014) to suggest that something critical occurs with additional information at the sentence level which influences language selectivity, or constrains the initial non-selective activation, perhaps in a way that directs a bilingual into a more monolingual mode for each of his/her languages for processing at the sentence level.

Bilingual Sentence Processing:

In an often-cited study, Schwartz & Kroll (2006) conducted online processing experiments at the word and sentence level using an RSVP (Rapid Serial Visual Presentation) sentence processing methodology (whereby words of a sentence are paced and presented independently on the screen). They analyzed the performance, as measured by reactions times, for young adult (university students) bilinguals of varying proficiency, intermediate to high, (Exp. 1 *n*=22 L1 Spanish-average proficiency: 9.2; L2 English average proficiency 8.6; Exp. 2 *n*=19, L1 Spanish- average proficiency-9.9; L2 English – average proficiency 7.9) levels during the processing of cognates and homographs embedded in sentences where there were two conditions, low constraint and high constraint. Constraint was operationalized to mean the degree to which the word(s) preceding the target word, biased that word. They found that in the low-constraint sentence condition, significant cognate facilitation was observed. According to the authors, this suggests that both languages were active and affecting processing. On the other hand, in the high-constraint sentences there was no cognate facilitation. This was observed in both intermediate proficiency and high proficiency bilinguals.

Dijkstra et al. (2014) conducted two lexical decision experiments. The participants for Exp 1 were 33 highly proficient bilingual young adult university students (18-32 w/mean age 22yrs) with L1Dutch and L2 English; Exp 2, *n*=39; same age and language profiles as for Exp 1. The purpose of the experiments was to test how the language of the sentence (English or Dutch) affects recognition of the target word, which was a Dutch-English cognate or a non-cognate word presented in isolation after a sentence with high or low semantic constraint. The language of the sentence and the target word were sometimes the same (i.e. English sentence; English target word), and sometimes different (i.e. English sentence; Dutch target word). They found that English cognates were facilitated irrespective of the language of the preceding sentence (Dutch or English) and irrespective of whether sentences were high or low constraint. For the Dutch cognates the results were a bit different, whereby inhibition was observed for Dutch cognates preceded by low constraint sentences in either language, and in English sentences in low and high constraint. Dijkstra et al., (2014) conclude that this suggests monolingual-like processing for sentence comprehension, and discuss this in the context of the BIA+ processing model.

More recently, a growing literature in cross-linguistic structural priming (Lim & Christianson, 2013;) is showing that L2 processing is similar to L1 processing which allows for 'fast and frugal processing' (Christianson, 2016) which is just 'good enough'. In a self-paced reading and translation task Lim & Christianson, (2013) found that L2 learners were able to use syntactic information the same as native speakers, and that processing and comprehension were impacted by their proficiency and goals for a reading task.

In general, for sentence processing, there is much evidence from a variety of methodologies including self-paced reading, eye-tracking, and ERPs to suggest that proficient bilinguals process sentences like native speakers, regardless of whether the syntactic structures

are the same or different across their languages. There is however still ongoing debate about monolingual and bilingual sentence-processing, and future research would have to address bilingual experience including proficiency and AoAB, and syntactic complexity.

Some of the key questions for sentence processing in monolinguals and bilinguals include: 1. How is syntactic ambiguity resolved in monolingual sentence processing? Does syntactic processing occur in a serial, syntax first manner, or in a parallel manner where multiple streams of information (e.g., lexical, verb, prosodic, etc.) interact? 2. Is sentence processing different in L2 as compared to L1? 3. How does the complexity of the syntactic structure, language proficiency, and the possibility of L1 transfer influence syntactic processing in L2 for bilinguals?

In the monolingual sentence processing literature, there is evidence to support various accounts of syntactic ambiguity resolution. Frazier & Clifton (1996) argue for a syntax-first, serial account, whereby the initial parsing of sentences occurs in a serial, syntax-dominant fashion. However, there is much evidence in monolingual sentence processing to support the claim that lexical information, verb bias (According to the view of syntactic processing in which verbal information guides sentence comprehension, verbs dictate which complements are allowed, i.e. direct objects or prepositions; verb bias refers to the preferential complement which can follow the verb), thematic and prosodic information, and/or referential context may all interact and inform online parsing simultaneously, or in parallel, to facilitate syntactic ambiguity resolution (MacDonald, M., 1997; Trueswell et. al., 1994; Altman et al., 1992; Wilson & Garnsey, 2009; Watson & Gibson, 2004).

When looking at bilingual sentence processing, the complexity of the syntactic structure must be considered, but proficiency and language transfer must also be considered. When

looking at the complexity of the syntactic structures, studies on the processing of English and French relative clauses have found that object-extracted relative clauses were more difficult to process than subject-extracted relative clauses (Holmes & O'Regan, 1981; Frauenfelder et.al., 1980; King & Kutas, 1995; Traxler et. al., 2002).

In eye-tracking experiments with French-English bilinguals, Frenck-Mestre, C. & Pynte, J. (1997) concluded that although there was some evidence of transfer from L1, bilinguals performed similarly to native speakers for syntactic ambiguity resolution when reading sentences that were ambiguous in only one of their languages. Frenck-Mestre (2004) reviewed studies of second language processing and resolution of syntactic ambiguity using eye-movement and ERP measures, and concluded that both methodologies produced similar patterns for native and proficient L2 speakers of a language, although there was some conflicting ERP evidence for the processing of anomalies.

Bilingual sentence processing studies have often compared bilinguals or L2 speakers to monolingual L1 speakers. Researchers are often interested in the possible impact of L1 on L2 language processing and whether L2 speakers adopt native-like processing strategies. For instance, Jackson and Dussias (2008) conducted self-paced reading experiments with proficient L2 speakers of German whose L1 was English. They found that highly proficient L2 German speakers demonstrated a subject-extracted preference similar to native German speakers which indicated that they can rapidly access L2 grammatical features in a native-like way. In a review of on-line sentence processing studies, Frenck-Mestre (2002) similarly concluded that proficient English-French bilinguals were able to parse structural ambiguities comparably to native speakers.

In a review of many studies of grammatical processing with L2 learners using a variety of methodologies including ERP measures, Clahsen & Felser (2006) noted a number of apparent differences between L1 and L2 sentence processing. On the other hand, other studies reviewed above, and more recent work (Lim & Christianson, 2013; Lim & Christianson, 2013) provide evidence that showing that L2 processing is similar to L1 processing.

Bilinguals: Lexical Access and Cognitive Control:

Some of the bilingual processing literature has argued that young bilinguals have advantages in cognitive control (defined as including the functions of 'selective attention to relevant aspects of a problem, inhibition of attention to misleading information, and switching between competing alternatives' p. 291 Bialystok et al. 2004). In addition, there is evidence that older bilinguals have comparable cognitive control advantages which seem to confer protection against cognitive decline, which can be defined as the normal age-related decline of these cognitive processes (Bialystok, 2001, 2004, 2009).

The BCA hypothesis assumes an integrated bilingual lexicon where there is non-selective access and activation, such that both languages of a bilingual are activated in parallel even in a monolingual context (Midgley et.al., 2008). It is argued that given this parallel non-selective activation in the bilingual lexicon, the high level of control required to suppress one language while producing another (or switching between one language and another) results in a cognitive control advantage, or generally improved executive control function in bilinguals, as demonstrated by their superior performance on tasks requiring cognitive control (e.g., with the Stroop task (Bialystok, 2001) and the Simon task (Bialystok et. al. 2004).

Simultaneous, or parallel, non-selective activation for bilinguals is also used to explain a bilingual lexical disadvantage (Bialystok, 2008, 2009), presumably because competition between

two lexical labels takes time to resolve, resulting in a lexical access disadvantage when bilinguals are compared to monolinguals. However, this presumed disadvantage could also be explained by an activation delay due to reduced frequency of exposure or weaker established links between lexical labels in each language. (Gollan et al., 2005; Gollan, 2008; Dijkstra & van Heuven, 2002). Irrespective of the phenomenon's underlying cause(s), it reminds us and further elucidates Grosjean's (1989) classic assertion that a bilingual cannot be viewed as two monolinguals in one. In studies of bilingualism, bilingual language experience, including AoAB, use patterns and proficiency, must be carefully examined (Kroll & Bialystok, 2013; Valian, 2015).

Bilingual Cognitive Advantage Hypothesis:

Support for the bilingual cognitive advantage hypothesis:

In Bialystok et. al. (2004), online reaction time measures were used to study cognitive control in two age-matched groups of monolinguals and bilinguals to see if there was a bilingual cognitive control advantage that would extend into adulthood, as had previously been observed for children (Bialystok, 2001; Bialystok & Martin, 2004). Age groups included younger adults ranging from 30-58 and older adults ranging from 60-88 years (mean age=71.9yrs). Three studies addressed the question of whether there is a cognitive processing advantage for bilinguals, and if there is, whether it is most apparent in older bilinguals. The results from the first study revealed that bilinguals were faster overall in responding to the Simon task. In addition, the bilinguals showed a smaller Simon effect overall for the incongruent trials, while the older bilinguals made fewer errors than the older monolinguals. Older adults and monolinguals in both age groups found it more challenging to inhibit the influence of the incongruent information, as demonstrated by longer reaction times, and a larger Simon effect,

which was also the case for older bilinguals; although bilingual adults had faster reaction times than monolingual adults.

Other studies have explored the BCA hypothesis using a bilingual Stroop task. Coderre et. al (2013) conducted several experiments using the Stroop task with Chinese-English and English-Chinese bilinguals to explore executive control abilities and lexical access speed in the Stroop task (Exp. 1 *n*=23, Average age=23yrs; English monolinguals; Exp 2 *n*=15, Average age=21.8, L1English, L2 Chinese; Exp 3 *n*=22, Average age=21, L1 Chinese (Mandarin), L2 English). They wanted to explore the bilingual lexical disadvantage (which posits that there is less efficient lexical access in L2 vs. L1 because of reduced proficiency) and the cognitive control abilities in their group of participants. They used a variation of the Stroop task with an SOA (stimulus onset asynchrony) manipulation where the word and color stimuli were presented at different times, such that the interference at each SOA provides information about the processing speed at each dimension. They found an effect of script such that Chinese and English had different RT patterns irrespective of L1 or L2 status of language such that script differences might be driving the RT patterns, and contribute to differences in the control condition. They found an advantage in interference effects (the interference effect is the RT difference between the incongruent condition minus the RT for control condition) for English – Chinese bilinguals, but not in both languages which they interpreted as less support for the bilingual cognitive advantage. From their findings, they concluded that for bilinguals there is both a lexical disadvantage and a cognitive advantage, and that the bilingual Stroop effect is influenced by both executive control abilities and lexical access speed.

Marian et. al (2012) used a 2x3 repeated measures design with analysis of production accuracy and error rates to study the effects of trilingualism and proficiency on inhibitory

control. The participants were all fluent in English and at least two other languages (*n*= 26, average age = 33.1; L1=English for 11 participants; L2=English for 12 participants; L3 English for 3 participants; multiple second and third languages as participants were participating in an international program at an American university). Proficiency was established by having all participants complete a language questionnaire which included providing self-rated proficiency measures for each of their languages in each modality (understanding, speaking, reading and writing). They used the classic color-word Stroop task and were interested in observing the impact of language proficiency on Stroop task performance, as well as the differences in within-language Stroop effect versus between-language Stroop effect. All the trilingual participants demonstrated the classic Stroop effect in all three languages with faster RTs on the congruent versus incongruent condition in each language. The within-language Stroop effect was stronger than the between-language Stroop effect. The statistical analyses revealed that there was an interaction in the between-language Stroop effect and language proficiency, such that there was a greater between-language Stroop interference effect when the stimulus was presented in the dominant language and when task performance response was in the less-dominant language. They also found that language proficiency (via self-rated proficiency measures) influenced speed, accuracy and error patterns in the Stroop task performance of multilinguals, such that performance was faster and more accurate in the participant's most proficient language, and that performance declined as a result of reduced proficiency on second and third languages. They concluded that there may be an interaction between the inhibitory control required to suppress the non-target language and the inhibitory control required to suppress the incongruent information of color/color ink during the Stroop task.

Bialystok et al. (2014) summarized findings of their research to clarify the conditions

under which a bilingual advantage, i.e., a phenomenon according to which bilinguals can show evidence of having certain cognitive advantages relative to monolinguals, can be observed. More specifically, bilinguals experienced less interference (hence, were better at interference suppression) on the Stroop task; this advantage was greater for older adults. Bialystok et al. (2014) conclude from this that the BCA is more likely to emerge and be salient/observed with nonverbal executive function tasks which involve slower and more effortful processing. This highlights the importance of choosing executive function tasks carefully, and understanding that duration of language use and age are critical factors to consider in future research.

It seems that the bilingual advantage is most likely to be observed with older bilinguals performing complex nonverbal executive function tasks. Not observing the bilingual advantage with younger adults would not necessarily mean that it does not exist, but rather that it might become most salient during periods of development and decline of the implicated cognitive processes versus when they are presumably at their stable peak in young adulthood. Labeling a phenomenon an advantage implies just that: if it exists, it is an advantage or a boost that is observable during dynamic, transitional life phases. By this reasoning, one might be less likely to observe such an advantage among people whose cognitive processing is at its peak, as with young adults.

There has been significant support for the BCA hypothesis (Bialystok et al., 2004, 2006, 2008; 2014; Blumenfeld & Marian, 2014; Costa et al., 2008; Hernandez et al., 2010; Salvatierra & Rosselli, 2011). However, recently there has also been controversy surrounding the claims of this hypothesis (Abutalebi & Clahsen, 2015; Hilchey & Klein, 2011; Kousaie & Phillips,2012, Kousaie et al., 2012, Paap & Greenberg, 2013, Paap et al., 2014) and calls for more research (Bialystok & Kroll, 2013; Titone & Baum, 2014; Valian, 2015), especially with older adults.

After a brief discussion of key research findings and considerations for future research of the BCA, a review of the literature which questions the robustness of the BCA will follow.

Although currently debated, the BCA has found support across disciplines and with various methodologies. For instance, Bialystok et al. (2004) used the Simon task, a classic reaction time measure thought to index inhibitory control, and found that older (mean age = 70) and younger (mean age = 43) bilinguals were faster overall (as compared to monolinguals) on incongruent and also on congruent items (albeit less so), and that they also had a smaller Simon effect (a classic and often-reproduced effect of inhibitory control). In addition, in this study, a second experiment with four colors versus two found that although both the Simon effect and working memory costs increased as would be expected with age, the increased processing costs were lessened by bilingualism; interestingly, this last effect was not observed with the classic 2 color Simon experiment. To assess the practice effect, they conducted a third experiment with middle aged adults (mean age = 40) with a classic Simon 2 color experiment to index inhibitory control and no working memory load, and with only the Center 4 color condition, which involves working memory and no inhibition, and also increased the total number of trials to 240 vs. the 192 trials which represented the total in Exp. 2. Bialystok et al. (2004) found that the performance of monolinguals eventually converged so that by the last block, monolinguals were as efficient as bilinguals were during the intial blocks. This speaks to a potential practice effect in studies exploring the BCA advantage which may impact the observation of the BCA.

Bialystok et al. (2005) used behavioral (RTs) and brain-based (fMRI) methodologies to explore the BCA. They used the 2-color Simon task (416 experimental trials; 208 control trials) with 10 English speaking monolinguals, 10 French-English bilinguals and 9 Chinese English bilinguals (all early, prior-to-age-6 acquisition of L2, with fluent, daily L2 use; mean age = 29).

They found evidence of the BCA as demonstrated by faster RTs by bilinguals versus monolingulas in all conditions. The performance speed was comparable for all groups in that they all performed fastest on control condition, and then faster on congruent versus incongruent trials. Interestingly, the Chinese-English bilinguals were overall faster than the two other groups. Neural evidence confirmed brain-based differences between bilinguals and monolinguals, such that while the same cortical areas were implicated for both bilingual groups, different cortical areas were implicated for monolinguals. Although subsequent studies (e.g., Paap & Greenberg, 2013) have often not found a bilingual cognitive advantage with younger participants (university undergraduates at American universities), it is interesting to note that in this study, the bilingual cognitive advantage was observed with a significantly larger number of trials than is typically included in studies (Paap & Greenberg, 2013), which speaks to a level of cognitive challenge or cognitive load which may be required in order for it to be observed. Paap & Greenberg (2013) completed one study with only 20 congruent and 20 incongruent trials (methodologically, not including a control condition is problematic and might call to question the validity of conclusions derived). In addition, their second study, which appeared more methodologically sound, included only 20 congruent trials, 20 incongruent trials and 20 control trials. This illustrates that there are quantitative, qualitative and methodological discrepancies between the studies of younger adults that would warrant additional exploration.

Costa et al. (2008) found support for the bilingual advantage with younger adults (mean age=22), 100 Spanish speaking monolinguals and 100 Catalan-English bilinguals. They completed a flanker task with a total of 96 trials. They found an across the board bilingual advantage whereby the bilinguals performed fastest on most conditions (congruent, incongruent and interference conditions).

Therefore, age matters, task challenge or number of trials matters, and bilingualism matters. These are all elements that will be taken into consideration in the present study, which by design included all three age groups in the same study to complete the same experimental protocol. This is not typically done, probably because of the participant recruitment challenges that it imposes. In addition, this study took into consideration the number of trials; however, given that older adults and fatigue factors had to be considered, the 416 trials in the Bialystok et al. (2005) study was deemed to be too large, while 60 trials as per Paap & Greenberg (2013) was not deemed sufficient for older or younger adults. Thus, a decision was made to incorporate 192 experimental trials for the Simon experiment. Design decisions for the other tasks in this study proceeded in a comparable fashion.

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192 trials which represented the total in Exp. 2. Bialystok et al. (2004) found that the performance of monolinguals eventually converged so that by the last block, monolinguals were as efficient as bilinguals were during the intial blocks. This speaks to a potential practice effect in studies exploring the BCA advantage which may impact the observation of the BCA.

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We can see from the studies discussed that age matters, task challenge or number of trials matters, and bilingualism matters. These are all elements that will be taken into consideration in the present study, which by design included all three age groups (to heed the call in the literature for more research with older adults per Valian (2015), but to also include younger participants) in the same study to complete the same experimental protocol. This is not typically done, probably because of the participant recruitment challenges that it imposes. In addition, this study took into consideration the number of trials; however, given that older adults and fatigue factors had to be considered, the 416 trials in the Bialystok et al. (2005) study was deemed to be too large, while 60 trials as per Paap & Greenberg (2013) was not deemed sufficient for older or younger adults. Thus, a decision was made to incorporate 192 experimental trials for the Simon experiment. Design decisions for the other tasks in this study proceeded in a comparable fashion.

Bilingual Cognitive Advantage Questioned:

The BCA has most typically been conceptualized as the bilingual advantage in inhibitory control due to the constant juggling of two languages in the bilingual brain, and stems from Green's inhibitory control model (1998). It has been referred to as the bilingual inhibitory control advantage (BICA), however, the exact nature and extent of the BCA is still open to debate.

Hilchey & Klein (2011) provide a nuanced review whereby they distinguish the bilingual inhibitory control advantage, BICA, for which they claim little empirical evidence actually exists, from the bilingual executive processing advantage, or BEPA. They review literature assessing the BCA and conclude that there is little support for the BICA, but rather significant support in the literature for the BEPA. Specifically, the BICA refers to the advantage that bilinguals are purported to have on nonlinguistic interference tasks as compared to monolinguals.

For bilingual language processing, we assume that both languages are activated and that one must be suppressed (when there are two competing languages, it is this ongoing practice of inhibiting one language that is thought to lead to the bilingual cognitive advantage, especially for cognitive control tasks) to allow for the other language to be expressed. Therefore, given their experience with bilingual language processing, it is hypothesized that bilinguals should have reduced interference on nonlinguistic tasks that require cognitive control in order to inhibit, or suppress, one element of a task in order to select the appropriate element (such as in a Simon or a Stroop task).

Hilchey & Klein (2011) argue that there is limited unequivocal evidence to support the BICA. They note that in Bialystok et al. (2004), a study whose findings were interpreted as evidence in support of the bilingual advantage in inhibitory control, the bilinguals demonstrated an advantage on both congruent and incongruent trials of the Simon task. Hilchey & Klein (2011) view this as support for a more general executive processing advantage (BEPA) versus an advantage in just inhibitory control. They conclude that there is stronger evidence in support of a general executive processing advantage in bilinguals than of a bilingual advantage in inhibitory control.

In a later study, Cordere & Van Heuven (2014) administered a bilingual Stroop to younger and older monolinguals and bilinguals (Chinese-English) while obtaining behavioral (RTs) and electrophysiological (EEG) data. From this, they concluded that there was inconsistent support for a bilingual inhibitory control advantage, but instead found what they termed a ‘domain general non-conflict specific advantage’, which is in line with the BEPA hypothesis. They concluded that the BICA and the BEPA are not mutually exclusive, but that further research was needed to explore the nature of the executive processing advantage that bilinguals exhibit.

When the results of all the studies that Hilchey & Klein (2011) reviewed were combined, these researchers concluded that they did not find strong support for the bilingual inhibitory control advantage in young children and adults. In studies in which the bilingual advantage was observed in older adults, the interference effects that were reported were large, as in Bialystok (2004); however, such results were not consistently observed across studies. In addition, when the inhibitory control advantage was observed in older adults, Hilchey & Klein (2011) concluded that this advantage disappeared as the participants were exposed to more trials. Similarly, Costa et. al. (2008, 2009) found that when there was a bilingual advantage for young adults, it disappeared with practice.

According to Hilchey & Klein (2011), the BEPA refers to a central executive processing system. The BEPA does not only refer to a bilingual advantage in inhibitory control, but rather to an advantage which is broader in scope and which "regulates processing across a wide variety of task demands" (p.17). Given that executive processing is a broad concept which encompasses several higher level processes, the bilingual inhibitory control advantage may be part of a general bilingual executive processing advantage viewed holistically versus being the only component which produces a processing advantage.

Paap & Greenberg (2013) reviewed the literature on the BCA, and concluded that there is 'no coherent evidence for a bilingual advantage in executive processing'. They provided a description of executive processes as including: inhibitory control, monitoring and switching. They conducted three studies with young university undergraduates to try to determine if there is consistent evidence to support a bilingual advantage in executive processing. Bilingual (n =122 and monolingual young adults (n = 155) completed various executive function tasks, including the Simon task. They concluded that there is no evidence for a bilingual inhibitory control

advantage. In addition, they found it to be problematic that the most frequently used nonlinguistic interference tasks (e.g., Simon and Stroop tasks) did not correlate with one another.

It may be that the young adult participants tested in Paap & Greenberg (2013) were at the peak of their cognitive processing and as such, it is more difficult to observe bilingual processing advantages in this population with the Simon and Stroop tasks. In addition, given that younger adults overall will invariably have cognitive processing speed advantages when compared to older adults (the population in which the bilingual processing advantage has been most frequently observed), it is too simplistic to categorically dismiss the existence of a bilingual processing advantage on the basis of Paap & Greenberg's study. Relatedly, Costa et. al (2009) reported that for Catalan-Spanish speaking young adults, a BCA is often only observed in situations of high cognitive demand.

Hilchey & Klein (2011) also discussed potentially confounding variables and some methodological and design issues which can impact and/or be associated with executive control and cognitive processing. For example, they argue that video game playing, high computer use and expertise in playing a musical instrument have been associated with executive control and have produced global reaction time advantages which are similar to those exhibited by bilinguals; thus they suggest that it might be beneficial to control for such potentially confounding variables in future experimental research studies. In addition, such factors as the number of trials required in order to see the bilingual inhibitory control advantage and the fact that it appears to disappear with practice, that it is not consistently seen in younger adults, and that the global processing advantage becomes more pronounced when task difficulty is elevated should not be ignored in any analysis of experimental results. Valian (2015) highlights the complexity of the many task considerations that impact performance and the inconsistencies that

exist among and within studies for participants, bilingualism variables and task considerations, and so a range of findings should not be surprising.

Kousaie & Phillips (2012) administered a bilingual Stroop task to non-immigrant younger and older monolinguals and bilinguals, and found that younger bilinguals had a general speed advantage, but not smaller interference effects. When they compared older bilinguals to older monolinguals, they did not find any effect of bilingualism. In a subsequent study, Kousaie et. al (2014) obtained behavioral reaction time measures and ERP measures on a battery of cognitive tasks performed by older and younger monolinguals and bilinguals. From the overall pattern of results, Kousaie et al. (2014) concluded that there was no unequivocal executive processing advantage for bilinguals when compared to monolinguals.

In reviewing a number of studies exploring cognitive control in older adults (Bialystok 2004, 2006, and 2014; Salvatierra & Rosselli, 2010; and Kirk et al., 2014), most studies did not find differences between monolinguals and bilinguals with respect to general response speed or accuracy. They did find however that older bilinguals had a smaller Simon effect, compared to older monolinguals, which suggests that the older bilingual adults possessed better inhibitory control. Salvatierra & Rosselli (2010) studied older and younger adults performing an easy Simon task (2 squares), and a hard Simon task (4 squares to increase working memory demands, as in Bialystok, 2004). They found that younger bilinguals did not demonstrate an advantage, but that older bilinguals were more efficient, that is they had faster RTs, with inhibitory control on the simple (2 squares) Simon task. Thus these results are in contrast to those reported in Bialystok et al. (2004), who also found a bilingual advantage for older adults performing the more challenging 4 square Simon task.

Finally, Kirk et al. (2014) looked at older bilingual and bi-dialectal speakers (n=80, mean

age = 70.8 yrs, SD = 7.5 yrs, range 60-89yrs). The participants included many bilinguals with varying levels of proficiency in English and a regional dialect (Gaelic-English, Dundonian – Scottish), and immigrants who spoke many East Asian languages as L1 (Bengali, Gujurati, Malay, Punjabi, Urdu) and English L2. They wanted to explore whether the bilingual advantage was associated with ethnic and cultural differences associated with immigrant bilinguals, and also whether the BCA might be observed in monolinguals who used a dialect. The participants completed the Simon Task in 2sq and 4sq conditions as per Bialystok et al., 2004). Kirk et al., (2014) found neither a bilingual advantage in inhibitory control on both conditions of the Simon Task, nor any global reaction time advantages for bilinguals. They concluded that there was no BCA associated with differences in the immigrant status of bilinguals, nor with use of a dialect by monolinguals. They suggest that their results may have been due to qualitative differences (i.e. no schooling in one of the languages) in the way their bilingual participants used their two languages.

BCA: Limited and mixed results at sentence level:

Very few studies have examined whether there is a bilingual cognitive control advantage at the sentence level. Moreno et al. (2010) explored conflict resolution at the sentence level by having young adult monolinguals and bilinguals perform semantic and grammaticality judgments and obtaining ERP data during these tasks. In analyzing the N400 and P600 waves that were generated, the researchers concluded that bilinguals were less accurate than monolinguals on the semantic acceptability task, but that both groups showed comparable levels of accuracy in the grammaticality judgment task which requires more executive control. In a discussion of the neural data obtained, Moreno et al. (2010) reported that bilinguals had a smaller P600 amplitude and more bilateral distribution of activation when compared to monolinguals performing the

grammaticality judgment tasks. The authors suggest that the grammaticality judgment task (where participants are instructed to ignore semantics and respond only to the accuracy of the syntactic structure) is a conflict condition which requires more executive control, and that the BCA allows bilinguals to perform comparably to monolinguals in the challenging task; an improvement from bilinguals' lesser performance during the simpler linguistic processing task.

Paap & Liu (2014) performed a study comparable to the Moreno et al. (2010) study, but using behavioral methods, specifically RTs from sentence processing experiments with different conditions (Exp.1 Homographs in sentence processing; Exp. 2 Grammaticality judgement sentence processing task with self-paced reading methodology; Participants were young adult university students who were monolingual and bilingual (Exp1 n=34 bilinguals; 55 monolinguals Exp. 2 24 monolinguals 24 bilinguals; bilinguals had various language combinations) The primary goal of this study was to test the BCA at the sentence level using behavioral data. Paap & Liu (2014) report that both monolingual and bilingual groups had comparable performance times in the task that required them to suppress the context-inappropriate meaning. They conclude that both the semantic acceptability and the grammatical acceptability task performances of bilinguals and monolinguals provided no evidence of a bilingual advantage for bilinguals during sentence processing. In an apparent response to the findings and conclusions of Moreno et al. (2010), Paap & Liu (2014) argue that the 'existence of a behavioral phenomenon (such as the bilingual advantage in conflict resolution) must be adjudicated at the behavioral level' (pg.54). Hilchey & Klein (2011) also argued for additional research with behavioral data, indicating that if there is no bilingual advantage with behavioral data, then it is difficult to know what differences in neural circuitry might be involved with the BCA (Abutalebi et al., 2012; Bialystok et al., 2005; Luk et al., 2010.

Although it is clear, as per Paap & Liu (2014) and Hilchey & Klein (2011), that more behavioral data are needed, it is also evident that research with different methodologies exploring neural correlates for bilingual language processing can contribute significantly to our understanding of the BCA hypothesis, as has been demonstrated by various studies using different methodologies to shed light on the neural correlates involved.

Neural imaging studies reveal an extensive network of brain areas involved in executive control functions including working memory, sustained attention, inhibition and resolution of cognitive conflict. The executive control neural network is located primarily in the prefrontal and parietal cortices and includes areas such as the ACC (anterior cingulate cortex), DLPFC (dorsolateral prefrontal cortex), left inferior parietal lobe, and right inferior frontal gyrus. An extensive domain-general neural network is activated for executive function and conflict resolution (Bunge et al., 2002; Fan et al., 2003; Hussey et al., 2015; Niendam et al., 2012)

Different methodologies can provide different and complementary information about bilingual cognitive-linguistic processing. To the degree that each study with each methodology increases our understanding of bilingual language processing, all results obtained are very valuable. Care must be taken, however, when comparing results using different methodologies, different linguistic and cognitive measures, and bilinguals with different bilingual language experiences.

Bilingualism and Executive Function: Factors to Consider

Given the complexity of bilingualism and cognition, the range of methodologies, participants and different tasks, it is not surprising that there would be variance in findings. This is not a reason to draw simplistic yes/no, either/or conclusions, about the existence of the BCA, but more so a call for additional research to try to understand the nature of the BCA and the

conditions which might allow for evidence of it to emerge. Additional research is therefore warranted that would take into consideration what we know thus far about the complexities of bilingualism, as well as the complexities of cognitive processing, the tasks used to index executive function, the design of experiments, and the participant-related factors. A discussion of bilingualism and executive function and the variables to consider when conducting new research will follow.

Bilingualism and Cognitive Implications:

Bialystok & Kroll (2013) argue that conflicting findings are a reflection of the complexity of executive function and bilingualism, and that such findings invite future researchers to further explore the cognitive consequences of bilingualism. One important suggestion they make on the basis of previous studies is that researchers should seek to operationalize bilingualism not as a binary variable (whereby a person either is or is not a bilingual), but rather as a gradable one (whereby a bilingual is to some measurable degree able to speak her/his two languages). In addition, Bialystok & Kroll (2013) identify AoAB (age of active bilingualism), level of language use, and language proficiency as other important factors that must be carefully considered in future studies.

It was once thought that bilingualism was a disadvantage. Fortunately, thanks to research in the field in the last 50 years, and especially in the last couple of decades with additional tools for exploration, it is clear that bilingualism is certainly not a disadvantage. However, a lot more work needs to be done to more fully understand bilingual language processing. What is clear is that ‘a bilingual is not two monolinguals in one’ (Grosjean, 1989), and that bilingualism changes the brain and confers certain executive processing advantages which we still do not fully understand. Bialystok & Kroll (2013) and others (Yow & Li, 2015) have argued for more fully

exploring the complexity of bilingualism in future research in order to better understand how different bilingual language experiences may impact cognitive processing differently.

At present it seems that the cognitive advantages more readily present themselves in individuals who are regularly using two languages on a daily basis; however, this is not definitive. What is still open to question is the degree to which all the different variables of bilingualism play a role in advantages in cognitive processes. At this point, enough research has been conducted which demonstrates that bilingualism changes the neural networks (Abutalebi et al., 2010; Bialystok et al., 2005; Luk et al., 2010) and cognitive processes of individuals (Bialystok et al., 2001, 2004, 2006, 2014); however, what is open to debate is how, when, to what degree, and under what circumstances these changes can occur. So, what is clear is that much more research is needed with bilinguals across the lifespan to explore these issues. It is important to study bilingualism not just as a categorical variable, but as a dynamic phenomenon and non-categorical variable (Bialystok & Kroll, 2013).

The nature of the bilingual experience and age of participants must be considered in future research. Many of the studies that show no support or mixed findings for a BCA tested very young adults (i.e., undergraduates, Cordere et al., 2013; Kousaie & Philips, 2012; Paap & Greenberg, 2013; Paap & Liu, 2014). Clearly this is not a complete sample of bilinguals across the lifespan; in fairness, the studies that used such participants did not claim that they were a complete sample, either. Instead, they were a convenient population for researchers to test. According to some researchers (Bialystok, Craik, Klein, & Viswanathan, 2004), it may be however that the positive effects of bilingualism, or the BCA do not manifest themselves until later in life, after much more additional practice, or ongoing use of two languages. Perhaps the most exciting and promising aspect of a bilingual advantage in the context of this discussion

concerns claims that it might be a neuro-protective mechanism against cognitive decline in aging: there are studies which have reported a neuro-protective advantage as a consequence of bilingualism in older adults (Tucker & Stern, 2011, Stern, 2009, 2012).

If bilingualism does indeed change the brain, then we need to continue to explore bilingualism with tools and tasks that might better capture what is occurring with bilingual cognitive and linguistic processing. By using tools and tasks that have been constructed for monolinguals and adapting them to bilinguals, and by continuing to compare bilinguals to the monolingual norm, however, researchers may not be capturing the richness of the bilingual experience. The main focus of this study will be to explore which bilingualism variables modulate performance on cognitive performance tasks.

Pelham & Abrams (2014) conducted a study to investigate the BCA in early onset and late onset English-Spanish bilinguals and monolinguals (Monolinguals *n*=30 avg age =19.3yrs; Late bilinguals *n*=30 avg age = 22; Early bilinguals *n* = 30 average age = 20.3yrs). All participants completed a picture naming task to assess lexical access, and attentional network task (ANT) to assess executive function. They found that both groups of bilinguals, late and early onset, had comparable performance on both tasks, which included the same degree of lexical access deficits on the naming task and comparable performance (on the ANT task) with a bilingual cognitive advantage observed for both groups. They concluded from their findings with late bilinguals that in order to observe evidence of a bilingual advantage, what matters most with respect to bilingual language use is the habitual use of the two languages, rather than the duration of that habitual use. Pelham & Abrams (2014) note that some duration of regular use is of course required; however, the necessary duration of consistent, proficient use of two languages such that evidence of a bilingual advantage can be observed requires additional research. In addition,

Pelham & Abrams (2014) cited the need for additional research to determine if becoming a proficient bilingual much later in life would also allow for bilingual advantages to emerge.

Bilingualism Factors to Consider:

Bilingualism is indeed a complex and dynamic phenomenon, and actually quite common on a global scale. In his 2010 book, *Bilingual: Life and Reality*, Grosjean provides a wide-ranging overview of the complexity of bilingualism, some key points of which will be summarized here. For instance, it is estimated that more than half the world's population is bilingual across cultures and age groups, and that there is a high percentage of bilingualism even in countries considered primarily monolingual, like the approximately 50 million bilinguals living in the US. Bilingualism is a dynamic phenomenon, and although there is debate on degrees and levels of bilingualism, individuals can become bilingual at various times in their life, including adulthood, and for many different professional, personal and logistical reasons. Being bilingual does not necessarily imply perfect knowledge and equal levels in all modalities in both languages. Some bilinguals have high levels of understanding and speaking in their second language, with limited reading and writing skills in the two languages. Highly proficient bilinguals in both languages are actually in the minority when considering bilingualism globally. In addition, it is common for bilinguals to vary in that they typically use their two languages in different situations with different people.

Grosjean (2010) also discusses differences in language dominance versus language proficiency. Proficiency often refers to an externally referenced phenomenon pertaining to the speed and accuracy of parsing vocabulary and grammar in a language. On the other hand, dominance refers to a construct that is more internally referenced and which is relative and dynamic. Dominance does not necessarily imply high proficiency, and vice versa, i.e., high

proficiency in a language does not necessarily imply dominance. In addition, being a balanced bilingual does not necessarily imply a high level of proficiency in two languages, but rather a comparable level of proficiency in two languages irrespective of the actual proficiency level. And given that dominance is dynamic, the concept of 'balanced bilingualism' may represent more of an ideal versus the more common reality (Grosjean, 2010). Broadly stated, a bilingual can be described as an active user of two languages irrespective of the level of proficiency in either or both of the languages (Grosjean, 2010; Hakuta & Butler, 2004)

It appears that just as a bilingual is not two monolinguals in one (Grosjean, 1989), a bilingual who code-switches and intersperses use of both languages daily may be different from a bilingual who compartmentalizes language use and uses L1 for family interactions and L2 for academic and professional purposes. An immigrant who must become bilingual to adapt to his or her new homeland may be different from a bilingual who chooses to acquire an L2 or is introduced to an L2 by family members for cultural enrichment. Sociolinguistic factors such as the value placed on bilingualism and biculturalism, and the relative perceived prestige or value of an L1 and an L2 likely also influence language use patterns, and thus also the linguistic and cognitive development and processing of individuals who actively use those languages.

Being bilingual should not be viewed as a static state, but rather as a process which may develop and change over time. As should be clear by now, many variables impact bilingualism. The following variables are associated with differences among bilinguals (Paradis, 1987 p. 6):

(1) *degree of proficiency*: the ability to use two languages like a native speaker ('true' bilingualism, ambilingualism, equilingualism), to use neither language like a native speaker (semilingualism) or to use each language in a specific context (diglossia)

(2) *types of organization of the grammar*: no interference (separate grammars), unidirectional interference, or bidirectional interference (shared grammar)

(3) *context of acquisition*: (a) both languages acquired at the same time by speaking one language to one person or group of persons; or by speaking both languages alternately and indiscriminately to both parents and/or other speakers of the bilingual community; (b) acquired as an L2 outside the home and/or at school as language of instruction and interaction with peers; only as language of instruction, all peers being of the same native language as learner and speech community; (c) acquired in school through formal language instruction with one of the following methods: grammar-translation (deductive), structuro-global audiovisual (inductive), audiolingual pattern drill (inductive), conversational (interactive, inductive), communicative (interactive, inductive)

(4) *age of acquisition*

(5) *motivation*

(6) *structural distance between the languages*

(7) *context of use*: home/community and/or work, frequency of use, used only for specific purposes (restricted lexicon, sociolinguistic registers), modality of use, different sociolinguistic status associated with use of each language

Because the BCA addresses the potential boost to cognitive processing as a result of one's bilingual experience, it would be important to understand the crucial elements of a bilingual experience which consistently produce a robust cognitive advantage. Notwithstanding the myriad individual differences which might also be impacting cognitive processes, in reviewing the literature, the following aspects of bilingualism appear to impact the observation of a BCA. The

variables below will be discussed in the context of findings in support of a BCA. Note that there is a degree of overlap between these variables and the bilingualism variables which were introduced and described above.

(1) *Age of Acquisition*: Some studies used participants who had acquired their L2 before the age of six, while others had an age of L2 acquisition of around 12 years. It appears that an earlier age of acquisition may be an important factor for observing the BCA (Kroll & Bialystok, 2013). Although this is definitely the case for children, very early acquisition may not be as important for the BCA to be observed in adults.

(2) *Age of Active Bilingualism*: It appears that the age at which an individual started to actively use two languages (AoAB) may be even more important than age of acquisition (AoA). Specifically, AoAB may be more sensitive than L2 AoA as a predictor of linguistic performance (Luk, de Sa & Bialystok, 2011; Bialystok & Kroll 2013).

(3) *Age at Time of Testing*: Age at time of testing appears to impact the observation of the BCA, as the BCA has appeared to be most robust with older bilinguals (Bialystok, 2004, 2014), while the studies which report no BCA have been primarily with younger bilinguals (Paap & Greenberg, 2013; Kousaie et al 2012), typically undergraduates in a university setting. Therefore, in any comprehensive study exploring the bilingual advantage, it would be important to include a range of ages. In particular, there have recently been calls for more research with older adults (Valian, 2015; Bialystok et al., 2014)

(4) *Duration of Active L2 Use*: The difference between Age of active bilingualism and Age at time of testing would yield the ‘duration of Active L2 use’, or the length of time that

the individual has been bilingual. Recent studies have confirmed the relation between this variable and cognitive outcomes (Luk, de Sa & Bialystok, 2011).

(5) *Language Use Context/Culture/Setting*: Some studies have incorporated bilinguals who are immigrants and thus in an L2 dominant environment (Paap & Greenberg, 2013), while other studies have studied non-immigrant bilinguals in a monolingual environment (Kousaie et al., 2014) or bilinguals in a bilingual environment. Setting and sociolinguistic factors likely impact language use. Some bilinguals use both languages daily, consistently, and interchangeably in all contexts; whereas others use each language in specific circumstances or contexts, e.g., L1 for family interactions and L2 for academic and professional purposes. In addition, factors such as whether one language is viewed as a prestige language, in addition to other sociolinguistic factors can impact a bilingual's language experience.

(6) *Duration vs. Consistency of Use*: Using two languages consistently and habitually, or daily, (which can also be referred to as intensity of use) may play a greater role in observing bilingual advantages than the duration of bilingual language use (Pelham and Abrams, 2014; Luk & Bialystok, 2013). Self-reported and more subjectively assessed measures may possibly not be as reliable as a more objective measure such as duration of active L2 use.

To summarize, the various components of the phenomenon in question, bilingualism and one's bilingual experience (AoA, AoAB, language use profile, culture/context) can impact the observation of differences in cognitive processing. It was beyond the scope of this project to incorporate all aspects of bilingualism into the analyses, but those that have been documented as most relevant for exploration of the bilingual cognitive advantage were incorporated, and will be

discussed later. That is, the most promising indices of bilingualism for observation of the BCA were chosen for the analyses. There have been calls for additional research to control for language and location, for example testing monolinguals and bilinguals in the same location vs. testing monolinguals in one location and bilinguals in another, etc. (Kousaie et al., 2014). An additional important consideration when exploring the bilingual advantage is the experimental conditions and tasks used for the observation of the phenomenon in question. Specifically, the executive function tasks used could impact the observation of a bilingual advantage.

Executive function:

Executive Function/Cognitive Control:

To review, executive function is as an umbrella term which refers to a range of cognitive processes including problem solving, attention, inhibitory control and task switching, working memory and cognitive flexibility. It is also referred to as the cognitive control and supervisory attentional system (SAS) (Diamond, 2013). Much of the research on the BCA hypothesis has focused on inhibitory control (Bialystok et al., 2004, 2008, 2009) however, other components such as working memory have also been addressed (Bialystok et al., 2004, 2014). Bilinguals have been shown to be better at such processes (Bialystok, 2004, 2008, 2014).

Inhibitory control, also known as response inhibition, is a key component in cognitive control which has been measured by various tasks such as Stroop task, Simon task, Flanker and go/no-go task. When inhibitory control is tested, researchers are interested in a participant's ability to inhibit or override a habitual or dominant behavioral response (Diamond, A. 2013). Performance on these tasks has been the key basis according to which researchers have found evidence for or against the BCA (Bialystok et al., 2004, 2008). It has been argued that because bilinguals must exercise ongoing inhibitory control to inhibit or override their dominant language

in order to speak in their L2 vs their L1, the result is a cognitive processing advantage for them when compared to monolinguals (Green, 1998, Diamond, A., 2013, Bialysok et al., 2004, 2008, 2014).

As described earlier, there has been recent discussion about whether the BCA represents only an advantage in inhibitory control (i.e., a bilingual inhibitory control advantage, or BICA) or rather a more general cognitive processing advantage (i.e., a bilingual executive processing advantage, or BEPA), as research has often found bilingual advantages on inhibitory control trials but has also found overall bilingual speed advantages (Hilchey & Klein, 2011). In addition, the contribution of working memory in bilingual processing advantages is being explored, and there have been calls for additional research to understand the role that working memory plays in cognitive processing advantages displayed by bilinguals across the lifespan (Bialystok et al., 2014; see also Kim & Christianson, 2013; Kim & Christianson, in press)

Working memory:

A key component of executive function is working memory. Using working memory tasks to observe a BCA is more complicated because of the verbal component which can be a part of such tasks. There are many variables which can influence cognitive-linguistic processing. Verbal working memory is considered to be a variable; however, the degree of impact is not conclusive and also has been shown to interact with proficiency level or language experience which is another variable which can impact linguistic processing.

The findings of Wells et al., (2009) provide compelling evidence for linguistic experience as a contributor to language performance with sentence processing once working memory was controlled for in the control and experimental groups. Notably, after increased and concentrated exposure to subject and object relative clauses during the training sessions, the relative clause

reading times of the experimental group were comparable to those of individuals with high working memory spans. By contrast, the control group (which had gotten only reading experience for equal amounts of time but without increased exposure to relative clause sentences) had reading times for the relative clause sentences which resembled the profiles for individuals with low working memory spans. There is evidence to support verbal working memory as a possible variable impacting syntactic processing; however, even in studies where verbal working memory is controlled for, it often does not provide a complete explanation for differences in syntactic processing (Swets et al., 2007).

Also, whereas working memory may be a factor for language learners, there is evidence to show that with an increase in language proficiency, individuals use less working memory capacity to perform target language tasks (Service, Simola, Metsanheimo, & Maury, 2002). So, for proficient bilinguals, it might make sense to assume that working memory capacity might be less of a factor in accounting for variance in cognitive-linguistic processing (see also, Wen, 2015, 2016).

Novick et al. (2005) conducted a review of neurocognitive and sentence processing literature to explore the role of the frontal lobes in complex cognitive processes, including language processing. Historically, Broca's area has been implicated in language processing. Broca's area is part of the the left inferior frontal gyrus (LIFG). Many studies have suggested the LIFG has a critical role in sytntactic processing at the sentence level. On the other hand, there are also many studies with data from brain-imaging and neuropsychological methods, that suggest that the LIFG has a direct role in cognitive control, especially for overriding habitual and automatic responses. After reviewing the studies using behavioral methods and those with brain based methodologies, Novick et al., 2005 concluded that there is support for the following

hypotheses : “(1) LIFG is part of a network of frontal lobe subsystems that are generally responsible for the detection and resolution of incompatible stimulus representations; (2) the role of LIFG in sentence comprehension is to implement reanalysis in the face of misinterpretation; and (3) individual differences in cognitive control abilities in non-syntactic tasks predict correlated variation in sentence-processing abilities pertaining to the recovery from misinterpretation” (p. 263) (see also Hussey, Ward, Christianson, & Kramer, 2015).

Evidence of a bilingual advantage has been found under experimental conditions with various cognitive tasks indexing various components of executive function. A review of studies with an emphasis on the executive function tasks used to explore the BCA will follow. After reviewing studies which look at the impact of bilingualism on cognitive processing, a review of select executive function tasks will be summarized, with a description of key tasks which have been used in research thus far including Stroop task, Simon task and the Aospan working memory task. And finally, in this section there will be a summary/discussion of the task considerations that may impact observation of a BCA, including task sensitivity, task length, number of trials, and task challenge.

Executive function/Cognitive Control Tasks/Bilingualism:

Luo et al. (2013) wanted to explore executive function advantages more globally by indexing and studying working memory in bilinguals and monolinguals. They argued that bilingualism seems to result in overall enhancement of executive function that extends beyond the classic bilingual advantage in inhibitory control. They cite bilingual advantages in task-switching contexts and in letter fluency tasks as evidence of an overall cognitive processing advantage resulting from bilingualism. Research has supported a BCA in executive function, not

only for inhibitory control (Bialystok et al, 2004, 2008, Hilchey & Klein, 2011), but as Luo et al. (2013) noted, "its genesis and boundary conditions are still being worked out".

In order to further explore the cognitive advantages of bilingualism across the lifespan, Luo et al. (2013) decided to study working memory in bilinguals as an additional way to index executive function, which is an umbrella term for many processes. They referred to Miyake & Shah (1999) to show the interrelationship between processes involved in executive function and working memory, arguing that working memory is involved in most cognitive processes. They wanted to explore the interrelationship between working memory and executive function, to see if, given the fact of enhanced executive function in bilinguals, whether their working memory performance would also be enhanced. In addition, Luo et al. (2013) argued that working memory is not domain neutral, but rather that performance is dependent on the type of material being processed, and as such can reflect domain general executive processes and domain specific abilities. They found that as predicted, working memory declines with aging, that bilinguals performed better than monolinguals on a spatial working memory task, that monolinguals did better on verbal working memory tasks, and that the interaction between bilingualism and the spatial WM domain was consistent across the adult lifespan.

Bialystok et al (2014) also argued that working memory is involved in executive function and in linguistic processing and that it is a key component of reading and auditory comprehension (Just & Carpenter, 1992), and that it is thus important to explore differences in WM in monolinguals and bilinguals. In Bialystok et al. (2014) it is suggested that because bilinguals are constantly managing two languages, that this may call upon more working memory resources thus resulting in enhanced working memory performance for other tasks. In this study, they found that bilinguals had reduced performance on lexical retrieval tasks relative

to monolinguals, similar performance to monolinguals on working memory tasks, and better executive function overall as compared to monolinguals.

Furthermore, in analyzing the data for the Stroop effect Bialystok et al. (2014) found that older bilinguals exhibited greater facilitation and smaller costs relative to older monolinguals, and argue that this results from the executive control required to focus attention on one language while suppressing the other language. They site Bunge et al. (2002) who coined the term 'interference suppression' to describe the process of attending to one set of information while simultaneously suppressing another set of information.

It is argued that bilinguals are consistently engaged in interference suppression as they use language. The authors further highlight and distinguish between response inhibition and interference suppression, arguing that interference suppression is the area in which bilinguals, especially older bilinguals, appear to excel.

Recent work exploring the nature of working memory performance in bilinguals is also a significant contribution to future research. Namely, the fact that there is evidence that bilinguals demonstrate domain-specific advantages in spatial working memory versus verbal working memory when compared to monolinguals (Luo et. al., 2013), but that in another study (Bialystok et al., 2014) exploring working memory performance, bilinguals were only found to have minor differences which were interpreted as largely similar to the working memory performance of the age matched monolinguals, is indicative of the fact that more research is required to explore how bilingualism affects working memory performance (Bialystok et. al, 2014). In addition, the type of task used and the linguistic experience of bilinguals selected is also very important. Of significance here is that Luo et. al (2013) found domain-specific advantages in spatial working memory, particularly for older bilingual adults.

Tasks which are used as indicators of executive function will now be discussed in more detail. Two classic measures, the Stroop and Simon tasks, to assess cognitive control will be described, in addition to a working memory task. The Simon task is a non-verbal measure of cognitive control, whereas another classic measure of cognitive control, the Stroop task, has a linguistic component.

Tasks indexing non-linguistic and linguistic executive function:

Simon Task:

The Simon task is a non-verbal measure of cognitive control. This task addresses executive functioning, specifically response inhibition in a nonverbal domain, and is thus considered a nonverbal measure of cognitive control. In the classic Simon design, participants see a series of colored rectangles displayed on a computer screen. Participants are asked to press a key on the left side of the keyboard if the colored rectangle is of one color, and to press a key on the right side of the keyboard if the colored rectangle is of a different color. This is the *congruent condition*. Sometimes the location of the colored rectangle changes such that it appears on the opposite side of where the matching color key is located, thus creating an *incongruent condition*. The third condition is the *control condition* where all the rectangles appear in the center, and the participant is instructed to press the right or left key depending on the rectangle's color.

The Simon effect describes the phenomenon whereby reaction times are typically faster and more accurate in the congruent vs. the incongruent conditions because it takes longer to inhibit the automatic response (Simon & Rudell, 1967).

Stroop Task:

The Stroop task (Stroop, 1935) is a classic measure of cognitive control. In this task, participants are asked to name the ink color of written color words when the meaning of the words is either congruent or incongruent with their ink color. The congruent condition is when the color word's meaning is the same as the color of the letters that the word is written in (e.g., the word "red" written with red letters). The incongruent condition is when the color word's meaning is different than the color of the letters that it is written in (e.g., the word "red" written with blue letters). There is also a control condition whereby participants are asked to name the color of colored squares (there are no words in this condition). Stroop (1935) found that naming colors in the incongruent condition was slower and less accurate. This difference between the incongruent and congruent color-naming conditions, i.e., the Stroop effect, has served as an indicator of cognitive or inhibitory control and language processing. The difference between incongruent and control RTs is referred to as the interference effect, whereas the difference between control and congruent RTs is referred to as the facilitation effect. The Stroop effect includes both interference and facilitation effects, and may confound conflict effects; therefore, it is important to include an appropriate control condition. (Stroop, 1935; MacLeod, 1991).

Verbal Fluency Test:

This is a language-based task consisting of two components: letter fluency, and category fluency. The letter fluency component of the VFT assesses the ability to produce words based on initial phonemes. Fluency tasks are used to assess the efficiency of word retrieval, and are based on cues consisting of either an initial letter or a semantic category (Spreen & Strauss, 1998).

Corsi Block Task:

This is a working memory task which also indexes spatial and visual processing. In this task, participants see a sequence of blocks light up on a computer screen. The individual is then asked to reproduce the sequence in the correct order by tapping on the blocks that lit up for each trial.

Aospan Task:

Over the years many different types of tasks have been used to measure working memory. The Aospan task (automated operation span task) has been tested against other working memory measures (e.g., the operation span task and the reading span task) and found to be a reliable measure of WM (Unsworth, Heitz, Schrock, Engle, 2005)

Moreover, it can easily be completed in 20 minutes online. The Aospan task uses letters and numbers, so there is no need to adjust for language or account for vocabulary knowledge as a possible variable. Engle, Nations, & Cantor (1990) have addressed variance between span tasks and suggested that word knowledge is the reason for the variance. Given the present study's focus on bilinguals and the fact that lexical knowledge could be a factor impacting performance on a working memory measure, it is ideal to have a WM measure that is reliable and does not use words or sentences. In addition, given that French and English both use a similar alphabetic script, the Aospan task can be used with all participants in this study.

Task Considerations:

The tasks used may impact the observation of a BCA. The following are some task considerations that may impact observation of a BCA:

Task sensitivity: It may be that certain tasks are not sensitive enough to allow for differences in cognitive processing between monolinguals and bilinguals to emerge. Also, some researchers

have indicated that the executive function tasks which are currently being used may not be sensitive enough to detect differences in young adults who are at the pinnacle of their cognitive processes abilities. This possibility is supported by studies which used both behavioral and brain-based methodologies, and which found differences in the cognitive processing of young monolinguals and bilinguals with the brain-based measures, but not with the behavioral measures (Kousaie & Philips, 2012b; Bialystok et al. 2005).

Task Length and Number of Trials: It may be that there is a practice effect such that with an increasing number of trials the monolinguals catch up to the BCA that the bilinguals may have initially had on task performance. If a BCA existed by virtue of one's bilingual experience, but a monolingual might be able to achieve it by becoming bilingual, or repeatedly performing cognitive exercises, this would be a good thing. Nevertheless, for experimental purposes the number of trials for a given cognitive task must be considered. And it may be that the 'just right challenge' may be required in terms of number of trials and task difficulty in order for the BCA to emerge, which brings us to the third component of the task that must be considered, namely task challenge. (Bialystok et al. 2004)

Task Challenge: Bialystok et al., (2004, 2006) have argued that the BCA is most likely to emerge under cognitively complex and demanding tasks, so task difficulty is an important element in testing for a BCA.

Present Study:

Given the recent controversy about the BCA, and the calls for more research, especially with older adults (Bialystok & Kroll, 2013; Titone & Baum, 2014; Valian, 2015; Abutalebi & Clahsen, 2015), the present study will shed needed light upon how bilingual language experiences can impact linguistic and cognitive processing across the lifespan. In reviewing various studies

including those which did and did not find support for the bilingual cognitive control advantage, it is clear that future research must continue to address various pertinent factors. These factors include bilingual language experience of participants, the executive function tasks used, and the age of participants. It appears that age at time of testing may impact the observation of the BCA. The BCA has appeared to be most robust with older bilinguals, while the studies which report no BCA have been conducted primarily with younger bilinguals, typically undergraduates in a university setting. Therefore, in any comprehensive study exploring the bilingual advantage it would be important to include a range of ages, and in particular a group of older adults (Valian, 2015)

The following factors, which have been implicated as reasons for varying results, will be considered and addressed in the present study's design: age, task difficulty, language proficiency and/or language dominance, age of acquisition, age of active bilingualism (AoAB), and frequency of use. The next chapter will summarize the details of design considerations and methodology for the present study.

Chapter 3: Methodology

The aim of the present research is to test the bilingual cognitive advantage hypothesis, with bilinguals of varying ages and levels of bilingualism as per calls in the literature, to further explore the conditions under which a bilingual advantage might emerge. There have been calls for additional research with older bilinguals (Valian, 2014; Bialystok et al., 2014) in the same location (Kousaie et al., 2014), with cognitively complex tasks (Bialystok et al., 2014), while also using both verbal and non-verbal tasks (Bialystok et al., 2014). To the extent possible, the present study has attempted to address each of these points while also controlling for both the L1 and the L2 of all participants.

To investigate the nature of the bilingual advantage across the lifespan, monolingual English and French speakers and bilingual English-French and French-English speakers were recruited according to the following age ranges: 18-29 yrs, 30-59 yrs, and 60-80 yrs. These ages ranges were adopted because they correspond generally to age groupings in other studies in this area for younger, middle aged and older adults (Bialystok et al., 2004, 2008; Kousaie et al., 2014).

The research protocol completed by participants consisted of linguistic and non-linguistic tasks that are thought to involve executive function. The tasks included the Stroop and Simon tasks as measures of executive function, specifically inhibitory control, a verbal fluency test as a measure of verbal functioning, and Corsi and Aospan for working memory. Biographical information related to language learning and use was also obtained, together with measures of language proficiency in either French or English for the monolingual controls, or in both French and English in the case of bilinguals. Given the controversy surrounding the bilingual cognitive advantage, this study was designed to provide additional perspective on cognitive processing changes which may

result from a bilingual language experience, and how this might impact cognitive changes due to normal aging. It was also designed to consider task elements which may impact performance and to include tasks thought to index different aspects of executive function. No one task can isolate only one aspect of executive function, but there are tasks which are thought to more consistently index certain aspects of them. For example, the Simon and Stroop tasks are thought to index inhibitory control (Bialystok et al., 2004; 2008). These two tasks were chosen to allow for possible comparisons with other research, and also because one task indexes inhibitory control without the involvement of a linguistic component (Simon Task) while the other includes an overt linguistic component (Stroop Task). The Verbal Fluency Test was chosen to measure verbal functioning, specifically because it encompasses both lexical knowledge and lexical retrieval and executive control ability (Lezak et al., 2012; Fisk & Sharp, 2004). The Corsi and Aospan tasks were chosen to index working memory, which is a key component of executive function. Specifically, the Aospan was chosen because it is a reliable measure of working memory capacity (Unsworth et al., 2005), and impressionistically it seemed to be more challenging and complex than the other measures, so it was chosen as a more challenging measure and positioned last in the protocol.

Whereas previously the discussion of the bilingual cognitive advantage was more focused on bilingual differences or advantages in inhibitory control, the evolution of the research has demonstrated that the BCA may be broader in scope. Therefore, efforts were made to include both language-based and non language-based tasks in order to better compare monolingual and bilingual performance. The language-based task was further intended to serve as a means by which the bilingual participants in the present study could be compared to bilinguals in other studies in which bilingual lexical disadvantages had been found (Bialystok et al., 2008). In addition, two

tasks indexing working memory were incorporated into the protocol because recent work has highlighted differences in working memory among bilinguals and monolinguals.

To attempt to address the question of whether a bilingual's working memory is just greater and consistently so over the course of their life, or whether a bilingual's working memory increases over time as a function of experience with their 2 languages, (as a component of improved executive function as a result of bilingualism) a simpler and more complex working memory task were included in the protocol. The Corsi block span is a straightforward nonverbal working memory measure, and as such would not be thought to preference monolinguals or bilinguals. The Aospan is a more complex working memory measure requiring sustained and alternating attention, problem-solving and vigilance to accomplish the goal. It includes letters and numbers, but given that there are no script differences in French and English, and that the task was administered with instructions in the dominant language for all participants French or English, it would represent a significantly more challenging working memory measure.

The Corsi block span was incorporated as a simpler measure to document the working memory performance of all participants. We might expect to see comparable performance for bilinguals and monolinguals and comparable declines for all participants associated with normal aging. As such this measure would confirm that this group of participants is a representative sample of the general population, and would also serve to rule out cognitive deficits. If bilinguals performed better on this measure as compared to the monolinguals, it would provide support for the bilingual cognitive advantage as spreading beyond just an advantage in inhibitory control, and an advantage which is broader in scope (Hilchey & Klein, 2011; Bialystok et al., 2014). However, given that the bilingual cognitive advantage has been observed with more cognitively complex

tasks, comparable performance among bilinguals and monolinguals on a simple working memory measure would not necessarily discount the possibility of a bilingual cognitive advantage.

Recently, working memory has been explored, and a bilingual advantage has been observed for spatial working memory (Bialystok et al., 2014) To explore working memory performance further a more complex working memory measure, with limited verbal components, Aospan, was included in the protocol. The rationale was that if there was a difference in performance between monolinguals and bilinguals, such that bilinguals performed better on this task, this would provide strong evidence for a bilingual cognitive advantage.

It has been suggested in previous research that task considerations and task challenge both impact the emergence of the bilingual cognitive advantage (Bialystok et al., 2004; 2008; 2014; Valian, 2015). In order to explore this assumption, the Aospan, which was likely the most cognitively challenging task in the protocol, was presented last. In addition, in order to keep performance variables constant and in the absence of reports of ordering effects associated with the tasks used, it was decided to keep the order of presentation of all tasks the same for all participants. The tasks were presented in the following order for all participants: Simon Task, Stroop Task, Verbal Fluency Test, Corsi Block Span, Aospan, LSBQ; however, the order of items within a given task was randomized. This design feature was adopted to ensure that all participants would be comparably fatigued when presented with the Aospan, which was thought to be the most challenging task and moreover the task that would be more likely to reveal working memory differences among participants.

Hypotheses:

The following hypotheses were addressed with this research project:

1. Younger participants will perform better than older participants. They will respond faster and show evidence of less interference when performing executive function tasks.
2. Older bilinguals will perform better on executive function tasks than older monolinguals.
3. Older and younger bilinguals with high levels of proficiency and consistent use of their two languages will perform better than their monolingual counterparts.
4. Bilingual language experience and language use profile will impact performance on executive function tasks.

I will next (1) describe the research methodology of this study, (2) explain the sample selection, (3) describe the procedure used in designing the materials and collecting the data, and (4) provide an explanation of the statistical procedures used to analyze the data, and (5) to discuss the ethical considerations of this study.

Recruitment:

A recruitment message with a general description of the project and a request for participants was distributed and posted via the researcher's personal and professional networks in the US and France. Instructions indicated that potential participants who were French or English monolinguals, and/or French-English or English-French bilinguals were to contact the researcher via email for more information and to indicate interest to participate. Recruitment message was presented in English and French, and clearly stated that participation was completely voluntary.

Participants:

The Language and Social Background Questionnaire (adapted from Luk & Bialystok,

2013) was used to obtain the demographic and language background information of the participants. The participants for this study consisted of French and English monolinguals and bilinguals who were between 18 and 80 years old. There were also bilinguals in the study who spoke other languages, in addition to French and English. The additional languages included: Arabic, Bulgarian, Fula, German, Italian, Malinke, Portuguese, Puel, Russian, Spanish, Tamazghit, Tamil, Urdu, and Wolof. The multi-linguals were considered in the same group as the bilinguals. The recruitment goal for the experimental group was to have 20 French-English (or English-French) bilinguals in each age group, organized in 3 groups according to the following age ranges: 18-29yrs, 30-59yrs, and 60-80yrs. The control group was designed to consist of 10 monolingual French and 10 monolingual English speakers in each age group. Please see Table 1 for details of actual participants obtained for study.

Participants who completed the research protocol independently and remotely did so via Inquisit software on their own individual computers. The participants who met with the researcher completed the research protocol via Inquisit software on a research-dedicated computer, which was a MacBook Pro. Participants who completed the protocol remotely resided primarily in France and the US, however there were participants living in other countries at the time of protocol completion. The following table represents the breakdown of participants who completed the protocols in French or English. The English dominant bilingual participants and English speaking monolinguals completed the protocols in English, while the French dominant bilingual participants and French speaking monolinguals completed the protocols in French. The instructions and tasks were identical in the French and English protocols.

Table 1

French Protocol:	**English Protocol**:	**Total**:
Bilingual Young:	Bilingual Young	
6 Female 5 Male	3 Female 0 Male	14 Young Bilinguals
Monolingual Young	Monolingual Young	
1 Female	20 Female	21 Young Monolinguals
Bilingual Mid	Bilingual Mid	
21 Female 17 Male	7 Female 3 Male	48 Mid Bilinguals
Monolingual Mid	Monolingual Mid	
3 Female	10 Female 5 Male	18 Mid Monolinguals
Bilingual Older	Bilingual Older	
7 Female 3 Male	4 Female 3 Male	16 Older Bilinguals
Monolingual Old	Monolingual Old	
3 Female	9 Female 1 Male	13 Older Monolinguals
66 participants	45 participants	131 Total Participants

The majority of participants were college educated, however the participant sample was representative of society at large in that it also included several participants with only a high school diploma or the equivalent, and many participants with graduate degrees. The majority of participants resided in Paris or Chicago at time of testing, but there were also participants in other cities, states and countries.

At its inception, a goal of the project was to include bilinguals as described in the research, that is, bilinguals with early onset bilingualism at around 6 yrs of age with high levels of proficiency in both languages and who had been actively using their languages on a daily basis within the five years prior to testing (Luk & Bialystok, 2013; Luk, de Sa, & Bialystok, 2013). Although many such 'ideal bilinguals' did participate in this study, the reality of bilinguals is that the majority do not fit neatly into this category. Thus, the participants of this study are likely a more representative sample of bilinguals in general.

The present pool of bilingual participants included many intermediate level proficiency bilinguals, that is, bilinguals with a functional conversational proficiency in their second language, who in the five years prior to testing had used their L2 regularly for a period of at least 6 months in their country of origin or in a country where the L2 was the dominant language. All the bilinguals self-rated their proficiency at least around 60% in speaking and listening, and often much higher in reading and writing.

Recruitment/Participation Challenges:

Due to the challenges of participant recruitment, technical difficulties with remote testing and time limitations for project completion, the participant pool for project completion was somewhat different than what had initially been planned. Recruitment flyers were distributed and posted both electronically and through hard copies of flyers in key locations via the researcher's professional and personal networks. The researcher communicated with almost 250 potential participants and received agreement for participation from over 200 participants. In the end, 131 participants completed the experimental tasks, although some did not complete the entire research protocol for various reasons. Technical difficulties with individuals' computers and/or with software which resulted in a protocol's not launching, or error messages, or screen freezing etc. all contributed to participant attrition.

In addition, it turned out that participation via remote completion of protocols was not a viable option for adults in the 60-80 yr. old group. Approximately 80% of the participants in this group required the researcher to be present to assist with computer set up and to provide encouragement for task completion. All participation which did not occur remotely on

individual's personal computers was completed on the researcher's research-dedicated computer. There were also participants in the mid and young age ranges who required the researcher to be present to provide assistance with set up and encouragement and who would have not otherwise participated. Due to logistical limitations and time/schedule restraints, the researcher was not able to meet with all the individuals who might have otherwise completed the protocol in her presence. When the researcher met the participants for testing, a time and a place were agreed upon ahead of time, and the researcher did everything possible to accommodate participants by going to their homes or meeting them at a quiet location that was convenient for them.

Materials:

The following tasks were used in this research project. Below, a brief description of each task is provided, together with a link to access a sample demonstration of the task from the website for the experiment generator which was used to administer them (Inquisit). The language history questionnaire (LSBQ) will also be described.

1. **Stroop Task**: As described earlier, this task addresses executive functioning, specifically response inhibition with a verbal component, and is thus a verbal cognitive control task. Participants see color words on a computer screen that are written in a font color that either matches or does not match the color word. In this task, participants are asked to indicate via the keyboard the font color rather than the written color word. For example, if a participant sees the word *red* written in a blue font, her task is to indicate via a keyboard response the color "blue". In this project, the Color Word Stroop with Keyboard responding was used in English and French, with the French version being an exact

translation of the English version (Stroop, J.R. (1935); MacLeod, (1991). A sample of the English task can be found at this URL: http://www.millisecond.com/download/library/v5/Stroop/StroopWithControlKeyboard.web

2. **Simon Task***:* As per prior description, this task addresses executive functioning, specifically response inhibition in a nonverbal domain, and is thus considered a nonverbal measure of cognitive control. In this task, participants see a series of colored squares displayed one at a time on a computer screen. Participants are asked to press a key on the left side of the keyboard if the colored square is one color, and on the right side of the keyboard if the colored square is a different color. Sometimes the location of the colored square changes such that it will appear on the opposite side of where the matching color key is located, thus creating an incongruent condition. The participant has to inhibit the response of pressing a key that is spatially congruent with the stimulus. This task also involves cognitive switching: depending on the color of the rectangle, the participant may have to switch the finger that is being used to respond. Perceptual switching is involved, because the stimulus can appear in two different locations. Trials can switch from being congruent to incongruent. An adapted version of the Simon task, based on the original task by Simon and Wolf, 1963, and on Bialystok, Craik, Klein, & Viswanathan, 2004 was used in this project. A demonstration of the Simon task can be found at this URL: http://www.millisecond.com/download/library/SimonTask/ Language

3. **Verbal Fluency Test**: This test of verbal functioning consists of two tasks. The letter or phonemic fluency task, and the category or semantic fluency task. In the standard

versions of the VFT, participants are given 1 minute to produce as many words as possible in the category or semantic fluency task (i.e. animals), and 1 min (per each letter; FAS) to produce as many words as possible in the letter or phonemic fluency task. The score is the number of appropriate words in each category. In the version of the VFT used in the present study, participants are given 2 minutes to type as many words as possible that start with the letters F, A, and S, excluding proper nouns, numbers, plural forms and variations on the same words. Letter fluency tasks are used to assess the efficiency of word retrieval based on cues consisting of either an initial letter (phonemic) or a semantic category (Spreen & Strauss, 1998). Accordingly, the category fluency component of the VFT assesses access to conceptual categories. In this component, participants are instructed to type as many items as possible in a semantic category, for example, animals, within a two-minute time frame. Monolingual participants complete the task in English or in French. Participants who are bilingual complete these tasks in both French and English, as well as in a condition in which they respond in either language, in randomized order of conditions. The same letters (F, A, S) and categories (animals) were used in both languages.

The Verbal Fluency Test has had wide-spread clinical and research use in large part because it is thought to reference both verbal ability and executive control. It definitely involves verbal functioning because participants have to access their mental lexicon to retrieve words; however, they also have to pay attention to the task, keep rules in mind to produce only words for given letter or category, and also avoid repetition, thus also calling upon executive function (Fisk & Sharp, 2004). A demonstration of this task can be found at this URL:

http://www.millisecond.com/download/library/v5/LetterFluency/LetterFluency.web

4. **Corsi Block Task**: This is a working memory task which also indexes spatial and visual processing. In this task, participants see a series of squares (the computerized version of the task is two dimensional, with squares appearing on the screen vs. blocks in the manual version of the task) which light up in different orders on the computer screen. The participant is asked to reproduce the order in which the squares lit up by clicking on the squares in the order in which they lit up. A sample demonstration of this task can be found at this URL: http://www.millisecond.com/download/library/v5/CorsiBlockTappingTask/CorsiBlockTappingTask.web

5. **Operation Span Measure (OSPAN)**: This is a classic working memory measure where participants are asked to solve math problems while remembering letters that appear on the computer screen in between each math problem. A sample demonstration of this task can be found at this URL: http://www.millisecond.com/download/library/v5/OSPAN/AutomatedOSPAN.web

6. **Language and Social Background Questionnaire** (LSBQ- adapted from Luk & Bialystok, 2013)This is a questionnaire which incorporates various demographic questions including age, location, computer and video game use, and language acquisition and use information, in addition to obtaining measures of self-rated use and proficiency. It has been shown that self-rated language proficiency and usage were good

predictors of degree of bilingualism (Fishman & Cooper, 1969) and self-rated proficiency measures of various kinds have been widely used in bilingualism research.

The LSBQ was chosen because it was developed to build on the reliability and validity of self-rated proficiency measures in language research. It also incorporates findings that age of active bilingualism (AoAB) is a more sensitive measure as a predictor of performance in linguistic and non-linguistic tasks than is onset age of L2 acquisition (Luk, de Sa & Bialystok, 2011), which has often been used in research with bilinguals. It further allows for documenting 'duration of active L2 Use' which is the difference in age at time of testing and age of active bilingualism, and which has also been shown to be significant in analyzing the cognitive performance of bilinguals (Luk, de Sa & Bialystok, 2011). In addition, the questionnaire was designed with the aim of better understanding a bilingual's experience "as a multi-dimensional construct rather than a categorical variable" (Luk & Bialystok, 2013, p.2) and of allowing for a way to quantify a bilingual's experience. Bilingualism is clearly a very complex phenomenon and describing it qualitatively and quantitatively remains a challenge; however, this questionnaire offers a research-informed set of questions together with efficient administration as part of a research protocol.

Description of Experiment Generator:

Data collection took place via Inquisit software. Inquisit is a software which allows for collection of various cognitive and neuropsychological behavioral measures over the web. The experiments were scripted and set up in Inquisit. The participants then completed all experiments on their computers in their location, or on the research dedicated computer with the researcher. Inquisit software offers millisecond accuracy when measuring response latencies during data collection, and according to developers is easy for participants to download and complete

experiments with it on their own computers. Inquisit offers a web server for administration of experiments and storing of data files which can be accessed for analysis at a later time. Inquisit takes into account that the personal computers of participants may have different processing speeds, and is described as a "lightweight, efficient engine that performs well on even the slowest computers still in use today" (Inquisit Info Webpage, http://www.millisecond.com/products/inquisit4/weboverview.aspx)

In addition to controls for processing speed, Inquisit also has built-in controls for additional differences among personal computers, such as graphic display size and resolution and vertical refresh rates. Inquisit has parameters in place to protect the security and privacy of all the participants and data collected. Specific information on how participants and data are protected is provided on the Millisecond Security Statement webpage: http://www.millisecond.com/products/securitystatement.aspx

Design:

The design for the Stroop and Simon experiments included two independent variables: age, and language. Age had three levels: Young, Mid, Old. Language had two levels: Monolingual, Bilingual.

The dependent variable for both the Stroop and Simon experiments was reaction time (RT) in terms of the main effects associated with both independent variables, as well as in any interaction effects between them. More specifically, the goal was to see whether and to what extent age and language impacted RT. Thus for these two experiments, the age X language interaction effects on RT were of primary interest. Other variables of interest are noted below. In particular, however, the experiments were designed such that their data would reveal any effects

of age and language, and whether bilinguals would perform better than monolinguals, that is, with faster RTs and a smaller Simon and Stroop effect, and a smaller interference effect.

Additional measures indexing executive function included a language-based measure and two working memory measures:

1. Verbal Fluency Test: 1. A letter fluency task, with the total number of words produced for three letters (F, A, S) as the dependent variable. 2. A category fluency task, with the total number of words produced for the given category of 'animals' as the dependent variable.

2. Corsi-Block Task: A working memory measure indexing visual and spatial attention, and recall. The block span value serves as the dependent value for analysis.

3. Ospan: A complex working memory measure indexing divided and alternating attention, and recall.

4. Language and Social Background Questionnaire for demographic information and self-rated proficiency measures.

Procedure:

Recruitment efforts began following approval to conduct this research project from the Institutional Review Board of the University of Illinois at Urbana-Champaign. Once participants agreed to participate, a secure link to the experimental protocol was sent to them via email after which they completed all tasks via the online experiment generator Inquisit.

Specific and detailed instructions were provided to all participants for completion of all the tasks in the protocol. The researcher was available via email and phone to answer any questions prior to initiation of data collection for each participant, during participation, and afterward to respond to questions. To facilitate data collection with participants who were unable to complete the experiments on their own, the researcher met with any such participants in order

to provide a computer and support for completion of the experimental protocol. The participants received instructions from the publisher of Inquisit indicating how to download and install the Inquisit player which was needed to run the research protocols. Based the potential participant's indicated preference, each participant received the protocol in either English or French. For monolingual speakers of French or English, protocols were completed in the participant's sole language. By design, the bilinguals completed all experiments in their preferred language, which was typically, but not always, their L1. This was done in order to ensure that all participants could be tested in their language of choice. Existing research on the BCA typically compares the performance of native speakers of English with that of L2 speakers of English who have a wide variety of L1 backgrounds. All participants in such studies (Bialystok et al., 2004, 2005, 2014; Paap & Greenberg, 2013) are tested in English irrespective of their first language, but see Kousaie et. al (2014) who tested bilinguals in one of their two languages in a randomized manner. In order to reduce any possible issues with understanding task instructions, etc. that might arise through being tested in one's non-native language (this seemed especially important, since participants varied in their L2 proficiency and were also to be testing themselves) and to better control for participants' L1 and L2, the decision was made to create two complete sets of identical protocols, one in English and one in French, and to test both English and French monolingual and French-English and English-French bilingual participants. Self-rated language proficiency information for each language and bilingual language experience information was obtained in the Language and Social Background Questionnaire (LSBQ) which was completed as part of the research protocol. Participants were presented with consent forms for their review and signature. It was made clear in the consent forms that participation in the study was voluntary, that results would be kept confidential, and that participants could withdraw at any

time. After participants reviewed and signed the consent forms they were presented with instructions to complete each task (Please see Appendix F for recruitment messages and consent forms). In order to ensure that participants were real people entering data and that data were being entered only once, a screen requesting a name and time/date entry had to be completed and submitted by a participant in order for them to be able to begin with the research protocol. Participants received a comparable message at the end after completing the LSBQ language history questionnaire, in order to mark the completion of online testing and data collection. After signing the consent form, agreeing to participate, and entering a name/date/time stamp, participants saw the following message:

Hello—

Thank you for your participation! A series of experiments will follow. Please make yourself comfortable in a calm place where there will be no interruptions. This is very important because this requires you to **concentrate** and we need your full attention in order to complete these experiments as **quickly** and **accurately** as possible. The most important thing is for you to **do your best**, without wondering if you're doing it right. When you start an experiment, you have to concentrate and continue working until you have finished. If you like, you will have the opportunity to take breaks (up to 3min each) in between each experiment. There are 5 experiments that will take approximately one hour to complete, and a questionnaire to fill out at the end. Thank you very much! Let's get started!

After this introductory screen, the participants saw the following instructions screen. These instructions were designed to make clear the parameters required for successful completion of the protocol, and to ensure the validity of the data obtained was the best effort of the participants.

In order to honor and ensure the integrity of this study we ask that you respect the following parameters:

1. Please complete the tasks when you are optimally alert and focused. All tasks depend upon speed and accuracy, so your undivided attention will be greatly appreciated.
2. Once a task is started, it must be completed without any breaks or interruptions.
3. You may take breaks in between tasks if desired.
4. Please do not consult any external tools (i.e. dictionaries, online resources etc.) before or during participation. Please do not consult with anyone else about the answers to the tasks. Please do not discuss task details with other potential participants.
5. If you have any questions before, during, or after completion of this project, please do not hesitate to contact Henrietta Boudros via phone or email: US: 312-217-5602/France: 06.31.88.63.16 */boudros2@illinois.edu* or henrietta.boudros@gmail.com

A detailed description of all the experiments will follow in their order of presentation. In the protocol, there were instructions after the completion of every experimental task to let

participants know that it was appropriate to take a short (less than 3 minute) break at beginning and the end of the task. The indications for a break were clearly marked on separate screens. However, given the widespread use of some of the tasks, the names of the experimental tasks were omitted from the research protocol presented to the participants. The names of the experimental protocols will be included in the procedural description below. Participants saw an introduction screen for a new task, followed by specific task instructions and written messages for demarcations between tasks, in addition to written encouragement to continue doing their best, and clear indications of when breaks were possible. Participants then completed the research protocol online and informed the researcher via email once they had completed all the tasks.

Detailed Description of Experiments/Task Procedures:

Experiment 1: Simon Task:

There were four conditions in one of four preset orders consisting of 24 trials per condition. The entire set of four conditions was then repeated in the reverse order, producing 48 trials for each of the four conditions for a total of 196 trials. The first two conditions consisted of two colored squares each (blue and brown) presented in the center for the first condition which served as the control condition. In the second condition, the blue and brown squares were alternately and randomly presented on either side of the screen in order to represent the congruent and incongruent conditions of the task. The congruent condition was when the colored square was presented on the same side as the key which the participants were instructed to press. A summary of the four Simon task conditions follows:

- Condition A: Center–2 (control). A series of squares that were either brown or blue appeared in the middle of the screen. Participants were instructed to press the left

shift key when they saw a blue square and the right shift when they saw a brown square.

- Condition B: Side–2. The parameters were the same as those in the control condition, but the blue and brown squares appeared on either the left or the right side of the screen.
- Condition C: Center–4. This condition was similar to the control condition except that the stimulus was one of four colors: pink, yellow, red, or green. Participants were instructed to press the left shift key when they saw a green square, the right shift key when they saw a red square, the left shift key when they saw a pink square, and the right shift key when they saw a yellow square. The instructions were presented as four individual rules (i.e., "press the left shift key for green"; "press the left shift key for pink") and not as two paired rules (i.e., "press the left shift key for green or pink"). All stimuli appeared in the center of the screen. This condition placed greater demands on working memory for the assignment of colors to responses than did the Center–2 condition.
- Condition D: Side–4. In this condition, the stimuli were the same four colors, but they appeared in one of two side positions. The order of trials was randomized and again divided equally between congruent and incongruent items.

The participants were instructed to press the left shift key when the blue square appeared on the left side of the screen; this was the congruent condition. When the blue square appeared on the right side of the screen, the participants were also instructed to press the same left shift key; this was the incongruent condition. When the brown square appeared on the screen, the participants were instructed to press the right shift key whether the brown square appeared on the

right side of the screen (the congruent condition for this color) or the left side of the screen (the incongruent condition for this color).

In adding two additional conditions, the goal was to increase the working memory demands of the tasks by presenting participants with four colored squares (pink, green, yellow, red). Participants were instructed to press the left shift key when they saw the pink or green squares on the screen, and the right shift key when they saw the red or yellow squares on the screen. These parameters were presented to participants as four separate rules as per the procedure described in Bialystok et al. (2004): “Press the left shift key when you see a green square.” “Press the left shift key when you see a pink square” “Press the right shift key when you see a red square” “Press the left shift key when you see a yellow square”.

In the first condition for this 4 colored square task, all the colored squares (pink, green, red, yellow) were presented in the center of the screen. This served as the control condition. In the second condition, each of the colored squares was presented on either the left or the right side of the screen to represent the congruent and incongruent conditions of the task. The participants had to keep in mind which shift key corresponded to which colors. Per the instructions, they were to press the left shift key when either the pink or the green squares appeared on the screen. If the pink or the green square appeared on the left side of the screen, this was considered the congruent condition. If the pink or the green squares appeared on the right side of the screen, the participant still had to press the left shift key though in this situation, this was considered to be the incongruent condition.

In this task, there was an added working memory load in that there were two additional colored squares, red and yellow, which also appeared on the screen. Participants were instructed to press the right shift key when either the yellow or the red squares appeared on the screen.

Comparably there was a congruent condition where the red or yellow squares appeared on the right side of the screen, and an incongruent condition where the red or yellow squares appeared on the left side of the screen. Thus for this task the participants had to keep in mind which of the four colors corresponded to which shift key, while also needing to inhibit an automatic response to press the shift key when a colored square appeared on the side which did not correspond to the shift key. Participants had to juggle four colors within two different parameters, congruent and incongruent and then produce an appropriate output by pressing a key on the computer keyboard.

For this task, each trial began with a sound (an embedded sound file with a beep) and a fixation cross in the center of the screen that remained visible for 300ms. Immediately after the presentation of the beep and the fixation cross, the stimulus appeared and remained on the screen until a response was made. Depending on the condition, the stimulus appeared in the center of the screen, on the right side of the screen or on the left side of the screen. The response clock started when the stimulus (the colored square) was presented. Once a response was made by the press of the shift key, a reaction time for that trial was recorded. Then 500ms after the response, a fixation cross (plus the sound) reappeared on the screen to signal the next trial with the appearance of another colored square.

Each of the 4 conditions was preceded by a set of practice trials. The two-color conditions had four practice trials while the four-color conditions had eight practice trials, demonstrating each unique stimulus configuration for the condition. The parameters of these trials were identical to those of the test trials. Participants had to complete all practice trials correctly to proceed with testing. If a mistake was made during a practice trial, the program recycled until all trials were completed without error. For the incongruent and congruent trials there was an equal number of 24 trials each which was presented randomly.

The order of the Simon Task conditions was randomly assigned by subject numbers:

- Subject numbers 1, 5, 9, etc. => order A
- Subject numbers 2, 6, 10, etc. => order B
- Subject numbers 3, 7, 11, etc. => order C
- Subject numbers 4, 8, 12, etc. => order D

The following measures were obtained for this experiment:

- Proportion correct: proportion correct across all test trials
- Mean RT: mean latency of correct test trials (in ms)
- Proportion correct congruent: proportion correct of congruent test trials
- Mean RT congruent: mean latency of correct congruent test trials (in ms)
- Proportion correct incongruent: proportion correct of incongruent test trials
- Mean RT incongruent: mean latency of correct incongruent test trials (in ms)

Experiment 2: Stroop Task**:**

Participants were presented with color words written in color and were asked to indicate the color of the word (not its meaning) by pressing a key corresponding to the appropriate color as fast as possible without making errors. The colors used were red, green, blue, and black. The keys on the keyboard corresponding to the colors were: D-Red; F-Green; J-Blue; and K-Black After instructions were presented, participants had the opportunity to complete a practice set which was then followed by the experimental trials. The participants completed a total of 300 experimental trials which included 100 trials in each of three conditions (congruent, incongruent and control) presented randomly on the screen. For congruent trials, the color word and the color it was presented in were the same (e.g., the word GREEN was written in green-colored letters). For incongruent trials, the color word and the color it was presented in were not the same (e.g.,

the word GREEN was written in blue-colored letters). For control trials, colored rectangles were presented and participants had to indicate the color of the rectangles displayed on the screen.

Each trial, a word or a rectangle, was presented at 200ms intervals in the center of the screen. For the practice trials, error feedback was presented at 400ms intervals. RTs to key presses were measured from onset of stimuli until a response via a key press occurred. Stimuli were presented in colored ink (red, green, blue, black) in Arial font on a white background.

The following measures were obtained for analysis from this experiment:

- Proportion correct: overall proportion correct of all trials
- Mean RT: overall mean latency (in ms) of all correct trials
- Mean RT correct congruent: mean latency of all correct congruent trials (in ms)
- Mean RT correct incongruent: mean latency of all correct incongruent trials (in ms)
- Mean RT correct control: mean latency of all correct control trials (in ms)
- Proportion correct congruent: proportion correct of congruent trials
- Proportion correct incongruent: proportion correct of all incongruent trials
- Proportion correct control: proportion correct of all control trials

Experiment 3 Verbal Fluency Test**:**

The Verbal Fluency Test consisted of two parts. The first was a letter fluency task with the letters A, F, and S. These letters were chosen because they have consistently been used for the letter fluency task in French and English. The second part, a category fluency task, required participants to produce items in the given semantic category (animals). For the version of the VFT used for this project, participants were given two minutes to type responses.

Instructions to participants were as follows: “Name all the words that you can think of that begin with the letter X” where X represented the letters A, F, and S. Each letter was tested in

a blocked design, with one block per letter. Participants had two minutes to type as many words as they could think of.

After the three screens with the three letters were presented, participants were then presented with a category fluency task, with the instructions, "Name all the ANIMALS that you can think of". Participants had two minutes to type as many animals as they could think of starting with each of the letters provided: F, A, S.

The measures obtained for this task include:

- Total number of words produced for all three letters (F, A, S) and for each letter individually
- Total number of words produced for the category of ANIMALS.

Experiment 4: Corsi Block Task:

This is a working memory task in which participants were asked to replicate a sequence of blocks (or squares, as they were two dimensional in this experiment) which have been illuminated on screen in a given order. The task is to repeat the illumination sequence in the correct order (Kessels et.al., 2000; Corsi, P. M., 1972).

Participants saw a screen with 9 squares. The squares lit up in yellow, in a predetermined sequence which was the same for all participants. The participants were then asked to click on the squares in the same order to repeat the sequence. The first sequence had 2 squares which lit up. Once a participant entered the sequence correctly, she/he was able to proceed to the next level which had three squares. Participants got two chances at each sequence length. When the sequence was entered correctly, the next sequence started. The maximum sequence length that a participant could achieve was the reproduction of a nine-square sequence in the correct order.

The task stopped when the participant failed to recall two sequences of equal length. The block span, which equaled the length of the last correctly recalled sequence, was used for analysis.

Experiment 5: Automated Operation Span Task:

This working memory task was per Conway et al. (2005). In it, participants saw a series of letters which were presented on a blank screen and which they needed to recall at the end of the presentation. Each letter in the sequence was preceded by a math problem (e.g., (8*2) - 8 = ?) followed by a proposed solution (e.g., 9). Participants had to decide whether the proposed solution was correct while simultaneously recalling series of letters. Recall of letter sequences was tested by asking participants to select letters from a provided letter matrix. Participants saw instructions for each part of the task including the letter presentation, the math problem presentation, and then both letter and math problem presented together. They had the opportunity to practice each task separately prior to seeing the tasks presented together.

The practice session proceeded as follows:

a) Practice of recalling sequences of letters of set sizes 2-3 in ascending order (4 trials)

b) Practice of math task (15 trials)

c) Combined practice of recalling sequence of letters (set size 2 only) and math problem: each letter is preceded by a math problem (3 trials)

The experimental task consisted of:

15 Trials (15 = 3 repetitions of 5 set sizes; order of set sizes is randomly determined)

Recalling sequences of letters (set size 3-7): each letter is preceded by a math problem

Scoring:

Several values were collected at the conclusion of the experiment, however the most pertinent was the OSPAN score which used the traditional "absolute ospan" scoring method,

which is the sum of all perfectly recalled sets. So, for example, if an individual correctly recalled 2 letters in a set size of 2, 3 letters in a set size of 3, and 3 letters in a set size of 4, their OSPAN score would be 5 (2 + 3 + 0). Additional values obtained included, total number correct, which was the total number of letters recalled in the correct position (2 + 3 + 4 = 9 in the above example); math errors which were reported as total number of times that a participant solved the operation incorrectly; and speed errors which were reported as the number of times that a participant ran out of time in attempting to solve a given operation. Only the OSPAN score was used for analysis in this project.

Language and Social Background Questionnaire:

Participants completed the Language and Social Background Questionnaire (LSBQ) (adapted from Luk & Bialystok, 2013) which includes a series of demographic questions and a series of scales to rate use/proficiency in their languages. This provided a profile of participants' bilingual language experience, portions of which were quantified for use in the analysis of performance on cognitive measures.

Debriefing/Compensation**:**

Participants were provided with written or verbal debriefing and acknowledgment of participation. They were informed that they would be entered into a drawing for the possibility to win a $50.00 gift card for having participated, which would be awarded after project completion.

Chapter 4 Analyses and Results

Simon Task Analyses and Results:

The aim of this study was to explore performance differences between bilinguals and monolinguals on all the tasks included in the protocol. An additional goal was to take a more in-depth look at the individual bilingualism of the participants in order to identify performance differences based on pertinent factors associated with bilingualism, which included self-rated L2 proficiency, age of active L2 use, and daily use patterns. As described earlier, the design for this study included one dependent variable (RT) and two independent variables: age and language. Age had three levels: Young, Mid, Old, while language had two levels: Monolingual, Bilingual. Raw reaction times in this study were comparable to other studies and so following the procedure of recent studies examining the BCA hypothesis (Bialystok et al., 2004, 2005, 2008a,b, 2014; Kousaie & Philips, 2012; Kousaie et al., 2014; Marian et al., 2012), the present study used analyses of variance (ANOVAs)[1]. The first phase of the analysis consisted of performing 2 X 3 Factorial ANOVAs with all participants and with all variables of interest. Descriptions and results for all ANOVAs performed on data for all tasks will follow. In addition, in order to treat bilingualism as a non-categorical variable and further explore the impact of bilingualism on performance, multiple ANCOVAs were performed on the Stroop and Simon Tasks for the bilingual participants only, with select measures of bilingualism used as covariates.

[1] While acknowledging that linear mixed-effects models can offer advantages over ANOVA and related models when used with designs and variables similar to those used in the present experiments (see e.g., Barr et al., 2013), the decision was instead made to adopt the statistical procedure used in virtually all research investigating the BCA as of the time of this writing, which is the by-participant ANOVA.

The mean RT tables for all conditions follow below**:**

Table 2: Simon Mean RT (in ms.) by Age/Language/Condition:

Age	Language	Center2sq	Congr2sq	Incong2sq	Centre4sq	Congr4sq	Incong4sq
YO	MONO	417	453	470	554	555	601
YO	BI	433	468	487	575	585	637
MID	MONO	538	567	596	689	761	768
MID	BI	486	513	607	629	630	669
OLD	MONO	561	632	735	789	810	830
OLD	BI	557	605	656	809	847	907

Table 3: Simon Mean RT (in ms.) aggregated by Age

Age	Center2sq	Congr2sq	Incong2sq	Centre4sq	Congr4sq	Incong4sq
YO	425	461	479	565	570	620
MID	500	527	604	644	663	695
OLD	559	617	690	800	831	874

Table 4: Simon Mean RT (in ms.) aggregated by Language

Language	Center2sq	Congr2sq	Incong2sq	Centre4sq	Congr4sq	Incong4sq
MONO	508	552	600	678	713	736
BI	492	525	597	658	668	714

Table 5: Mean RT Simon Effect (in ms.) 2sq/4sq by Age/Language/Condition

Age	Language	Simon Effect 2	Simon Effect 4
YO	MONO	17	46
YO	BI	19	52
MID	MONO	28	7
MID	BI	94	39
OLD	MONO	102	20
OLD	BI	51	59

Table 6: Mean RT Simon Effect (in ms.) 2sq/4sq Aggregated by Age

Age	Simon Effect 2	Simon Effect 4
YO	18	49
MID	77	31
OLD	73	42

Table 7: Mean RT Simon Effect (in ms.) 2sq/4sq Aggregated by Language

Language	Simon Effect 2	Simon Effect 4
MONO	47	23
BI	72	46

Data Treatment:

In order to address the issue of possible outliers within RT distributions from both younger and older participants, while retaining as many responses as possible from all populations including the older ones since examining this population's performance was of particular interest, it was decided to adopt an RT data treatment method that would not identify and remove outlier RTs on the basis of standard deviations, interquartile ranges, etc., but that would instead allow for keeping all RTs. Following discussion in Van Zandt and Townsend (2014), therefore, all RTs were inversely transformed (i.e., 1/RT) prior to running the statistical analyses (see also, Ashby & Townsend, 1980; Dzhafarov & Schweickert, 1995; Holden, 2005; Holden, Van Orden & Turvey, 2009; Ratcliff, 1993, Stevens, Brennan, Petocz & Howell, 2009; Townsend & Eidels, 2011; Van Zandt, T., 2000; Wei, 2012). All the analyses that follow represent the examination of the data with inversely transformed reaction times, unless otherwise indicated.

Simon ANOVAs:

For the following analyses the pertinent dependent variables of interest for the 2square and 4square Simon experiments, were the inversely transformed mean RTs for all conditions

(control/center 2sq, congruent 2sq, incongruent 2sq, control/center 4sq, congruent 4sq, incongruent 4sq).

The first analysis performed was a 4-way ANOVA including all two way interactions (age, language, color, position). See the Tables in Appendix A for results. The 4-way ANOVA, including all two-way interactions revealed that the main effect of language just missed significance $F(1,130) = 3.67$, $p = 0.055$. There were main effects of age $F(2,129) = 84.13$, $p < 0.0001$, with middle aged ($t = -6.93$, $p < 0.0001$) and older ($t = -9.60$, $p < 0.0001$) participants performing more slowly than younger participants. There was a main effect of color $F(1,130) = 147.94$, $p < 0.0001$, with slower RTs for 4 color squares ($t = -12.16$, $p < 0.0001$) versus 2 color squares. There was a significant main effect of position $F(1,130) = 14.40$, $p = 0.0002$, with the incongruent position slower than congruent condition ($t = -3.79$, $p = 0.0002$). And lastly, there was a significant age and language interaction $F(2,129) = 4.27$, $p = 0.01$, with younger adults being faster overall than the older participants ($t = 2.853$, $p = 0.005$). See Simon Table 1 in Appendix A for details.

4 Way ANOVA Results and Discussion:

The 4 way ANOVA results revealed that 1) there was a trend for bilinguals to perform better than monolinguals, which provides some support for a bilingual cognitive advantage, 2) older people had significantly slower reaction times than younger participants, 3) reaction times in the incongruent condition were significantly slower than reaction times in the congruent condition, 4) reaction times were slower when there were 4 color squares versus when there were 2 color squares, and 5) there was a significant interaction between language and age such that the middle aged bilinguals had faster RTs than the middle aged monolinguals. The fact that middle aged bilinguals performed significantly better than middle aged monolinguals can be viewed as support for the bilingual cognitive advantage for this group, as per Bialystok et al. (2005) where

middle age bilinguals performed better than middle aged monolinguals on the standard Simon task, and contrary to Kousaie et al.(2014) who found no language effect for better performance of bilinguals when compared monolinguals on the Simon task (although this latter study did not include a middle aged group). It may be that Simon performance is generally too fast in the younger group and too slow in the older group to allow a bilingual cognitive advantage to be observed. Following the initial 4way analysis which revealed the main and interaction effects described above, a more focused analysis with a series of two way factorial ANOVAs was performed.

Factorial (2way) ANOVAs Results:

For the Simon experiment with 2 squares and the Simon experiment with 4 squares, four factorial (2way) 2X3 ANOVAs were next performed on RTs as a function of age (yo, mid, old) and language group (bi, mono) for main and interaction effects on the following conditions: control/center 2sq, Simon effect 2sq, control/center 4sq, Simon effect 4sq).

The 2X3 ANOVA examining the dependent variable of RTs in the control/center 2sq condition (i.e. the control condition for the 2sq Simon experiment) for age and language group revealed significant main effects of age, $F(1,130) = 16.02$, $p < 0.0001$, with middle-aged ($t = -3.1$, $p = 0.002$) and older ($t = 4.24$, $p < 0.0001$) participants being slower than younger participants. There was no statistically significant difference for language. See Table 2 in Appendix A for details.

The 2X3 ANOVA examining the dependent variable mean RT for the Simon effect 2sq condition for age and language group revealed no significant main or interaction effects. See Table 3 in Appendix A for details.

The 2X3 ANOVA examining the dependent variable mean RT in control/center 4sq condition (i.e., the control condition for the 4sq Simon experiment) for age and language group revealed a significant main effect of age $F(1,130) = 15.68$ $p < 0.0001$. This main effect of age was confirmed for middle aged ($t = 2.45$, $p = 0.02$) and older ($t = 4.06$, $p < 0.0001$) participants compared to younger participants. Again, no statistically significant differences for language emerged. See the Table 4 in Appendix A for details.

The 2X3 ANOVA examining the dependent variable mean RT for the Simon effect 4sq condition for age and language groups revealed a trend towards a significant main effect of language $F(1,130) = 2.7$, $p = 0.10$, with bilinguals having numerically faster RTs overall. There were no other main effects or interactions. Although planned comparisons revealed a significant main effect of both age ($t = 2.13$, p = 0.04) and language effect of (t=2.18, p=0.03) and no interaction between them for the Simon effect 4sq condition, these findings should be viewed with caution in light of the results of the ANOVA. See Table 5 in Appendix A for details.

Results Discussion Factorial 2way ANOVAs:

A summary and discussion of results for the four factorial (2way) ANOVAs for Simon experiments will follow. From the above analyses the following conclusions were obtained:

1. The 2 way factorial ANOVAs revealed no significant interaction effect between age and language. The results can be interpreted to mean that the reaction time differences between bilingual and monolingual language groups were quite consistent across the different age groups. Although numerically, with the untransformed mean reaction times, bilinguals were faster than monolinguals in almost all conditions, the results here were not statistically significant as they were in Bialystok et al. (2004) where bilinguals had statistically significant faster RTs than monolinguals in all conditions (except for the control condition in the 2sq Simon experiment).

2. There was consistently a main effect of age, such that older participants demonstrated significantly slower reaction times compared to younger participants for both the 2sq control condition and for the 4sq control condition. These findings are consistent with other studies that have found normal age related declines in performance as measured by slower reaction times for older versus younger adults (Bialystok et al., 2004, 2005; Kousaie et al. 2014).

3. There was no significant main effect of language either for the 2sq control condition or for the 4sq control condition, that is, there was no statistically significant reaction time difference between monolinguals and bilinguals. These results diverge from Bialystok et al. (2004) who found language group differences, and are more in line with Kousaie et al. (2014) who did not find significant differences between bilinguals and monolinguals.

4. There was no significant main effect of age or language for the Simon effect in the 2sq experiment condition. These results diverge from Bialystok et al. (2004) who found a significant bilingual advantage for the Simon effect in the 2sq experiment.

5. Although it must be interpreted with caution, there appeared to be a trend towards a main effect of language for the Simon effect in the 4sq experiment condition, and a main effect of age**.** In contrast to findings above with the 2sq condition Simon effect, it appears that in the 4sq condition Simon effect which is arguably more complex and involves greater working memory demands than the 2sq Simon experiment, bilinguals as a group demonstrated a smaller Simon effect than monolinguals. However, these results should be viewed with caution. When looking at age effects, older adults as a group had a greater Simon effect. For language effects there was a trend towards a significant main effect and the planned comparison analyses revealed a significant main effect of age. Although these results are not entirely clear, they are reminiscent of results from Bialystok et al. (2004; 2005) and might be interpreted to support conclusions that

bilingualism affords advantages in bilingual inhibitory control which otherwise tends to decline with aging, as was also observed here with slower reaction times for older adults.

Simon ANOVAs for Working Memory Costs**:**

An ANOVA to examine dependent variable working memory costs (defined as the difference between four-color RTs and two-color RTs,) was performed for age and language and for both main and interaction effects. No significant main or interaction effects for age or language were observed for this ANOVA. See Table 6 in Appendix A for details.

A second ANOVA was performed to explore working memory costs associated with the dependent variable of the Simon effect, defined as the RT difference between incongruent and congruent trials, and with the independent variables of Age (with three levels: young, mid, and old), Language (with two levels: monolingual, bilingual), and Number of Stimuli (with two levels: 2-colors, 4 colors). No significant results were revealed for this analysis. See Table 7 in Appendix A for details.

For this sample of participants, in contrast to Bialystok et al. (2004) the ANOVAs to explore working memory costs as defined by performance differences in the 2 square versus the 4square Simon experiments revealed no significant main effects for age or language.

Simon Analysis Results Summary:

No statistically significant Simon effect difference was found for the three age groups and the two language groups for the 2sq experimental condition. For the 4sq experimental condition, a trend towards a significant main effect of language was found for the Simon effect which could be interpreted as evidence that bilinguals had a smaller Simon effect than monolinguals. Although promising for the support it appears to provide for the BCA, this finding must be interpreted cautiously as it appeared only after additional analyses with contrast coefficients.

There was also a main effect of age such that younger participants had a smaller Simon effect as compared to older participants. There was no significant interaction effect between age and language for all four ANOVAs, which can be interpreted to indicate that reaction time differences between bilingual and monolingual language groups were consistent across the different age groups. The main effect of age was statistically significant and observed consistently, in both center 2sq and center 4sq conditions where older participants demonstrated significantly slower RTs in the control conditions compared to younger participants. This finding is in line with normal age-related declines in cognitive processing efficiency, as reported in other studies (Bialystok et al.2004).

Stroop ANOVAs:

The Stroop experiment included two independent variables: age and language. Age had three levels: Young, Mid, Old. Language had two levels: Monolingual, Bilingual.

The dependent variable for the Stroop experiments was RT, while the aim of this analysis was to observe any main effects associated with both independent variables, as well as any interaction effects between them. Of interest in this analysis was to know whether and to what extent age and language affected RT. The primary purpose of this analysis was to reveal an age and language interaction effect on RT.

The dependent variables of interest included:

- Mean RT: overall mean latency of all correct trials (in ms)
- Mean RT Congruent Items: mean latency of all correct congruent trials (in ms)
- Mean RT Incongruent Items: mean latency of all correct incongruent trials (in ms)
- Mean RT Control Items: mean latency for all correct control trials (in ms)

Mean RTs Results and Discussion:

Untransformed mean RTs were calculated for all results in all conditions. Please see the Tables in Appendix A for mean RT by Age/Language/Condition, and then mean RTs aggregated by age, and then the Table for mean RTs aggregated by language. When looking the mean RTs we see that the bilinguals were faster than the monolinguals in all conditions and in all age groups. When results were aggregated by age we observed, as might be expected that the oldest participants had the slowest performance. For mean RTs when results were aggregated by language, bilingual participants performed consistently faster across all conditions. Please see the Tables below for details:

Table 8: Stroop Mean RT (in ms.) by Age/Language/Condition:

Age	Language	Mean RT	Mean RT congruent	Mean RT incongruent	Mean RT control
YO	MONO	911	823	1047	874
YO	BI	817	768	905	780
MID	MONO	1163	1069	1327	1103
MID	BI	1119	1044	1283	1045
OLD	MONO	1422	1293	1784	1306
OLD	BI	1338	1271	1513	1240

Table 9: Stroop Mean RT (in ms.) aggregated by Age

Age	Mean RT	Mean RT congruent	Mean RT incongruent	Mean RT control
YO	873	801	990	836
MID	1131	1051	1295	1061
OLD	1374	1280	1630	1269

Table 10: Stroop Mean RT (in ms.) aggregated by Language

Language	Mean RT	Mean RT congruent	Mean RT incongruent	Mean RT control
MONO	1126	1025	1328	1062
BI	1113	1044	1265	104

Table 11: Mean RT Stroop Effect (in ms.) by Age/Language/Condition

Age	Language	Stroop Effect
YO	MONO	224
YO	BI	137
MID	MONO	258
MID	BI	238
OLD	MONO	491
OLD	BI	241

Table 12: Mean RT Stroop Effect (in ms.) aggregated by Age

Age	Stroop Effect
YO	189
MID	244
OLD	350

Table 13: Mean RT Stroop Effect (in ms.) aggregated by Language

Language	Stroop Effect
MONO	303
BI	221

Stroop Factorial ANOVAs Results and Discussion:

The factorial ANOVAs were performed on inversely transformed mean RTs for all conditions (overall mean RT, congruent condition RTs, incongruent condition RTs and mean RTs for the control condition). These analyses revealed no significant interaction effects of age and language. This indicated that for the Stroop task with this population, the RT differences between bilinguals and monolinguals were consistent across age groups. This ANOVA analysis further revealed a main effect of age in all conditions (overall mean RTs $F(1,130) = 33.39$, $p < 0.0001$,

mean RTs congruent condition $F(1, 130) = 34.91$, $p < 0.0001$, mean RTs incongruent condition $F(1,130) = 31.80$, $p < 0.0001$, and for mean RTs control condition $F(1,125) = 28.60$, $p < 0.0001$, such that older participants had significantly slower RTs than younger participants. This finding was consistent with other reported findings (Bialystok et al. 2004). Although numerically there were differences in untransformed raw mean RTs such that bilinguals consistently performed better than monolinguals in all Stroop conditions, in the ANOVA analysis this bilingual speed advantage did not achieve statistical significance. The processing speed advantage for bilinguals in all conditions has elsewhere been widely observed (for review see Hilchey & Klein, 2011). See Tables 1, 2, 3 & 4 and associated graphs in Appendix B for details.

Stroop ANOVA for Interference effect:

The next ANOVA was performed with the Interference effect as the dependent variable. The Interference effect is the difference between the mean RTs for the control condition subtracted from the mean RTs for the incongruent condition. This ANOVA revealed no significant interaction effect between age and language. This was confirmed with the interaction plots, and was interpreted to mean that the reaction time difference between monolingual and bilingual language groups was consistent across different age groups. These results were different from Kousaie et al. (2014), who found that younger monolinguals (mean age = 21) had less of an interference effect than older monolinguals (mean age = 72; and also Bialystok et al. (2014) who found the same result for age (younger monolinguals mean age = 20, older monolinguals mean age = 70, and in addition a main effect of language such that the interference effect was greater for monolinguals versus bilinguals (with comparable ages in younger and older groups). This analysis did not reveal any significant difference in reaction time between monolinguals and bilinguals. The findings here did not provide support for the BCA. Possible

reasons for different findings specifically pertaining to bilinguals will follow later. See Table 6 and graph in Appendix B for details.

Stroop Effect ANOVA analysis:

The next ANOVA was performed with the Stroop effect as dependent variable. The Stroop effect is the difference between the mean RTs for the congruent condition subtracted from the mean RTs for the incongruent condition. This ANOVA revealed no interaction effects between age and language. This was confirmed with the interaction plots, and was interpreted to mean that the reaction time difference between monolingual and bilingual language groups was consistent across different age groups. The ANOVA revealed a main effect of age F (1,130) = 3.79 p = 0.03, such that older participants had a larger Stroop effect than younger participants. See Table 6 in Appendix B for details.

Stroop Analysis Results Summary:

To summarize, for the Stroop ANOVA analyses there appeared to be no significant interaction between age and language. This was interpreted to mean that reaction time differences between monolingual and bilingual groups were consistent across age groups. Additionally, older participants had significantly slower reaction times compared to younger participants. Finally, there was no significant difference between monolingual and bilingual participants in terms of reaction times. There is no strong evidence for a BCA in this group, which was perhaps due to variation in the bilingual language group's second language proficiency. This will be explored further with additional analyses.

Consistent with previous studies, this study was conducted with a group of bilinguals whose second language abilities varied according to a number of objective/experiential and subjective/self-rated measures. As the bilinguals in earlier studies have often been equally diverse, this fact may have methodological implications and may likely impact observation of the

BCA. For example, the bilinguals in the Bialystok et al. (2014) study were primarily immigrants with a wide range of L1s, and with an age of L2 acquisition prior to age 8, and an average self-rated proficiency on the LSBQ of 4.2 out of 5. The bilinguals in Kousaie et al. (2014) were non-immigrants, the majority of whom were older bilinguals (approx. 70%) who were L1 speakers of French living in a predominantly French speaking community and whose levels of self-rated L2 proficiency were high (average 4.8 on a 5 point Likert scale, with 5 representing native-like proficiency) prior to age 13. Bialystok et al. (2004, 2006, 2008) administer their research protocol in English, which is the L2 of the participants, versus Kousaie et al. (2014) who tested non- immigrant bilinguals living in the community of their L1. Participants completed a series of tasks in English, French or with a bilingual administration which was randomized across bilingual participants. These are just a couple of examples that highlight the differences in how bilingualism has been addressed in previous research studies. These differences in addressing bilingualism are discussed here because it is clear that they might contribute to the variance in findings, especially with respect to the Stroop Task which is a measure of cognitive control with a linguistic component, thus varying levels of bilingualism may have more of an impact on performance.

Verbal Fluency Test Analysis and Results:

The measures of interest for this task which served as the dependent variables for analysis included: *Letter fluency* (this was the total number of words generated that start with the letters F, A, and S), and *Category Fluency* (this was the total number of words generated for the category of animals). Means and standard deviations for each language and age group were generated for letter fluency (FAS), as Number of Items generated for all three letters and category fluency (Animals), Number of Items generated in the animal category. Please see Table below for results.

Two factorial ANOVAs were performed to explore age X language interactions, one for letter fluency total, and one for category fluency total. No significant interactions or results were found for Letter fluency (See Table 1 Appendix C for details) or Category fluency (See Table 2 Appendix C for details).

The total number of words generated for letter and category fluency was numerically larger for monolinguals versus bilinguals, which is in line with previously reported findings (Bialystok et al., 2008). However, when ANOVAs for age and language effects were performed, no statistically significant differences were revealed. See Tables 1 & 2 in Appendix C for details.

Table 14: Letter Fluency Means

Age	Language	FAS Total	Animals Total
YO	MONO	72.37	30.37
YO	BI	58.20	27.13
MID	MONO	68.56	29.63
MID	BI	59.21	25.53
OLD	MONO	56.77	25.08
OLD	BI	61.87	25.00

Table 15: Letter Fluency Standard Deviations

Age	Language	FAS	Animals
YO	MONO	25.72	8.85
YO	BI	31.10	13.44
MID	MONO	29.79	9.23
MID	BI	32.69	12.23
OLD	MONO	32.67	11.65
OLD	BI	16.55	5.18

Corsi Block Task Analysis and Results:

The following measure served as the dependent variable for this ANOVA.

Block span (the achieved Block Span equaled the length of the last correctly-recalled sequence). The means for Block span values or number of blocks recalled, and the standard deviations were calculated for each age and language group (see Table below). There was no difference in block spans among bilinguals and monolinguals. A factorial ANOVA was performed with block span value, Number of blocks recalled the dependent variable and as a function of Age (Yo-Mid-Old) and Language (Mono- Bi) to test for main and interaction effects. Planned comparisons revealed that middle aged (t=-2.21, p = 0.03) and older adults (t= -4.65, p <0.0001) have significantly smaller block span values than younger adults. See Table 3 in Appendix C for details.

Block Span Results Summary***:*** Monolingual and bilingual participants in comparable age groups had the same block span values. The ANOVA revealed that older adults had significantly smaller block span values than the young and middle aged groups. These findings support normal age related cognitive declines, but do not appear to provide support for a BCA (Bialystok et al. 2007; Stern, 2002).

Table 16: Block Span Means

Age	Language	Block Span
YO	MONO	6.21
YO	BI	6.40
MID	MONO	5.20
MID	BI	5.59
OLD	MONO	4.00
OLD	BI	4.50

Table 17: Block Span Standard Deviations

Age	Language	Block Span
YO	MONO	1.13
YO	BI	1.50
MID	MONO	1.66
MID	BI	1.21
OLD	MONO	1.29
OLD	BI	1.34

Aospan Analysis and Results:

The Aospan Measure (working memory), OSPAN score, uses the traditional "absolute ospan" scoring method, which is the sum of all perfectly recalled sets. First, the Mean Aospan score was calculated for each age and language group (see Table below).

A 3 X 2 factorial ANOVA was performed with Aospan score as the dependent variable, and as a function of Age (Yo-Mid-Old) and Language (Mono - Bi) for main and interaction effects.

Aospan Results: This ANOVA revealed a significant main effect of language $F(1,118) = 13.18$, $p=0.0004$, such that bilingual participants performed significantly better than monolinguals for older and middle aged group*s* and had comparable performance in the young group. There was also a significant main effect of age $F(1,118) =12.85$, $p< 0.0001$, such that older adults had significantly smaller Aospan values compared to younger adults. No age and language interaction effects were revealed for the Aospan ANOVA. See the tables below for a summary of the span values.

Table 18: Aospan Means

Age	Language	Aospan
YO	MONO	47.42
YO	BI	47.07
MID	MONO	35.56
MID	BI	54.65
OLD	MONO	18.64
OLD	BI	34.00

Table 19: Aospan standard deviations

Age	Language	Aospan
YO	MONO	18.80
YO	BI	15.71
MID	MONO	24.14
MID	BI	17.68
OLD	MONO	18.70
OLD	BI	24.36

Aospan Analysis Results Summary:

Statistical analysis revealed a significant difference between monolinguals and bilinguals, and older adults. Bilinguals performed better than monolinguals, as exhibited by significantly larger Aospan values. In addition, older adults had significantly smaller Aospan values as compared to younger participants. This finding was significant and can be viewed as support for a BCA which presents a more general cognitive processing advantage, such as the BEPA (bilingual executive processing advantage) discussed in Hilchey & Klein, 2011, versus just an advantage in inhibitory control. It is beyond the scope of this project to provide an in depth analysis of working memory tasks and functions, but for the purpose of demonstrating that the

Aospan results provide evidence of a BCA, it will suffice to say that there is much research to support the relationship of complex working memory tasks like the Aospan and higher level cognition; that is tasks like the Aospan have proven to be good predictors of high level cognition (Lepine et al. 2005; Colom et al. 2006)

Bilingualism variables and LSBQ:

While analyses of the Stroop and Simon tasks provided some indication of a BCA, there were no significant results to provide strong evidence for one; in particular, although the bilingual advantage in the Simon effect 4sq experiment provides evidence of a bilingual advantage, it is not strong support. Results from the Verbal Fluency Test indicate that this group is overall linguistically comparable to the participants of other studies in that numerically, bilinguals in all age groups produced fewer words than monolinguals, however these results did not reach statistical significance. The block span results confirmed normal age related changes in working memory, which indicates that this is a representative sample of bilinguals and monolinguals and that results obtained here can be generalized. There was a significant main effect of language on the Aospan task, which was arguably the most complex cognitive task and which involved many components of executive function. As the effect was such that bilinguals had better span scores than monolinguals, this finding can be interpreted as evidence in support of the BCA, and as evidence that the BCA may indeed extend beyond an advantage in inhibitory cognitive control. By design, the Aospan was the last task in the protocol which consisted of five experimental tasks. It is noteworthy that in the presence of a potential fatigue effect, bilinguals performed better than monolinguals. To the degree that other measures support the notion of the generalizability of these results, there is no reason to believe that this particular group of bilinguals had beyond average stamina. Participants who provided comments expressed

frustration with this task, which they perceived to be the hardest, and they commented that it was ‘not very nice’ on the part of the researcher to include such a hard task last. So, anecdotally, there was evidence of awareness of task difficulty and potential impact of fatigue, even though the entire protocol was designed to be completed in approximately an hour.

Although the Simon and Stroop results do not provide unequivocal support for the BCA, there was still some evidence that the bilinguals were performing differently than the monolinguals. Thus, the next phase of the analysis will involve taking a more in depth look at the bilinguals and at the pertinent factors of bilingualism that might impact cognitive performance. In addition to identifying performance differences on executive function tasks, a primary focus of this project was to take a closer look at the bilingualism of the participants in order to identify performance differences based on relevant bilingualism factors. These include: Self-rated L2 proficiency, Duration of active L2 use, and Daily use patterns in home and work environments.

A closer look at the information obtained from the LSBQ (Language and Social Background Questionnaire), revealed that the participants varied in terms of their degree of individual bilingualism. Given the discussion earlier, the possibility exists that this variability may have contributed to not finding unequivocal support when considering all participants in this sample. It is important to keep in mind the complexity of factors impacting bilingualism, the variability among bilinguals and the calls in the research to pay closer attention to the details of bilingualism when exploring the bilingual advantage (Kroll & Bialystok, 2013, Valian, 2015; Grosjean, 2010). In light of this, the next set of analyses incorporated the suggestions of other researchers. It incorporated elements from the background questionnaire that previous work has identified as promising but which have not yet been pursued in research (see e.g., Kroll & Bialystok, 2013). Specifically, instead of just reporting background variables associated with

bilingualism (Bialystok et al., 2004, 2008, 2014; Kousaie et al. 2014; Kousaie & Philips, 2012), a primary focus of this study was to quantify bilingualism-related variables and when possible incorporate them into the statistical analysis, which is something that has been called for (Kroll & Bialystok, 2013), but which had not yet been done or reported when this project was undertaken.

What will now follow is a description of further analyses which incorporated additional variables associated with bilingualism. The Language and Social Background Questionnaire completed by all participants provides much valuable information which has been identified in previous studies as being pertinent for more thoroughly exploring the BCA. In particular, the following variables have been identified as important for consideration when studying bilingualism and its impact on cognitive performance differences. Although all the variables are listed, due to time and resource limitations only a subset were able to be chosen for the present study. All of the variables would be promising to explore in future research studies (see Luk, de Sa & Bialystok, 2011; Kroll & Bialsytok, 2013).

1. Age of participant at time of testing
2. Average overall L2 proficiency
3. L1
4. L2
5. Dominant Language
6. Age of Start Learning L2 formally at school
7. Age of Start ACTIVE L2 use (if subtracted from age at time of testing it would yield length of time that individual has been bilingual or ‘Duration of Active L2 use’; and

recent studies (Luk, de Sa & Bialystok, 2011) have confirmed relation between this factor & cognitive outcomes.

8. Proportion of L1 to L2 daily use at Home
9. Proportion of L1 to L2 daily use at School Work

To review, for daily use, the LSBQ asked participants to rate their L2 use in their home and school/work environments. For each setting, participants were asked to rate their use of L2 on a scale of 0 to 100, with 0 being no L2 use, and 100% indicating that the L2 was used 100% of the time in that environment. The participants were asked to rate their level of L2 use in the following areas: Speaking, Listening, Reading, Writing, Watching TV, and Listening to the radio. In order to come up with a unitary measure for daily L2 use in each environment, the ratings for all six of the areas were added and divided by six to establish one 'daily L2 use measure' which could be incorporated into further analysis for each environment, Home (Variable 8), and School/Work (Variable 9). The benefit of a questionnaire like the LSBQ is that it has been vetted and widely used as a tool which provides quantitative measures of bilingualism that allows for direct comparison and direct incorporation into statistical analyses versus just using bilingualism data as descriptive information.

The rationale for choice of covariates stems from prior research which has indicated that age of active bilingualism is more sensitive than onset age of L2 as a predictor of linguistic performance, and that length of time that individual has been bilingual is related to cognitive outcomes. In addition, it has been documented that age of active bilingualism and daily usage both need to be considered for a full picture of bilingual language use. (Kroll & Bialystok, 2013; Luk, de Sa & Bialystok, 2011)

ANCOVA Analysis for Bilingualism:

A series of ANCOVAs were performed to explore the impact of covariates referencing bilingualism. All of the ANOVA analyses performed for the Simon Task and for the Stroop Task were performed as ANCOVAs with the bilingualism covariates.

As with the ANOVAs performed earlier, the dependent variable for both the Stroop and Simon experiments is Reaction Time (RT). The goal was to explore the main effects associated with both independent variables age & language, and the impact of the covariates through analyses of covariance, i.e., ANCOVAs. As before, prior to running the analyses an inverse transformation was performed on all the RT data.

The covariates of interest for the ANCOVAs are as follows:

1. ANCOVA 1: The covariate for this ANCOVA was **Duration of Active L2 use.**
2. ANCOVA 2: The covariate for this ANCOVA was **L2 Average Rating** (self-rated proficiency).
3. ANCOVA 3: The covariate for this ANCOVA was **L1-L2 Home Use.**
4. ANCOVA 4: The covariate for this ANCOVA was **L1-L2 School/Work Use.**

The covariate Duration of Active L2 Use, which indicates the length of time that individual has been actively using his/her languages, was established by subtracting variable number 7, Age Start Active L2 use, from variable number 1, Age at time of testing. Duration of active L2 use has been shown to impact cognitive performance (Kroll & Bialystok, 2013; Luk, de Sa & Bialystok, 2011; Valian, 2015) and so was chosen as a covariate in the ANCOVA analyses. In addition, age at which L2 started to be used actively, or age of active bilingualism (AoAB) combined with daily use in home and work environments use has been shown to impact cognitive performance in bilinguals (Kroll & Bialystok, 2013; Luk, de Sa & Bialystok, 2011). To

determine Duration of L2 use, AoAB was subtracted from age at timing of testing. And thus because AoAB is taken into consideration to determine Duration of Active L2 use, a separate analysis for the covariate of AoAB was not performed. Self-rated L2 proficiency which has consistently been used to address bilingualism in the research (Bialystok et al. 2004, 2008, 2014; Kousaie & Philips, 2012; Kousaie et al. 2014) was chosen as another covariate. The ANCOVA analyses were performed with the various dependent variables for the Simon and Stroop Tasks to explore whether these covariates of bilingualism impact performance. As these L2-related variables did not apply to the monolingual participants, only the bilinguals were included in the ANCOVA analyses.

The following are the results from the age X language ANCOVA models for the Simon dependent variables of interest (RTs in various conditions: Center 2sq Control; Simon Effect 2sq; Center 4sq Control; congruent and incongruent conditions) with the covariates for bilingualism (Duration of Active L2 use, Self -rated Average L2 proficiency, Proportion of L1-L2 use in the home; Proportion of L1-L2 use at school/work). The first ANCOVA explored duration of Active L2 use as a covariate with Mean RTs. The multiple models which analyzed the covariate of 'duration of Active L2 use' will be summarized here.

Simon Task ANCOVA Analyses:

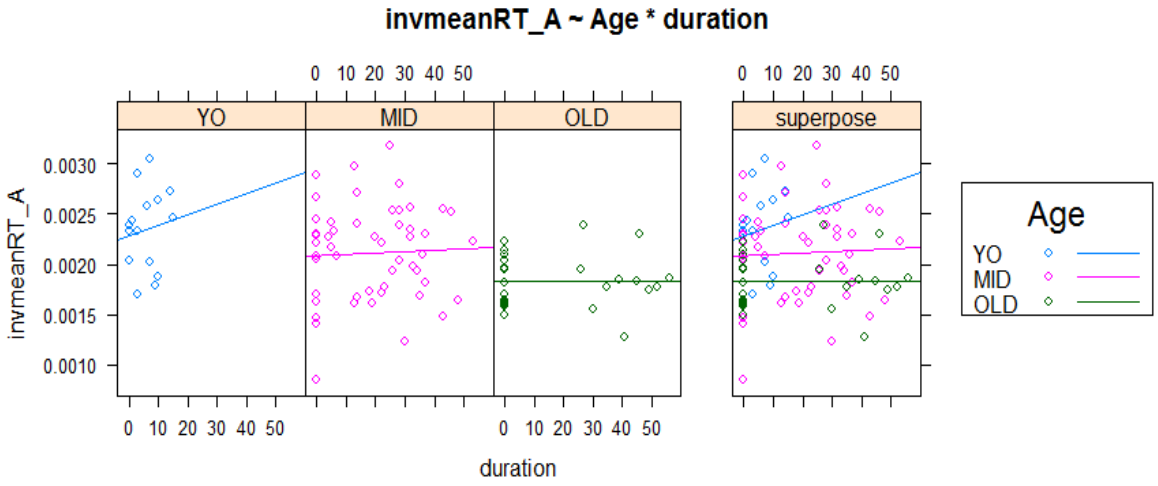
The following series of ANCOVAs was performed in order to answer the call in the literature to look at bilingualism as a continuous variable in analyses (Kroll & Bialystok, 2013). That is, in order to explore the impact of bilingualism in its own right, the ANCOVA model used replaced the categorical Language variable (monolingual vs. bilingual) used in the ANOVA analyses by several more informative continuous variables indexing bilingualism. The first ANCOVA explored Duration of Active L2 use as a covariate. Then the other ANCOVAs for the other

conditions which were analyzed with the covariate of 'Duration of Active L2 Use' will be summarized here. Subsequently all of the additional ANCOVAs performed will be described and results discussed.

ANCOVA 1: Covariate: Duration of Active L2 use

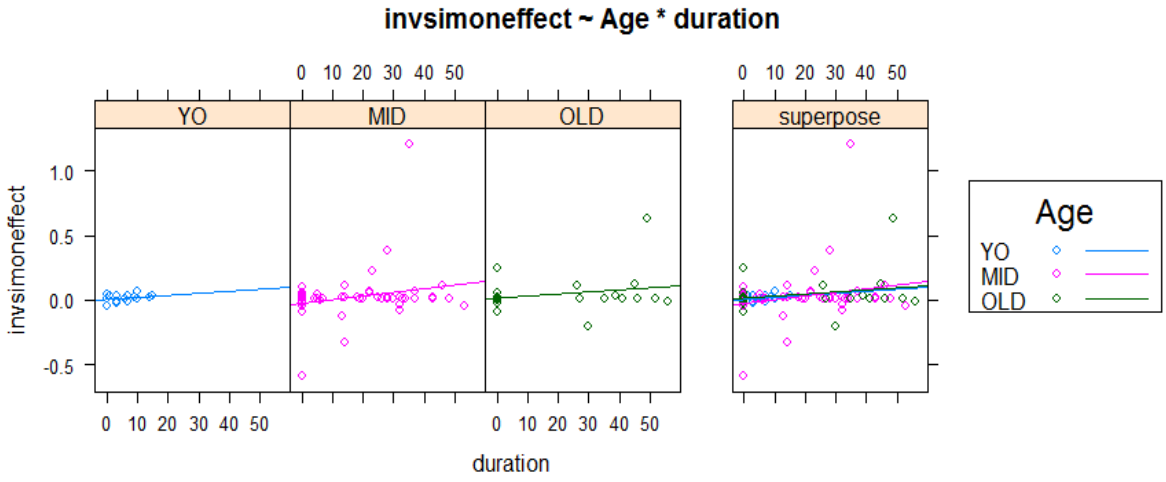
In ANCOVA model 1 with the dependent variable RT for 2sq center control condition, there was a significant main effect of Age, $F(2,76) = 7.95$, $p < 0.001$, and no other significant interactions. This result indicated that older participants have significantly slower reaction time. Although the Duration effect was not significant, there was still a positive value estimation indicating that reaction time decreases when someone has a longer length of time knowing another language (as with the ANOVAs earlier, since RTs were transformed, numerically larger transformed values are indicative of correspondingly smaller untransformed RTs). This was also confirmed in Plot1 as slopes of lines were positive. The interaction between age and duration was not significant, thus the slopes were not significantly different across the different age groups. (See Table 1 in Appendix D for details)

Plot 1: **Simon ANCOVA with Duration active L2 use and mean RT**



In ANCOVA model 2, the Simon effect of the 2sq condition was explored with the covariate of 'Duration of Active L2 use'. For this model, the analysis failed to find an effect of age. There was however a significant main effect of Duration of Active L2 use, $F(1,77) = 4.43$, $p = 0.04$. There was no interaction between age and Duration of Active L2 Use. (See Table 2 in Appendix D for details).

Plot 2: **Simon ANCOVA with Duration active L2 use and Simon effect 2sq**



Taken together, this means that when Duration of Active L2 use was controlled for, there was no longer an effect of age, and a significant effect of the covariate itself on the size of the Simon effect in all three age groups. Recall that the Simon effect represents the processing cost associated with inhibiting an automatic response; and is a response which has been widely replicated with monolinguals. Specifically, this task requires participants to use inhibitory control to inhibit the automatic response to press the key adjacent to the stimulus color when the correct response requires them to press the key on the opposite side.

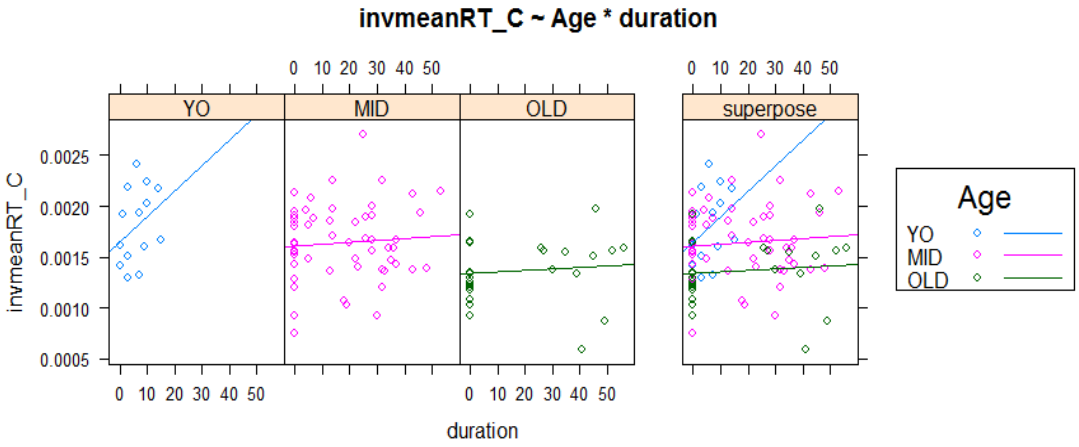
That for the Simon effect 2 square condition there was a main effect of Duration of Active L2 use, no main effect of age, and no interaction between them provides clear evidence of a bilingual cognitive advantage in inhibitory control. It means that as the time that someone uses their L2 increases, the Simon effect or processing cost for inhibiting irrelevant information decreases.

In short, in the Simon effect 2 square condition, it is not age but is instead Duration of Active L2 use that modulates the Simon effect. Since there was no interaction between age and Duration of Active L2 Use, this means that the relation between the size of the Simon effect and the covariate was the same in all age groups. As can be seen in Plot 2, there is a comparable effect irrespective of age in the graph on the right where all the slopes are superimposed. The plot reveals that longer Durations of Active L2 use result in smaller Simon effects for younger, middle-aged and older bilinguals. Moreover, the influence of Duration of Active L2 Use on Simon effect size is the same for all age groups. This result is particularly significant for the older adults, because for all other bilingual variables there was always a main effect of age. In brief, while age does not matter here, Duration of Active L2 use does matter.

In ANCOVA model 3, with RTs for 4sq control condition with the covariate of Duration of

active L2 use, there was again a significant main effect of Age F (2,89) =7.80, p=0.0008. As for the 2sq control condition, these results show that older participants had significantly slower reaction time, such that reaction time in the 4sq condition decreases when someone has a longer length of time knowing another language. As this was a control condition, this result cannot easily be interpreted as supporting that Duration of L2 use mitigates the working memory costs associated with aging (See Table 3 and Plot 3 in Appendix D for details).

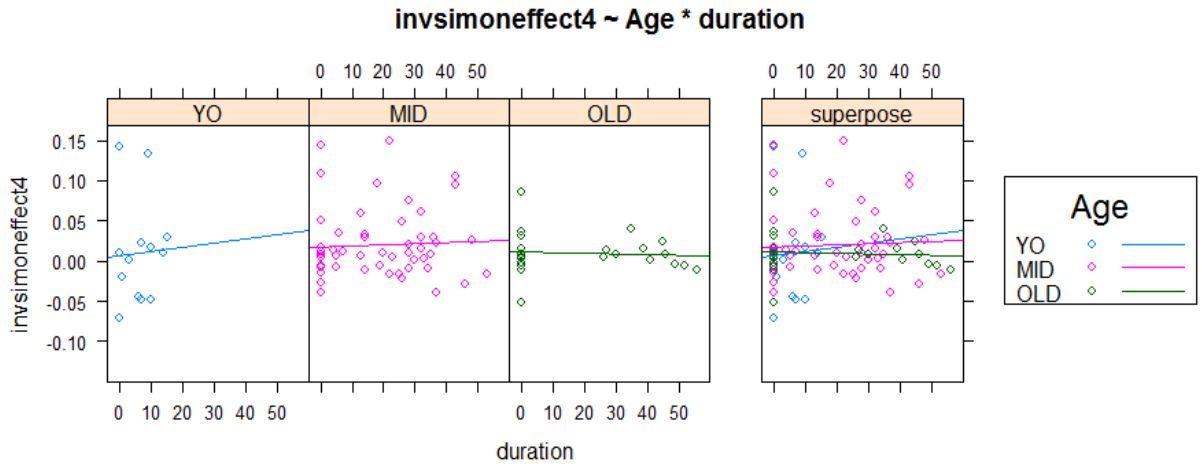
Plot 3: **Simon ANCOVA with Duration active L2 use and mean RT 4sq**



In ANCOVA Model 4, which was for the Simon effect in the 4sq condition, there were no significant main or interaction effects (see Table 27 and Plot 4 for these results). Although this condition was designed to cause increased working memory costs, the results suggest that for this population the condition did not work as planned. Anecdotally, several of the participants who completed the experimental protocol in the presence of the researcher may have been adopting an unanticipated "chunking or grouping" memory strategy, whereby the participants in question appeared to be chunking the condition's four separate rules into two general rules, and thus in essence dealing with two rules versus four rules. In any case, in contrast to the findings of

(Bialystok et al. 2004) who found a bilingual advantage for working memory costs, the results in this study suggest that this condition may not have elicited additional working memory costs (See Table 4 in Appendix D for details).

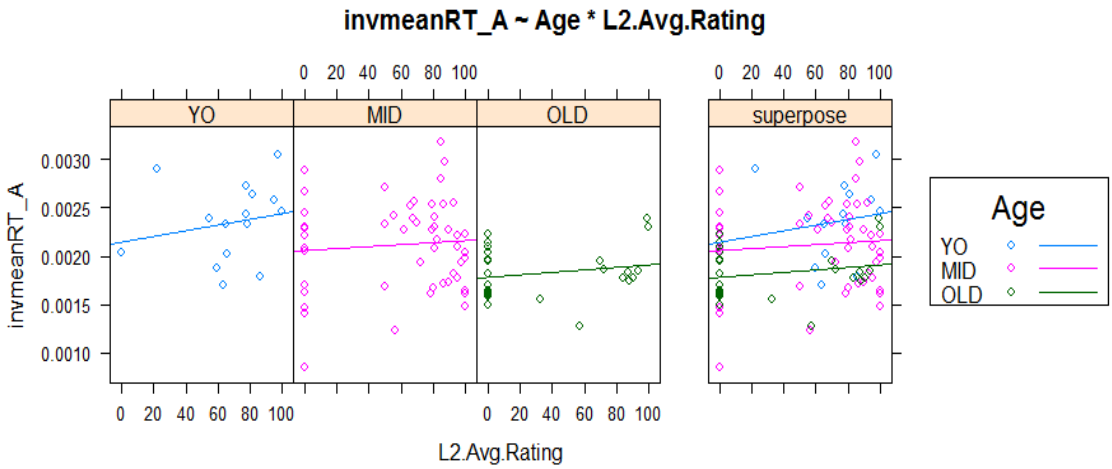
Plot 4: **Simon ANCOVA with Duration active L2 use and Simon effect 4sq**



ANCOVA 2: Covariate: Self-rated average L2 proficiency

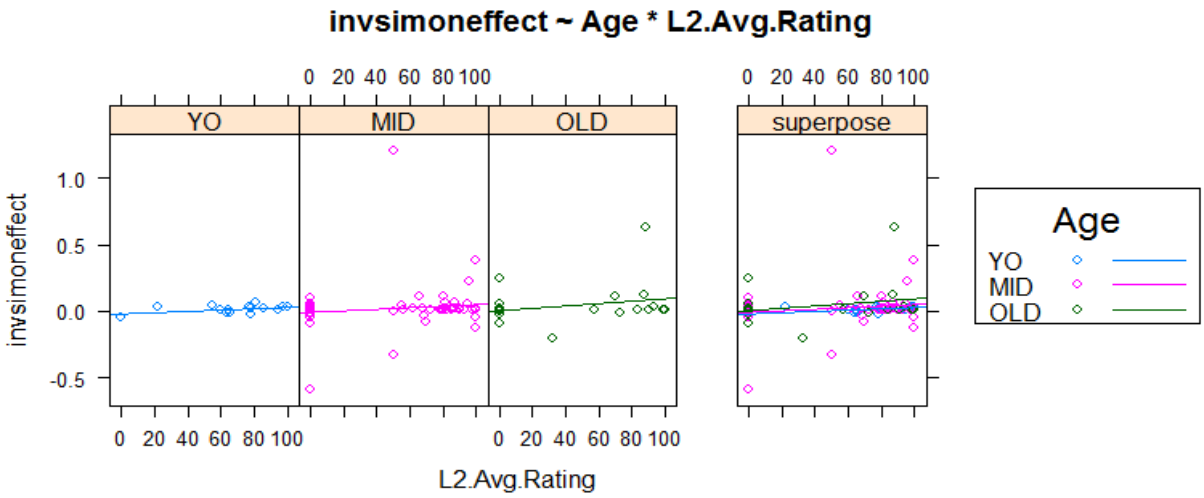
In ANCOVA Model 5, in the 2sq control condition with the covariate of self-rated Average L2 proficiency there was again a significant main effect of age $F(2,76) = 8.05$, $p = 0.0006$, with older participants having significantly slower RTs than younger participants. Where this result was charted in Plot 5, the slopes of lines were positive. Because the interaction term was not significant, this indicates that slopes were not significantly different across different Age groups. See Table 5 in Appendix D for details.

Plot 5: **Simon ANCOVA with Self-rated average L2 proficiency and mean RT**



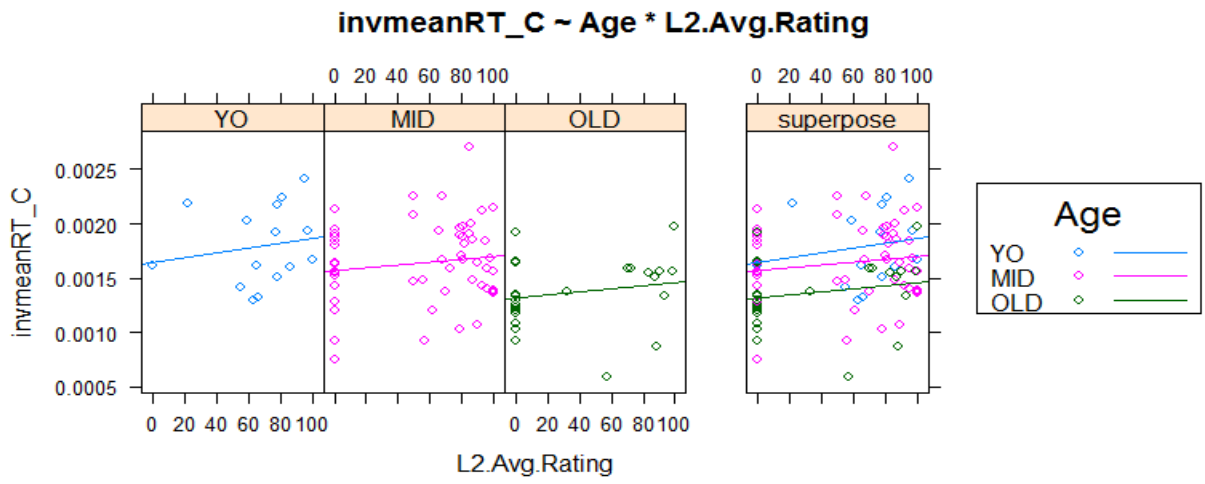
In ANCOVA Model 6, with the covariate of self-rated Average L2 proficiency and the dependent variable of the Simon Effect in the 2sq condition, no significant main or interaction effects were observed. The effects of self-rated average L2 proficiency $F(1,77) = 2.28$, $p = 0.13$ was not significant. See Table 6 in Appendix D for details.

Plot 6: **Simon ANCOVA with Self-rated average L2 proficiency and Simon effect 2sq**



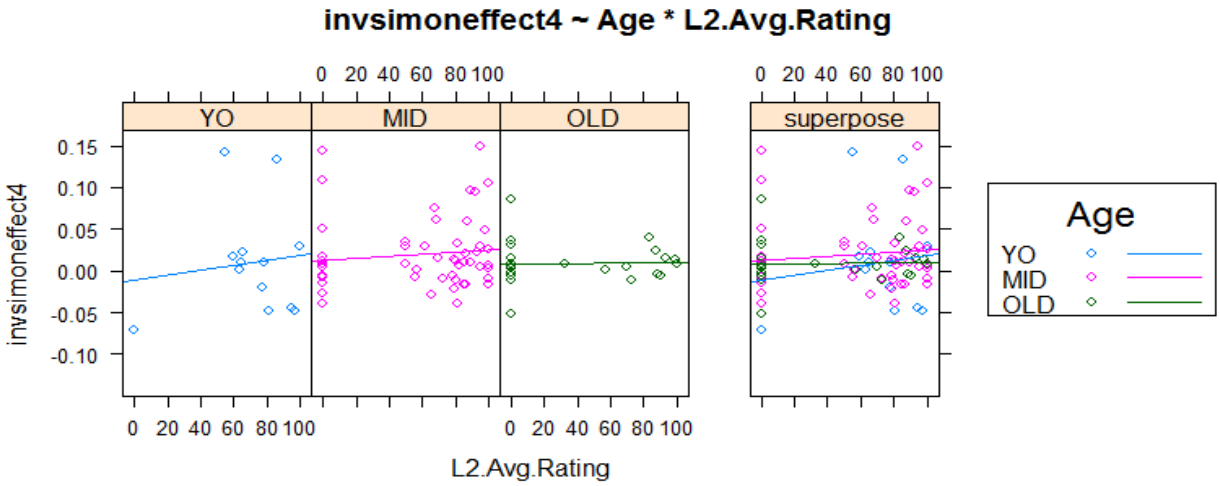
In ANCOVA Model 7, with the covariate of Self-rated Average L2 proficiency and the dependent variable of mean RT in the center control 4sq condition, there was a significant main effect of age $F(2,76) = 7.80$, $p = 0.0008$, with older participants having significantly slower reaction times. This suggested that older participants exhibit more of a decline in reaction time performance associated with normal aging as a result of higher self-rated proficiency. See Table 7 in Appendix D for details.

Plot 7: **Simon ANCOVA with Self-rate average L2 proficiency and mean RT 4sq**



In ANCOVA Model 8 with the covariate of Average L2 proficiency with the dependent variable of Simon effect 4sq RTs, no significant main or interaction effects were observed, as demonstrated in Plot 8. See Table 8 in Appendix D for details.

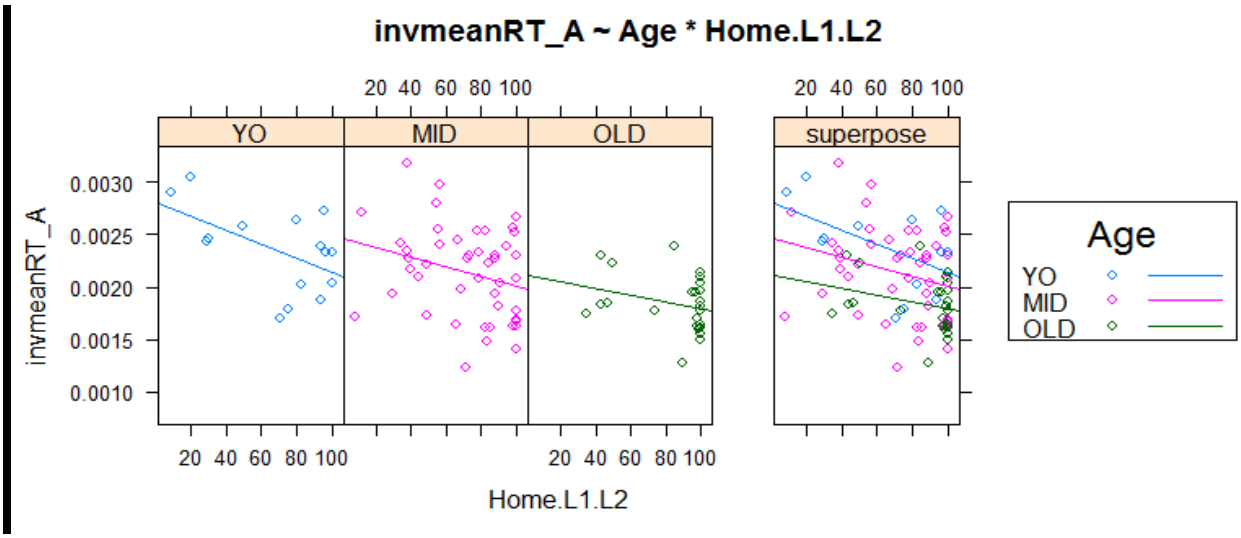
Plot 8: **Simon ANCOVA with Self-rated average L2 proficiency and Simon effect 4sq**



ANCOVA 3: Covariate: Daily L1-L2 home use

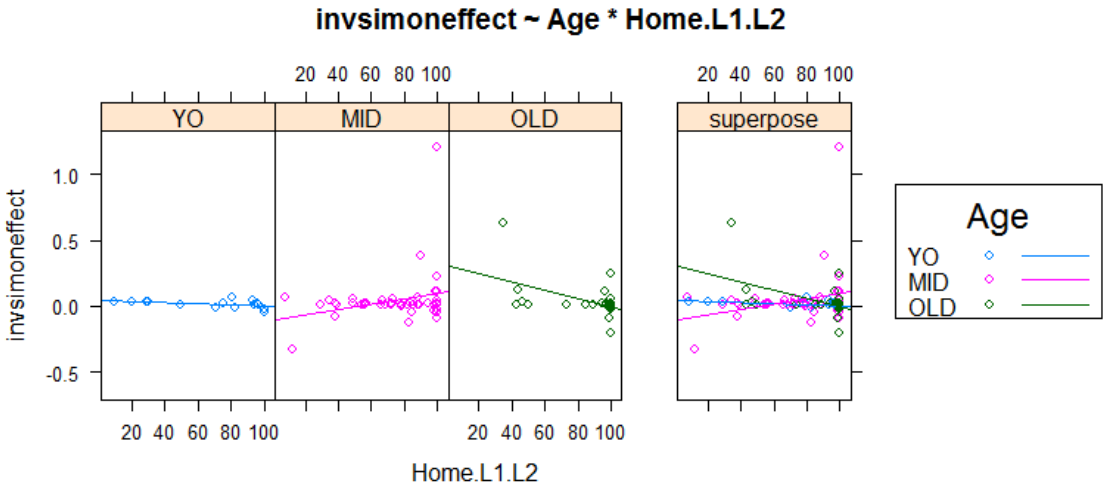
In ANCOVA Model 9, the covariate, 'L1-L2 Home use' with the dependent variable of mean reaction time in Center 2sq revealed a significant main effect of age $F(2,76) = 9.6$, $p = 0.00019$, with older participants having significantly slower reaction times. In addition, the L1-L2 Home use effect was also significant, $F(1,77) = 9.64$, $p = 0.0026$. Where this result was charted in Plot 9, the slopes of lines were negative, indicating that individuals would have faster reaction times if they used their L2 in the home relatively more often. As the interaction term was not significant, we inferred that slopes were not significantly different across different age groups, and that there would be faster reaction times for all age groups as a function of using their L2 more often in their home environment. See Table 9 in Appendix D for details.

Plot 9: **Simon ANCOVA with Daily L1-L2 home use and mean RT**



In ANCOVA Model 10 the covariate, 'L1-L2 Home use' with the dependent variable of mean RT for the Simon effect 2sq condition, there was a significant interaction effect between the covariate 'L1-L2 Home Use' and 'Simon effect 2sq RT' $F(2,76) = 4.56$, $p = 0.013$. By looking at the slope lines in Plot 10 interaction is different depending on the age group. Of particular relevance is that it appears from the slope lines for the older participants that as L1-L2 Home use increases, the Simon effect 2sq condition decreases; the implications are less clear for the middle aged participants, while for the younger participants L1-L2 Home use does not appear to greatly impact their RTs for the Simon effect 2sq. See Table 10 in Appendix D for details.

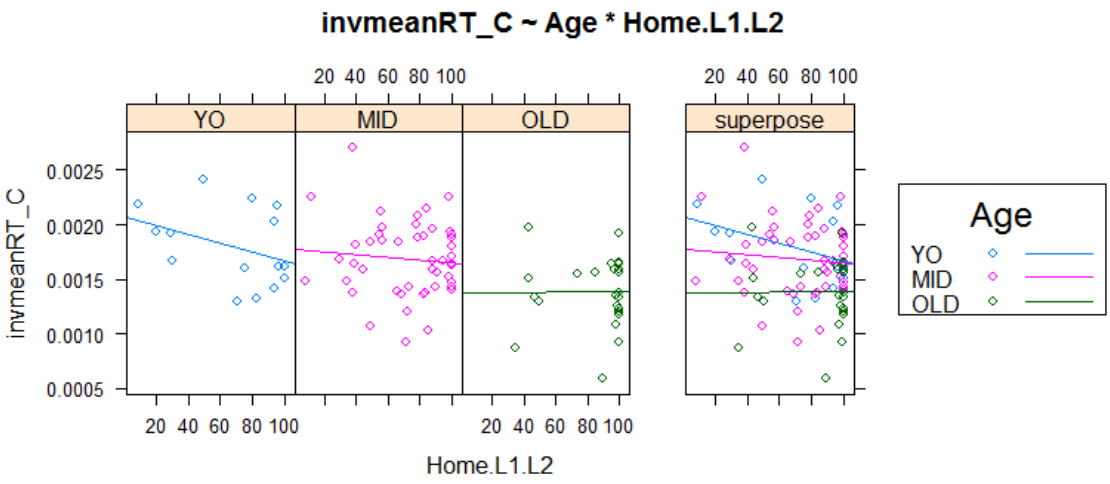
Plot 10: **Simon ANCOVA with Daily L1-L2 home use and Simon effect 2sq**



This analysis also provides some support for the bilingual cognitive advantage hypothesis, because although there was no main effect of age and no main effect of L1-L2 Home use, the significant interaction of age and the amount of L2 use in the home impacts results for the Simon effect. This significant interaction warrants additional research with the L1-L2 Home Use variable to further understand impact of bilingual experience on cognitive performance.

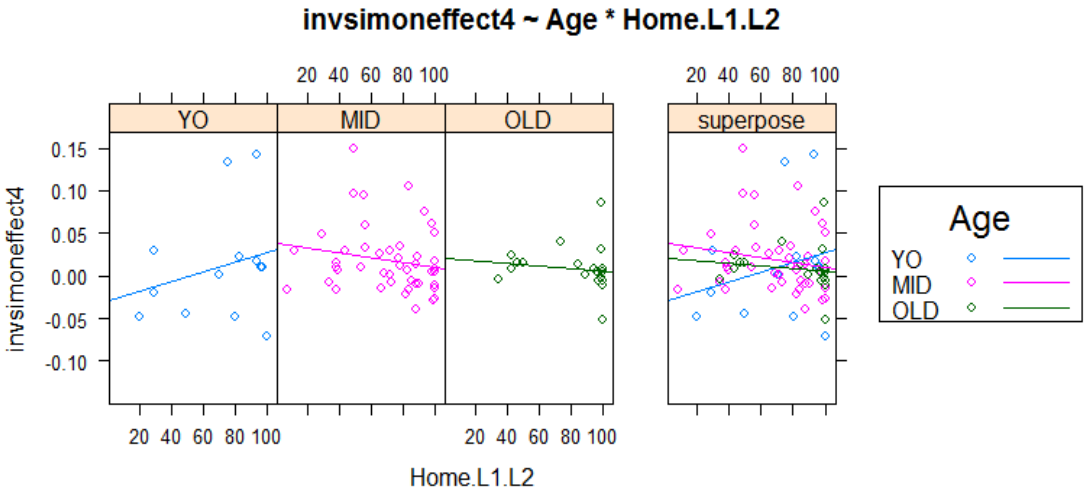
In ANCOVA Model 11, the covariate 'L1-L2 Home use' with the dependent variable of mean RT in the Centre 4sq condition once again revealed a significant main effect of age $F(2,76) = 8.87$, $p = 0.00042$, with older adults having significantly slower RTs when compared to younger adults, as demonstrated in Plot 11. See Table 11 in Appendix D for details.

Plot 11: **Simon ANCOVA with Daily L1-L2 home use and mean RT 4sq**



In ANCOVA Model 12 the covariate, 'L1-L2 Home use' with the dependent variable of mean RT for the Simon 4sq condition revealed no significant main or interaction effects, as seen in Plot 12. See Table 12 in Appendix D for details.

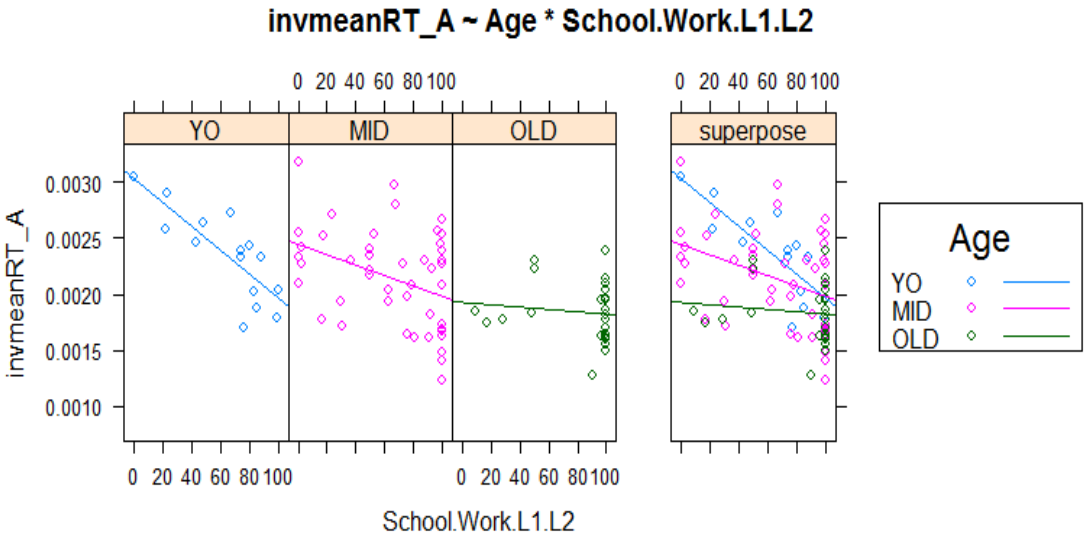
Plot 12: **Simon ANCOVA with Daily L1-L2 home use and Simon effect 4sq**



ANCOVA 4: Covariate: School/Work Proportion L1-L2 Use

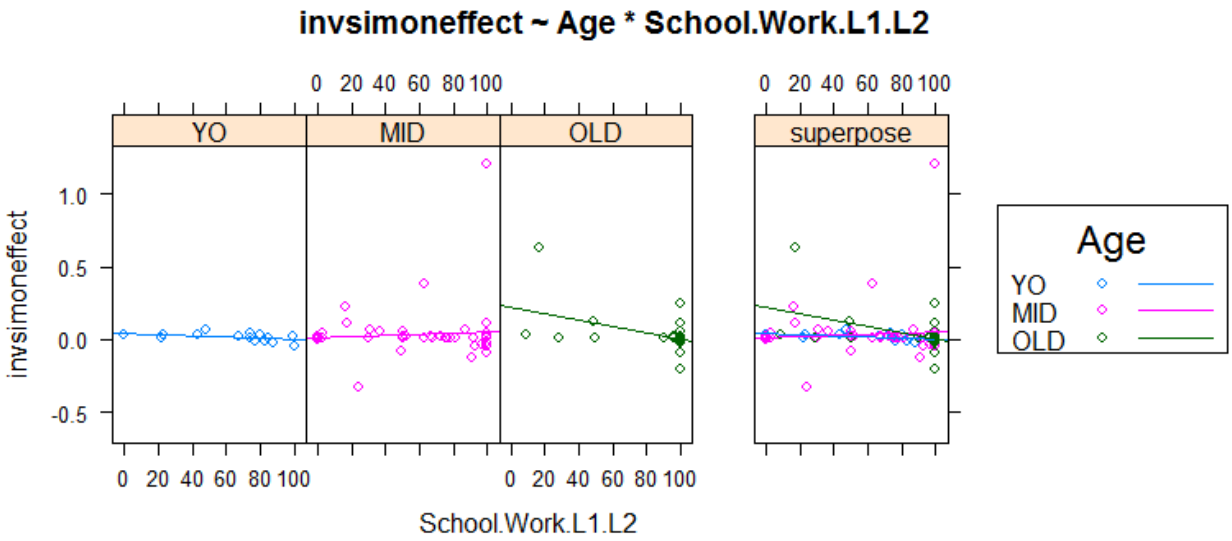
In ANCOVA Model 13, the covariate 'L1-L2 School/Work use' with the dependent variable of mean reaction time in control 2sq condition revealed a main effect of age $F(2,76) = 10.87$, $p < 0.0001$, which meant that older bilinguals had significantly slower reaction times than younger bilinguals. There was also a significant main effect of School/Work Proportion L1-L2 Use $F(1,77)= 16.39$, $p =0001$, such that the bilinguals reacted faster if they used their L2 relatively more frequently at School/Work. Please see Plot 13 where this effect was charted as slopes of lines were negative, and also Table 36 for results. The age and L1-L2 School Work use interaction was also significant $F(2,76) = 3.05$ $p = 0.05$. The slopes, seen in Plot 13, which were different among the different age groups, suggested that the greatest interaction might have occurred for the younger and middle aged participants whereby it appears that they had faster RTs if they used their L2 more frequently at school or work; and that this was less pronounced for older adults, perhaps because fewer of them worked so this variable was less of a significant predictor of cognitive performance, whereas L1-L2 Home use was a strong predictor of performance. See Table 13 in Appendix D for details.

Plot 13: **Simon ANCOVA with L1-L2 school/work use and mean RT 2sq**



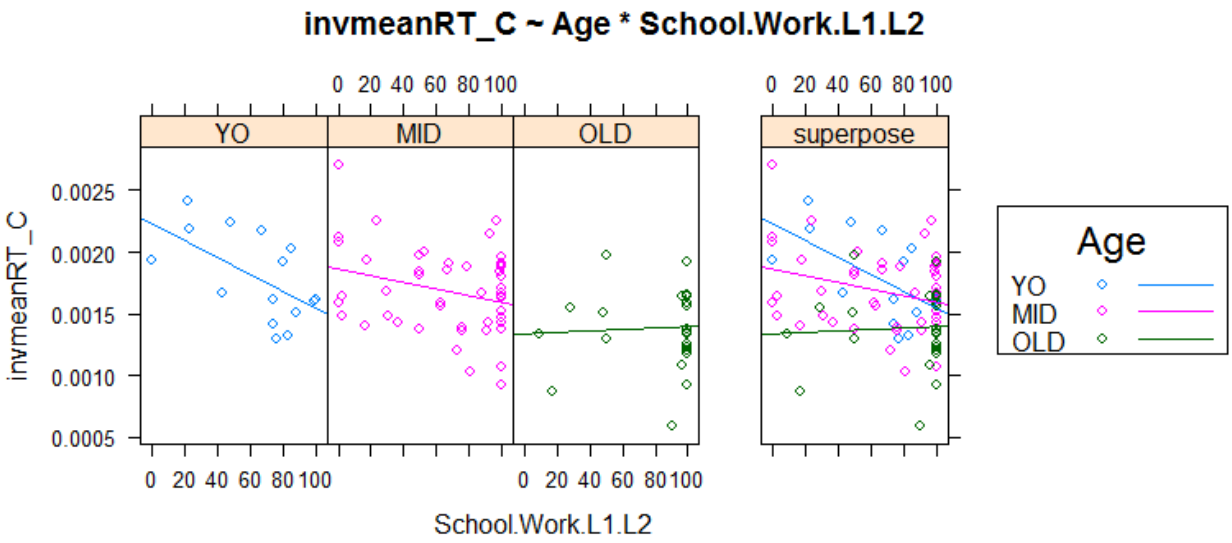
In ANCOVA Model 14 the covariate, ‘L1-L2 School/Work use’ with the dependent variable of the mean RT for the Simon Effect 2sq revealed no significant main effects or interactions, as demonstrated in Plot 14. See Table 14 in Appendix D for details.

Plot 14: **Simon ANCOVA with L1-L2 school/work use and Simon effect 2sq**



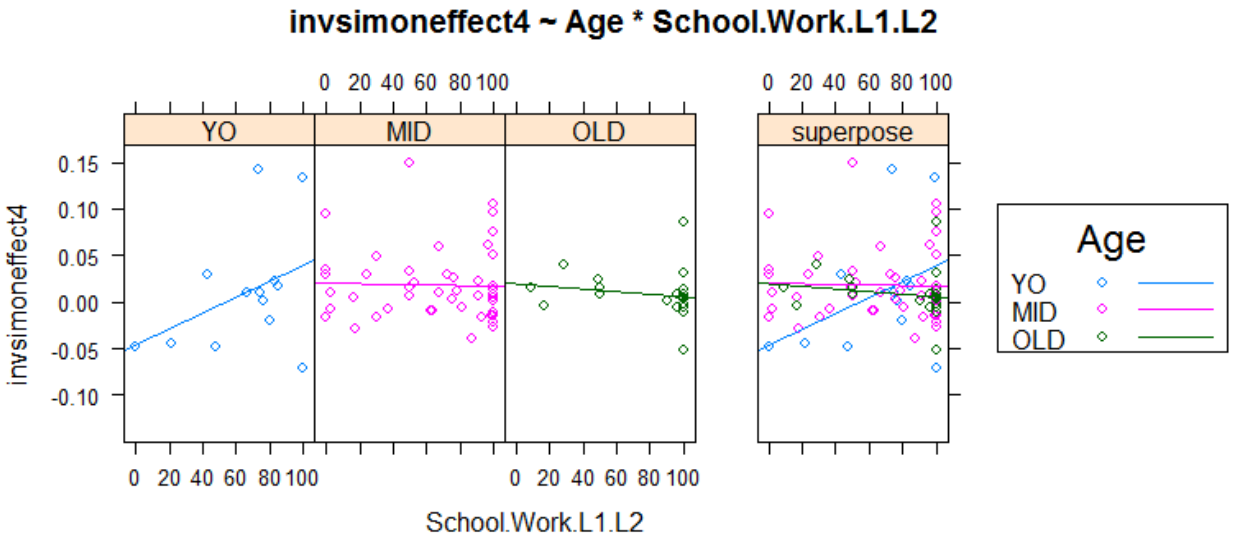
In ANCOVA Model 15 the covariate, 'L1-L2 School/Work use' with the dependent variable Mean Reaction Time in Center 4sq revealed a significant main effect of age F (2,76) = 9.33, p =0.00023, and 'L1-L2 School/Work use' F(1,77) = 5.56, p =0.021, which confirmed that older bilinguals had significantly slower reaction times. The significant main effect of School/Work Proportion L1-L2 Use means that participants reacted faster if they used L2 relatively more frequently at School/Work. See Table 15 in Appendix D for details.

Plot 15: **Simon ANCOVA with L1-L2 school/work use and mean RT 4sq**



In ANCOVA Model 16 the covariate, 'L1-L2 School/Work use' with the dependent variable of mean RT for the Simon Effect 4sq no significant main effects or interactions were observed, as demonstrated in Plot 16. See Table 16 in Appendix D for details.

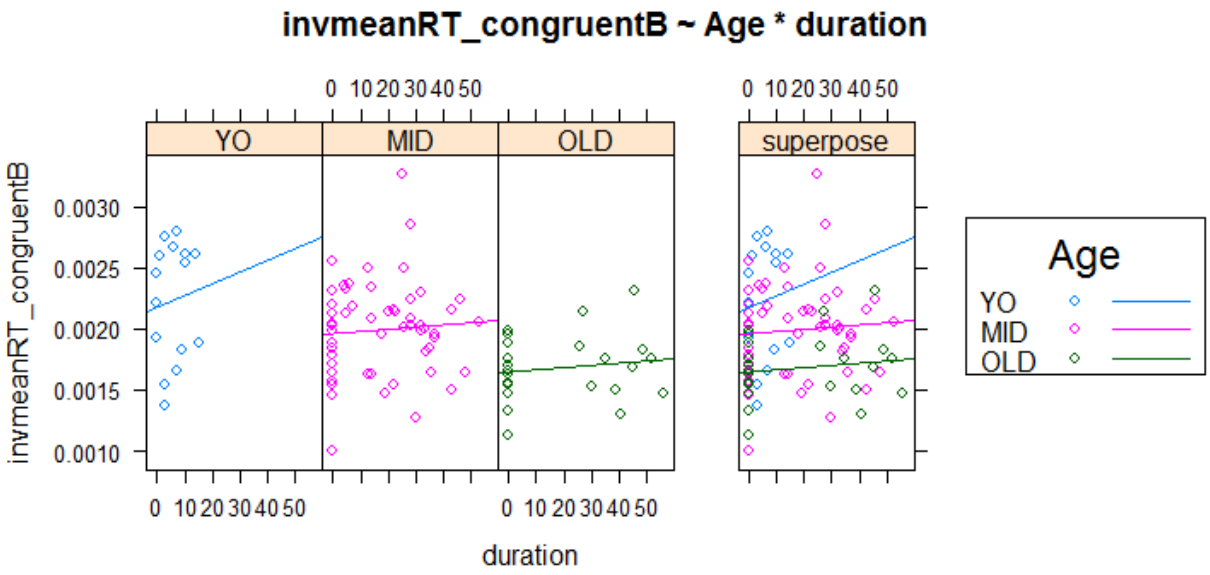
Plot 16: **Simon ANCOVA with L1-L2 school/work use and mean RT 4sq**



ANCOVA 5: Covariate: Duration Active L2 Use

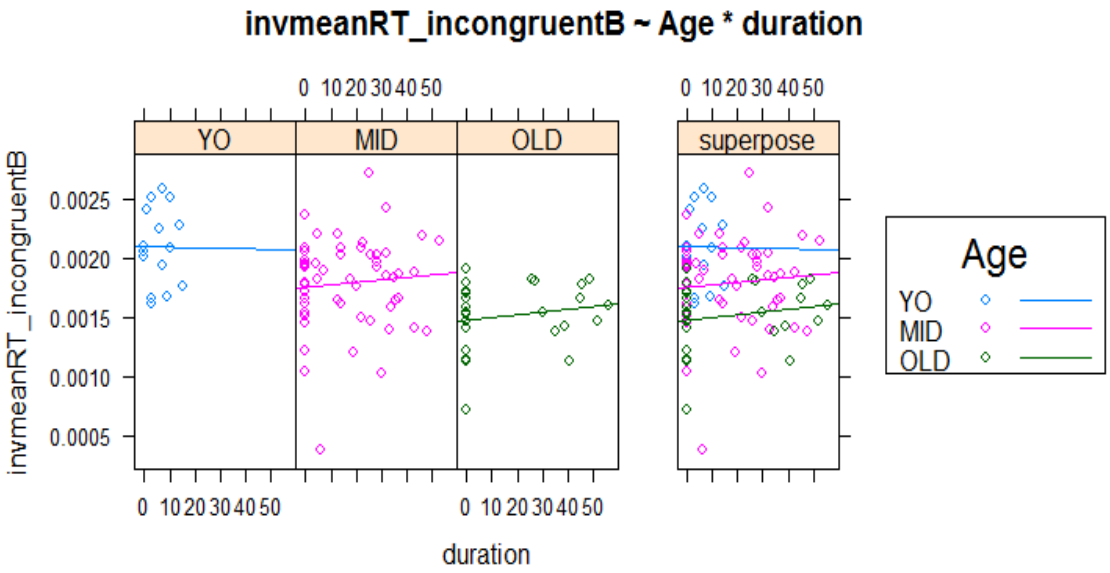
In ANCOVA Model 17 the covariate, 'Duration Active L2 Use' with the dependent variable of RT in the Simon Congruent Condition 2sq revealed a main effect of age, $F(2,76) = 10.72$, $p<0.0001$, confirming that the older bilinguals had significantly slower RTs in the congruent 2sq condition as compared with younger bilinguals. The covariate of duration effect did not reach significance; however, where the results were charted in Plot 17, there was a positive value estimation which suggests that reaction time decreased for the 2sq congruent condition as a function of having had a longer duration of active L2 use. The age and duration interaction was not significant, which suggests that these results were comparable for all age groups. See Table 17 in Appendix D for details.

Plot 17: **Simon ANCOVA with Duration active L2 use and Simon congruent condition 2sq**



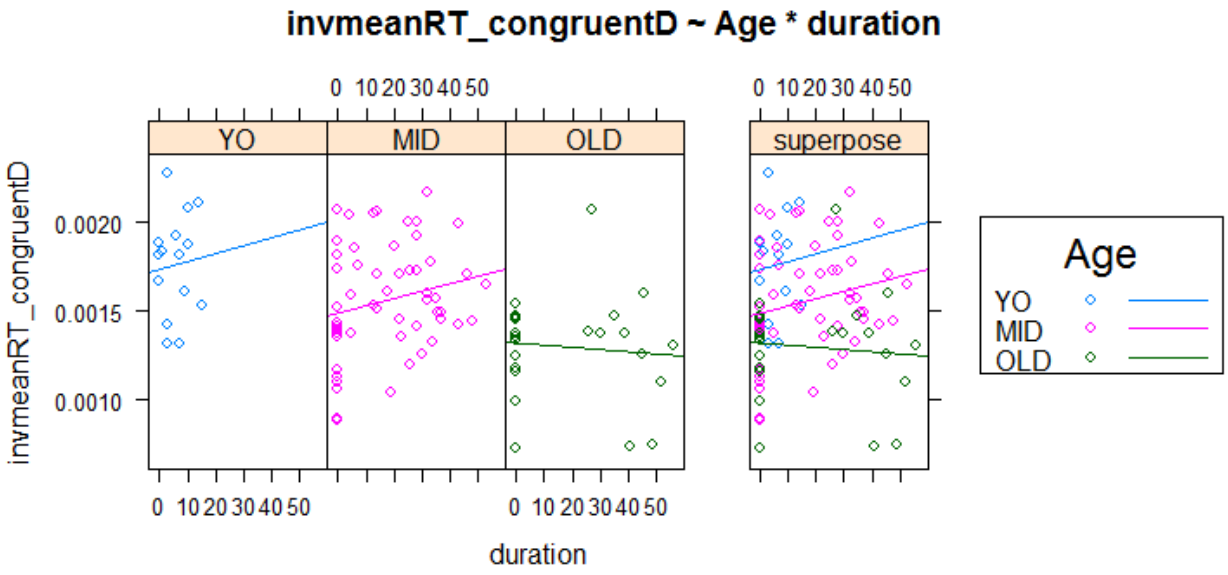
In ANCOVA Model 18 the covariate, 'Duration Active L2 Use' with the dependent variable of RT in the Simon Incongruent Condition 2sq revealed a main effect of age, F (2,76) =12.54, p<0.0001, which means that the older bilinguals had significantly slower RTs in the incongruent 2sq condition. In addition, for this condition, the covariate of duration effect did not reach significance; however, where the results were charted in Plot 18 there was a positive value estimation which suggests that reaction time decreases for the incongruent 2sq condition as a function of having a longer duration of active L2 use. The age and duration interaction was not significant which suggests that these results were comparable for all age groups. See Table 18 in Appendix D for details.

Plot 18: **Simon ANCOVA with Duration active L2 use and Simon incongruent condition 2sq**



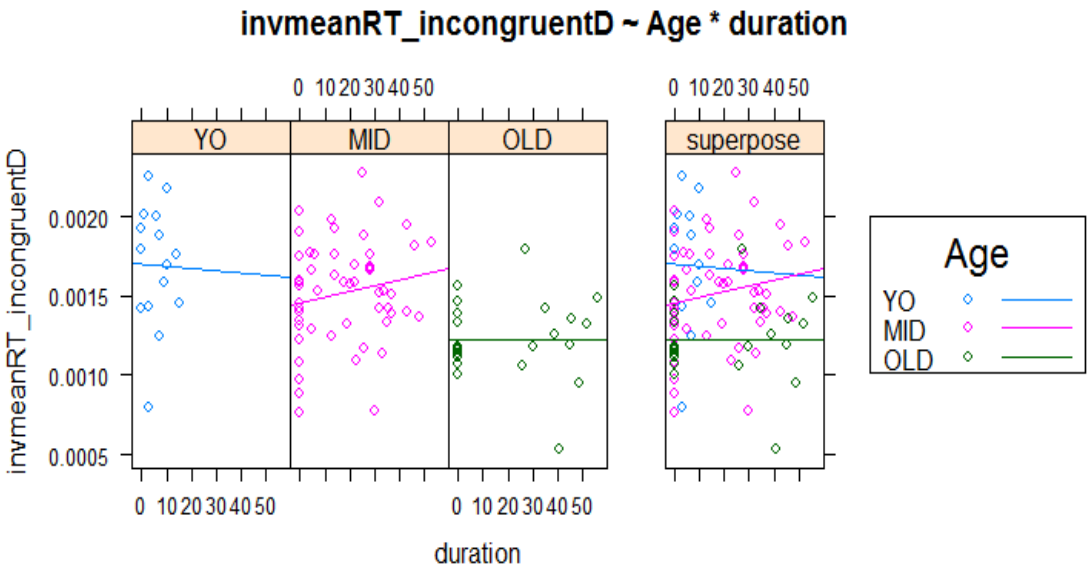
In ANCOVA Model 19 the covariate, 'Duration Active L2 Use' with the dependent variable of RT in the Simon Congruent Condition 4sq revealed a main effect of age $F(2,76) = 12.32$, $p<0.0001$, which means that the older bilinguals had significantly slower RTs in the congruent 4sq condition. Similar results for this condition showed that the covariate of duration effect did not reach significance; however, where the results were charted, in Plot 19, there was a positive value estimation which suggested that reaction time decreases for the 4sq congruent condition as a function of having had a longer duration of active L2 use. The age and duration interaction was not significant, which suggests that these results were comparable for all age groups. See Table 19 in Appendix D for details.

Plot 19: **Simon ANCOVA with Duration active L2 use and Simon congruent condition 4sq**



In ANCOVA Model 20 the covariate, Duration Active L2 Use with the dependent variable of RT in the Simon Incongruent Condition 4sq revealed a main effect of age $F(2,76) = 11.86$, $p<0.0001$, with the older participants showing significantly slower RTs in the incongruent 4sq condition. As for all other conditions, the covariate of duration effect did not reach significance; however, where the results were charted there was a positive value estimation which suggested that reaction time decreased for the 4sq incongruent condition as a function of having had a longer duration of active L2 use. The age and duration interaction was not significant, which suggests that these results were comparable for all age groups. See Table 20 in Appendix D for details.

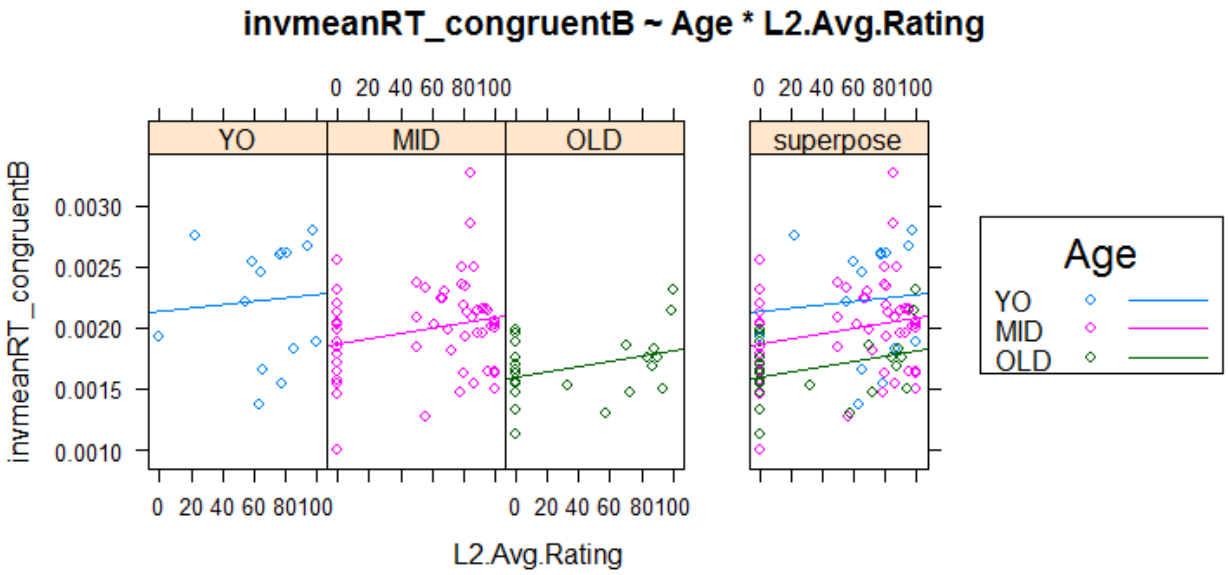
Plot 20: **Simon ANCOVA with Duration active L2 use and Simon incongruent condition 4sq**



ANCOVA 6: Covariate: Self-rated average L2 proficiency

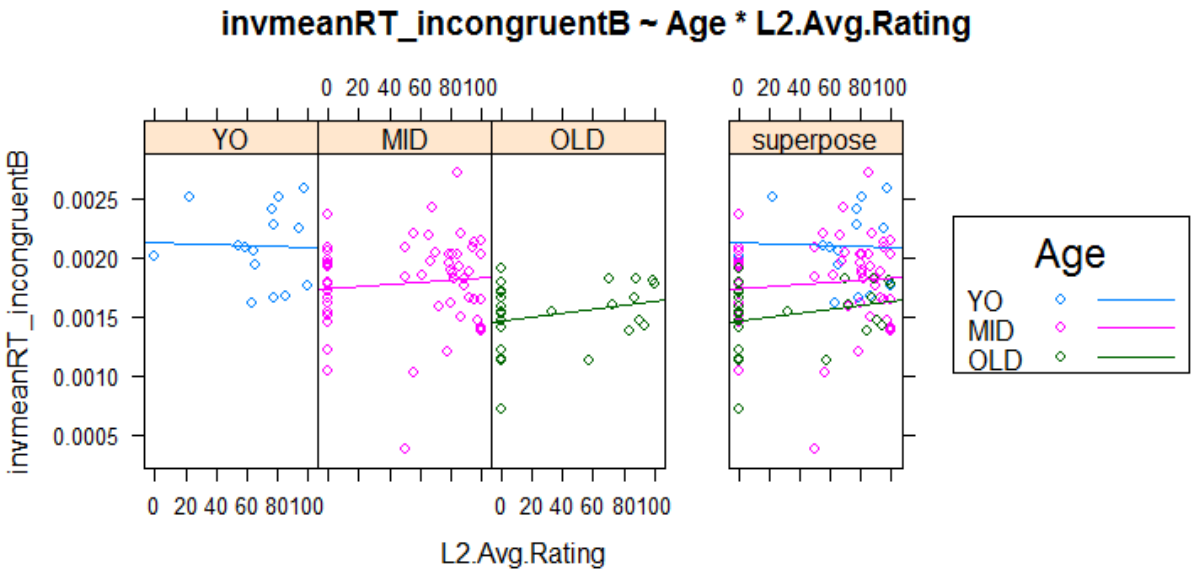
In ANCOVA Model 21, the covariate L2 Average Rating, a measure of self-rated proficiency, was analyzed with the dependent variable of RT in the Simon Congruent Condition 2sq. This analysis revealed a main effect of age $F(2,76) = 11.15$, $p<0.0001$, indicating that when self-rated L2 proficiency was controlled for, older bilinguals had significantly longer reaction times. In addition, the L2 Average Rating effect was also significant, $F(1,77) =4.38$, $p=0.04$, in that reaction time decreased as a function of increasing self-rated L2 proficiency. Where these results were charted in Plot 21 the slopes of lines were positive, thus demonstrating that RTs in this condition decreased as a function of increasing self-rated L2 proficiency. The interaction between age and L2 Average Rating interaction was not significant. See Table 21 in Appendix D for details.

Plot 21: **Simon ANCOVA with Self-rated L2 proficiency and Simon congruent condition 2sq**



In ANCOVA Model 22, the covariate L2 Average Rating was analyzed with the dependent variable of RT in the Simon Incongruent Condition 2sq. This analysis revealed a main effect of age $F(2,76) = 12.62$, $p < 0.0001$, with older bilinguals having significantly slower reaction times as demonstrated in Plot 22. See Table 22 in Appendix D for details.

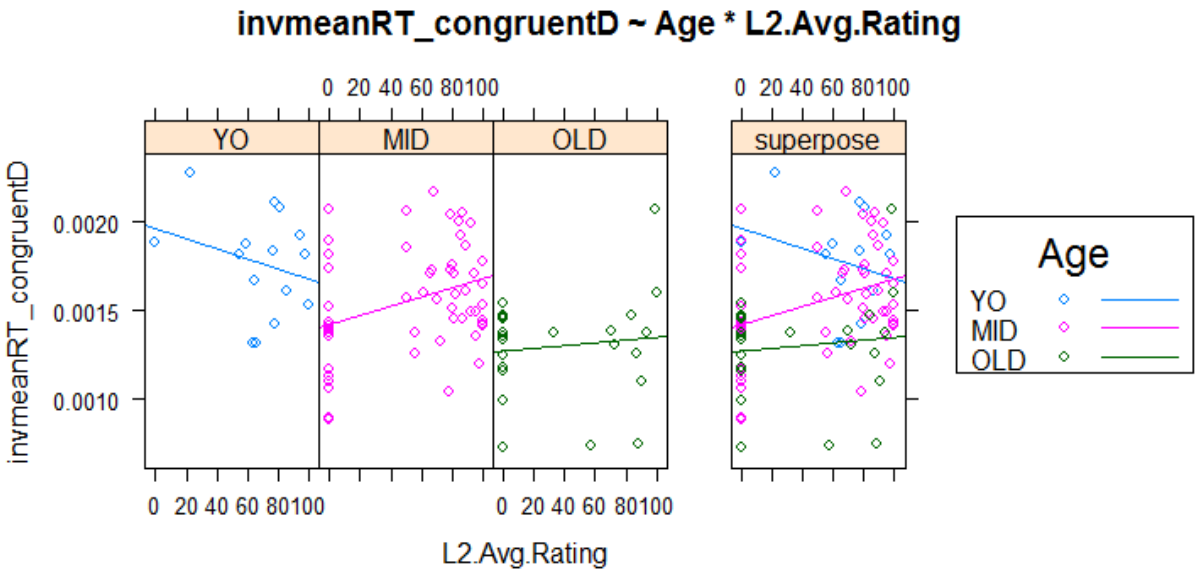
Plot 22**: Simon ANCOVA with Self-rated L2 proficiency and Simon incongruent 2sq**



In ANCOVA Model 23, the covariate L2 Average Rating was analyzed with the dependent variable of RT in the Simon Congruent Condition 4sq. This analysis revealed a main effect of age $F(2,76) = 12.98$ $p<0.0001$, and a main effect of the covariate 'L2 Average Rating' $F(2,76) = 4.16$, $p = 0.04$). Results showed that older bilinguals had significantly slower reaction times. From Plot 23, it appears that young participants had a negative slope, whereas middle age and older participants had positive slopes. This means that younger people had slower reaction times as a function of increasing L2 self-ratings. On the other hand, middle aged and older participants had faster reaction times as a function of increasing L2 self-ratings. See Table 23 in Appendix D for details.

Plot 23:

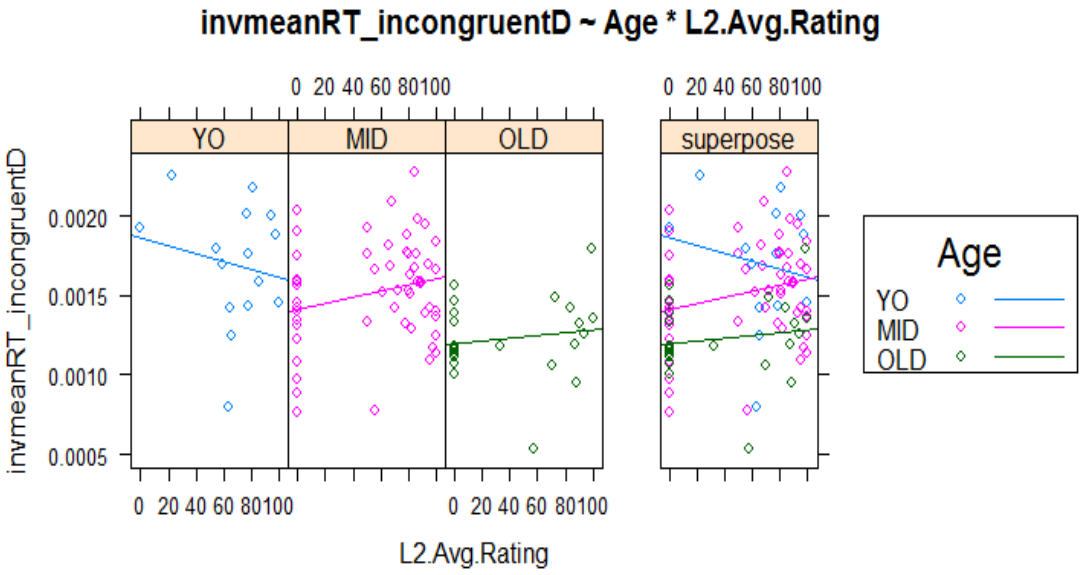
Simon ANCOVA with Self-rated L2 proficiency and Simon congruent condition 4sq



In ANCOVA Model 24, the covariate L2 Average Rating was analyzed with the dependent variable of RT in the Simon Incongruent Condition 4sq. This analysis revealed a main effect of age $F(2,76) = 12.14$ $p<0.0001$, in that older participants had significantly slower reaction times, as seen in Plot 24. See Table 24 in Appendix D for details.

Plot 24:

Simon ANCOVA with Self-rated L2 proficiency and Simon incongruent condition 4sq

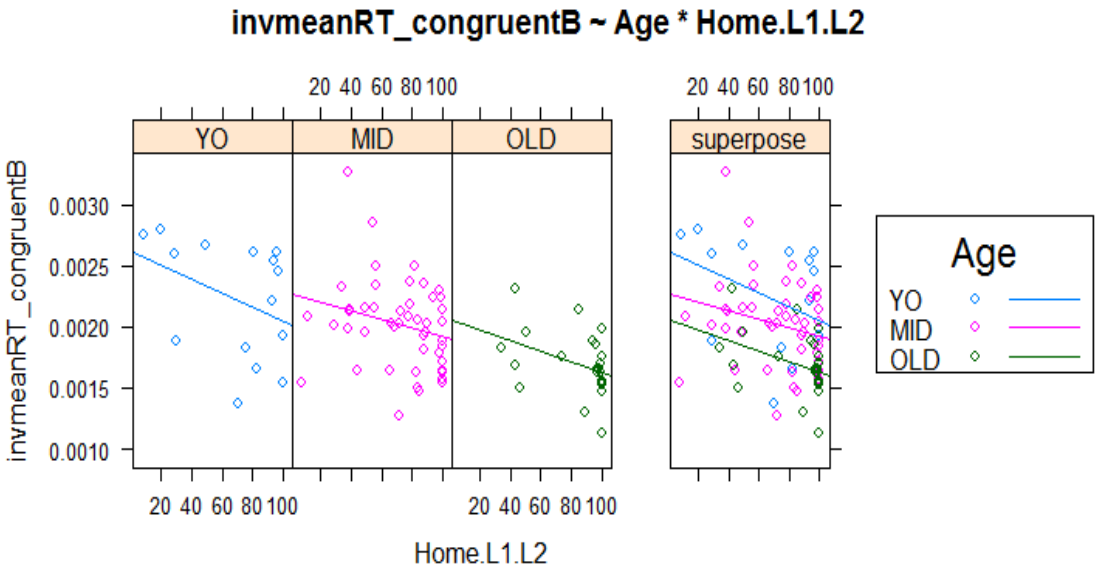


ANCOVA 7: Covariate: Daily L1- L2 home use

In ANCOVA Model 25, the covariate Home L1- L2 Use, a measure of self-rated use of L1-L2 in the home environment, was analyzed with the dependent variable of RT in the Simon Congruent Condition 2sq. This analysis revealed a main effect of age $F(2,76) = 11.85$, $p<0.0001$, and a main effect of the covariate Home L1- L2 Use $F(2,76) = 8.22$, $p=0.0053$. The results showed that older bilinguals had significantly slower reaction times as compared to younger adults. In addition, the main effect of Home L1-L2 Use was such that the bilinguals reacted faster as a function of more frequent L2 vs. L1 use in the home. This was also confirmed in Plot 25 as line slopes were negative. There was no significant interaction between Home L1-L2 Use

and age, thus it was concluded that slopes were not significantly different across different age groups. See Table 25 in Appendix D for details.

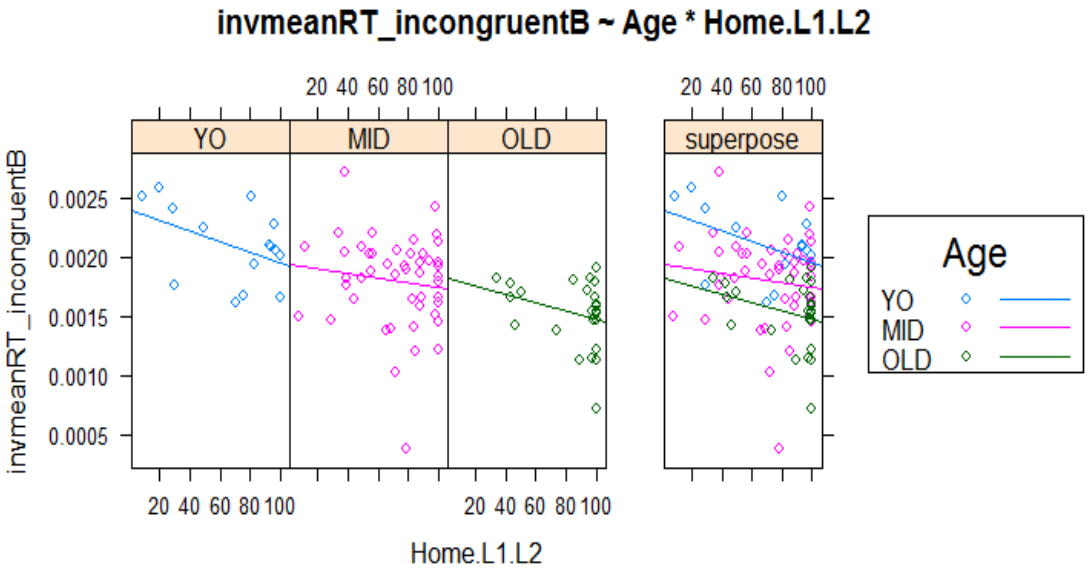
Plot 25: **Simon ANCOVA with Daily L1-L2 home use and Simon congruent condition 2sq**



In ANCOVA Model 26, the covariate Home L1- L2 Use was analyzed with the dependent variable of RT in the Simon Incongruent Condition 2sq. This analysis revealed a main effect of age $F(2,76) = 12.59$, $p < 0.0001$, and a main effect of the covariate 'Home L1- L2 Use' $F(2,76) = 4.01$, $p = 0.049$. The results were comparable to the prior analysis. Older bilinguals had significantly slower reaction times. In addition, the significant main effect of 'Home L1-L2 Use' was such that as a bilingual used theirL2 more in the home, this lead to faster RTs. There was no significant interaction between Home L1-L2 Use and Age, as demonstrated in Plot 26, therefore it was concluded that slopes were not significantly different across different Age groups. See Table 26 in Appendix D for details.

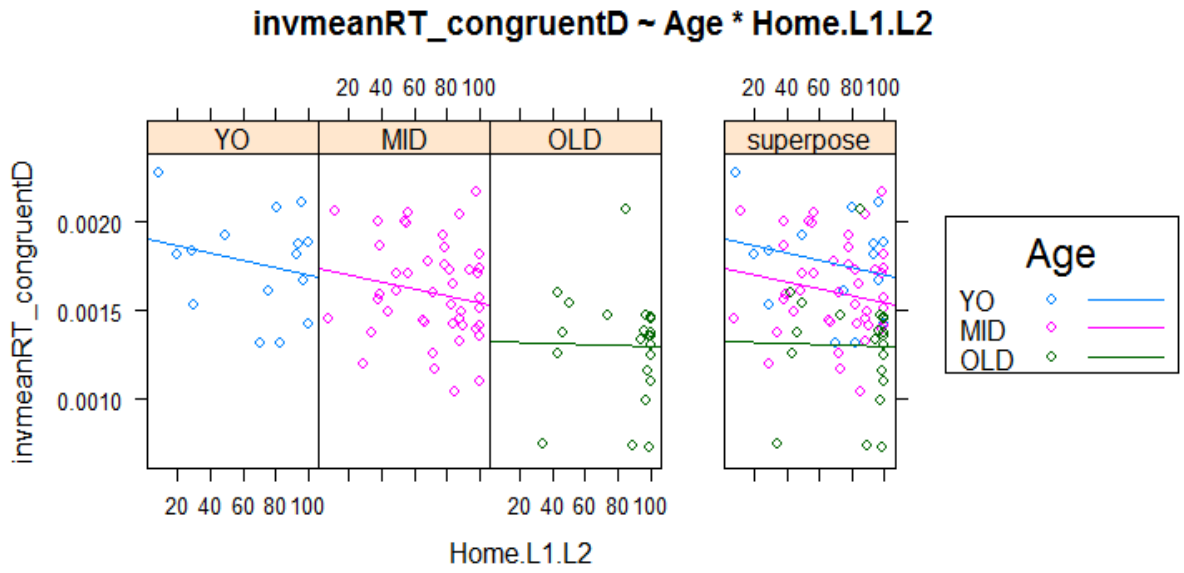
Plot 26:

Simon ANCOVA with Daily L1-L2 home use and Simon incongruent condition 2sq



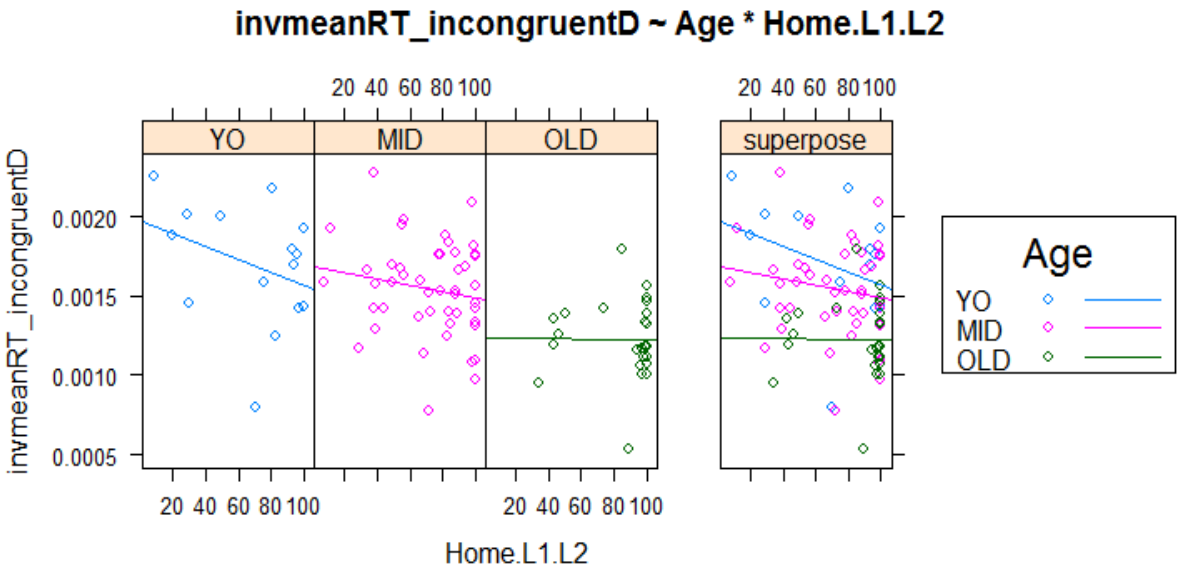
In ANCOVA Model 27, the covariate Home L1- L2 Use was analyzed with the dependent variable RT Simon Congruent 4sq. This analysis revealed a main effect of age $F(2,76) = 14.37$, $p<0.0001$, which showed that older bilinguals have significantly slower reaction times, as demonstrated in Plot 27. See Table 27 in Appendix D for details.

Plot 27: **Simon ANCOVA with Daily L1-L2 home use and Simon congruent condition 4sq**



In ANCOVA Model 28, the covariate Home L1- L2 Use was analyzed with the dependent variable RT Simon Incongruent 4sq. This analysis revealed a main effect of age $F(2,76) = 13.28$, $p < 0.0001$) which showed that older bilinguals have significantly slower reaction times. The main effect of Home L1-L2 Use showed a trend, $F(2,76) = 2.79$, $p = 0.099$. The result showed that older bilinguals had significantly slower reaction times. In addition, there was a near-significant main effect of Home L1-L2 Use, suggesting that a bilingual will tend to react faster if he/she uses L2 relatively more often. This was also confirmed in Plot 28 as slopes of lines were negative. As there was no significant interaction between Home L1-L2 Use and Age, it was concluded that slopes were not significantly different across different Age groups. See Table 28 in Appendix D for details.

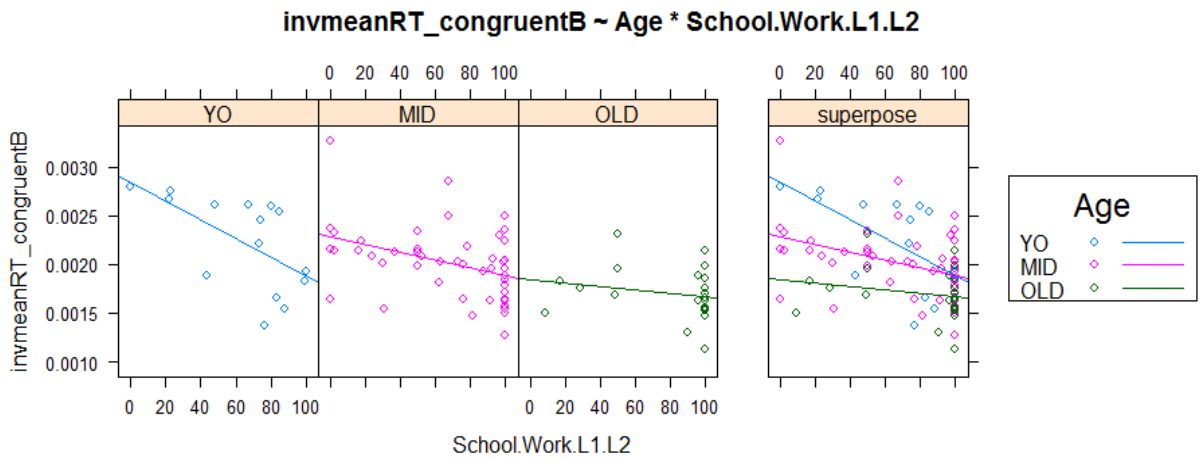
Plot 28: **Simon ANCOVA with Daily L1-L2 home use and Simon incongruent condition 4sq**



ANCOVA 8: Covariate: L1-L2 School/Work L1- L2 use

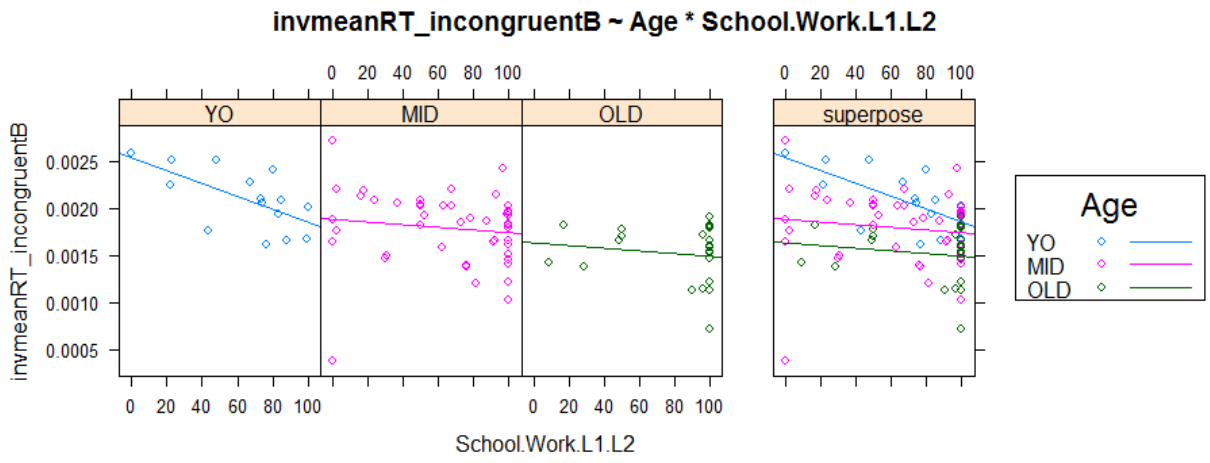
In ANCOVA Model 29, the covariate School/Work L1- L2 Use, which was a measure of self-rated use of L1-L2 in the school/work environment, was analyzed with the dependent variable RT Simon Congruent Condition 2sq. This analysis revealed a main effect of age $F(2,76) = 13.4$, $p < 0.0001$, and a main effect of the covariate School/Work L1- L2 Use $F(2,76) = 15.70$ $p = 0.0001$. Results showed that older bilinguals have significantly slower reaction times. In addition, the School/WorkL1-L2 Use effect is also significant with a negative estimation. This means that reaction time decreases when a bilingual has a smaller value of School/WorkL1-L2. That is, one will react faster if he/she reports using the L2 relatively more often at school. This can also be confirmed in Plot 29 as slopes of lines are negative. See Table 29 in Appendix D for details.

Plot 29: **Simon ANCOVA with L1-L2 school/work use and Simon congruent condition 2sq**



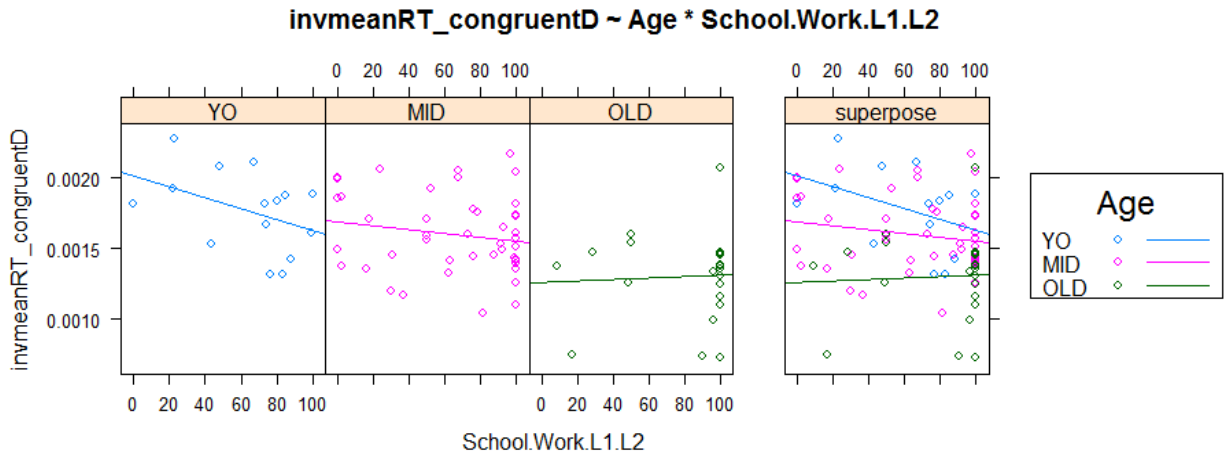
In ANCOVA Model 30, the covariate School/Work L1- L2 Use was analyzed with the dependent variable RT Simon Incongruent Condition 2sq. This analysis revealed a main effect of age $F(2,76) = 12.86$; $p < 0.0001$, and a trend toward significance of the covariate School/Work L1- L2 Use $F(2,76) = 3.57$; $p = 0.062$. Results for this analysis revealed that when school/work L2 use is controlled for, older bilinguals had significantly slower reaction times in this condition. Had the School/Work L2 use effect also reached significance, it would have suggested that a bilingual would react faster as a function of using the L2 relatively more often at school. This can also be confirmed in Plot 30 as slopes of lines were negative. See Table 30 in Appendix D for details.

Plot 30: **Simon ANCOVA with L1-L2 school/work use and Simon incongruent condition 2sq**



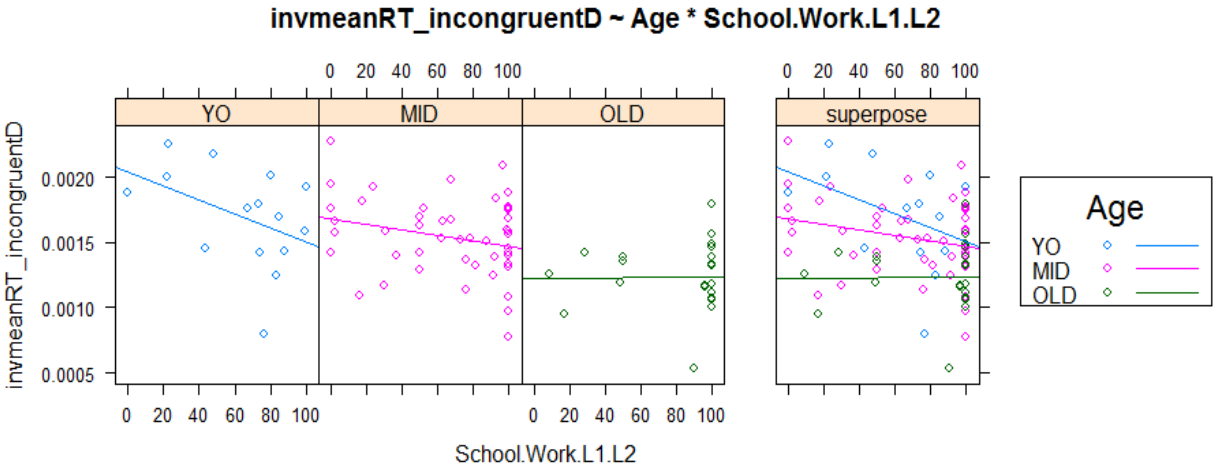
In ANCOVA Model 31, the covariate School/Work L1- L2 Use was analyzed with the dependent variable RT Simon Congruent 4sq condition. This analysis revealed a main effect of age $F(2,76) = 14.68$ $p < 0.0001$, Results for this analysis revealed that older bilinguals had significantly slower reaction times, as demonstrated in Plot 30. See Table 31in Appendix D for details.

Plot 31: **Simon ANCOVA with L1-L2 school/work use and Simon congruent condition 4sq**



In ANCOVA Model 32, the covariate School/Work L1- L2 Use was analyzed with the dependent variable RT Simon Incongruent 4sq condition. This analysis revealed a main effect of age $F(2,76) = 13.80$ $p < 0.0001$, and a significant main effect of the covariate School/Work L1- L2 Use $F(1,77) = 4.52$, $p = 0.04$. Results showed that older bilinguals have significantly slower reaction time. In addition, the 'School/WorkL1-L2 Use' effect is also significant with a negative estimation. This means that reaction time decreases when a bilingual has a smaller value of School/WorkL1-L2. That is, the bilingual will react faster if he/she reports using the L2 relatively more often at school. This can also be confirmed in Plot 32 as slopes of lines are negative. See Table 32 in Appendix D for details.

Plot 32: **Simon ANCOVA with L1-L2 school/work use and Simon incongruent condition 4sq**



Summary of Simon ANOVA and ANCOVA Analyses:

As the earlier ANOVA results did not allow for unequivocal support of the BCA, it was decided to heed calls in the literature and investigate how variables associated with bilingualism influence the manifestation of the BCA. To this end, a series of ANCOVA analyses was carried out on the data from the bilinguals in order to take into account bilingualism-related variables which have been implicated in discussions of the bilingual cognitive advantage.

When the ANCOVA analyses were performed with the different covariates which were chosen as relevant indices of bilingualism, a different and more nuanced picture emerged. First, in nearly all conditions a main effect of age remained when the effects of the covariates were controlled for. Strikingly, when analyzing the dependent variable of Simon effect size with the covariate of Duration of active L2 use controlled for, there was no main effect of age upon the Simon effect. There was however a significant main effect of the covariate itself upon the Simon effect, and no interaction between the covariate and the variable of age. Plots of the main effect of the covariate revealed that as duration of active L2 use increased, the Simon effect decreased

accordingly. This finding was consistent across all age groups. This set of results was interpreted as evidence of a bilingual inhibitory control advantage.

Some additional findings were also noteworthy. For instance, when analyzing the dependent variable of mean RT for the two color Simon effect in the ANCOVA using the covariate Self-rated average L2 proficiency, the main effect of language just missed significance. In addition, for the ANCOVA in the two color Simon effect condition there was a significant interaction between age and the covariate L1-L2 home use, which appeared to be different depending on the age group. For the older bilinguals, as the L1-L2 Home use increased, the Simon effect decreased; this did not appear for the younger group. These results clearly demonstrate that different bilingualism-related variables can differently impact cognitive performance for the same condition, and also that there also appears to be a different impact when age is taken into consideration. Based on these results, there is evidence to be found among the bilinguals to support the BCA when bilingualism-related variables are carefully considered. Furthermore, age matters, as a main effect of age was consistently and repeatedly observed in the form of faster performance on almost all conditions and with younger adults performing faster than older adults. Additional research is needed to further investigate the impact of the various factors related to bilingualism on cognitive performance. The present results indicate that bilingualism, and in particular the time which someone has been actively bilingual, does indeed matter, and that this variable needs to be carefully considered in studies exploring the BCA.

Stroop Task ANCOVA analysis:

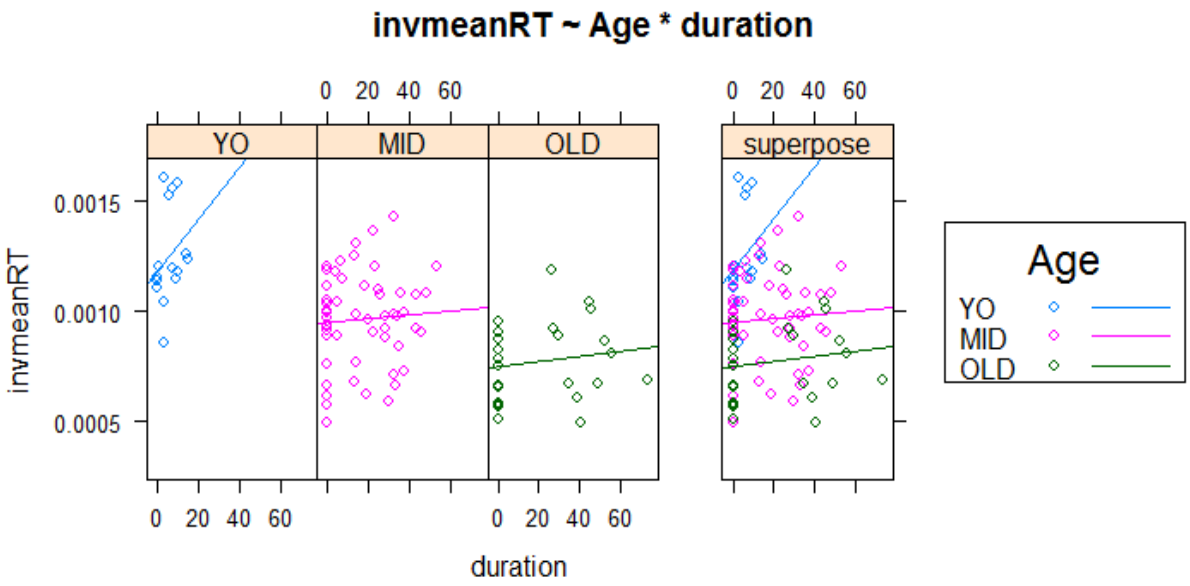
As per the Simon Task analyses, after performing the ANOVAs for the Stroop Task, a series of ANCOVAs was performed in order to analyze the performance impact of bilingualism as a continuous variable. As in the Simon Task, the continuous variable of interest, bilingualism, was

operationalized through the covariates indexing bilingualism (Duration of Active L2 Use, Self Rated Average L2 proficiency, L1-L2 use in the home; L1-L2 use at school/work). The following are the results from the multiple Age X Language ANCOVA models for the Stroop dependent variables of interest (these again were Mean RT, Mean RT Congruent, Mean RT Incongruent, Mean RT control, RT Interference Effect, RT Simon Effect). As for the ANOVA analyses, the RTs for the dependent variables were inversely transformed. The multiple models which analyzed the covariate of 'Duration of Active L2 Use' will be presented here. The first ANCOVA, which explored Duration of Active L2 use as a covariate with Mean RTs., follows below.

ANCOVA 1: Covariate: Duration of Active L2 use

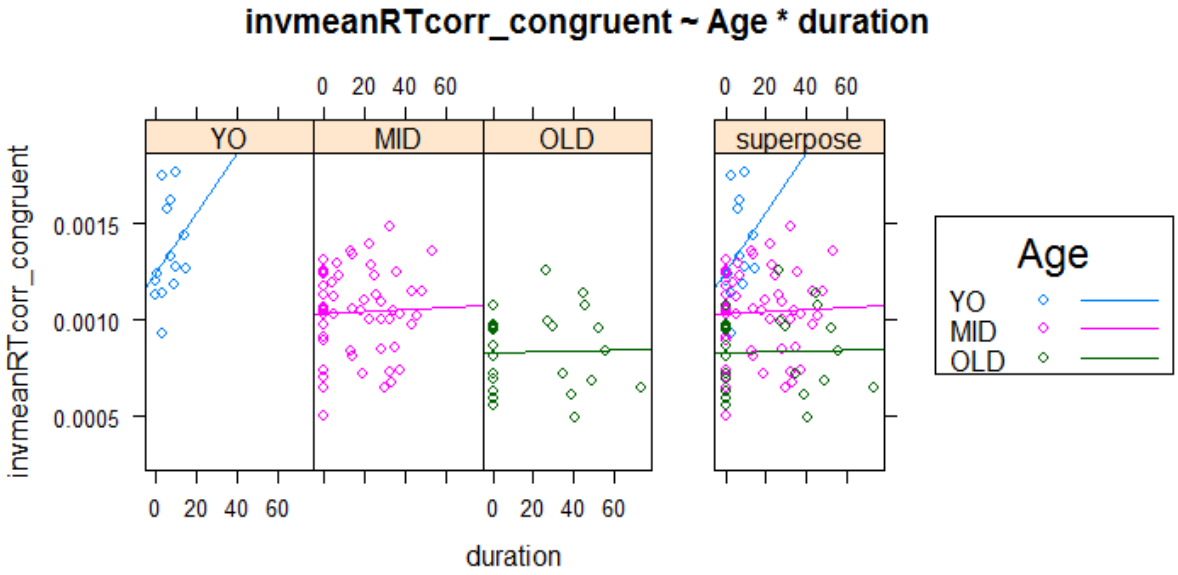
In ANCOVA Model 1, the Mean RT was explored with the covariate of Duration of Active L2 use. For the Mean RT condition there was a significant main effect of Age $F(2,76) = 25.15$, $p < 0.0001$. Results showed that older bilinguals had significantly slower reaction times. The duration effect did not reach significance, but there was still a positive value estimation indicating reaction time decreases when someone has a longer length of time knowing another language. Where this result was charted in Plot 33 the slopes of lines were positive. The Age x Duration interaction was not significant. See Table 1 in Appendix E for details.

Plot 33: **Stroop ANCOVA with Duration active L2 use and mean RT**



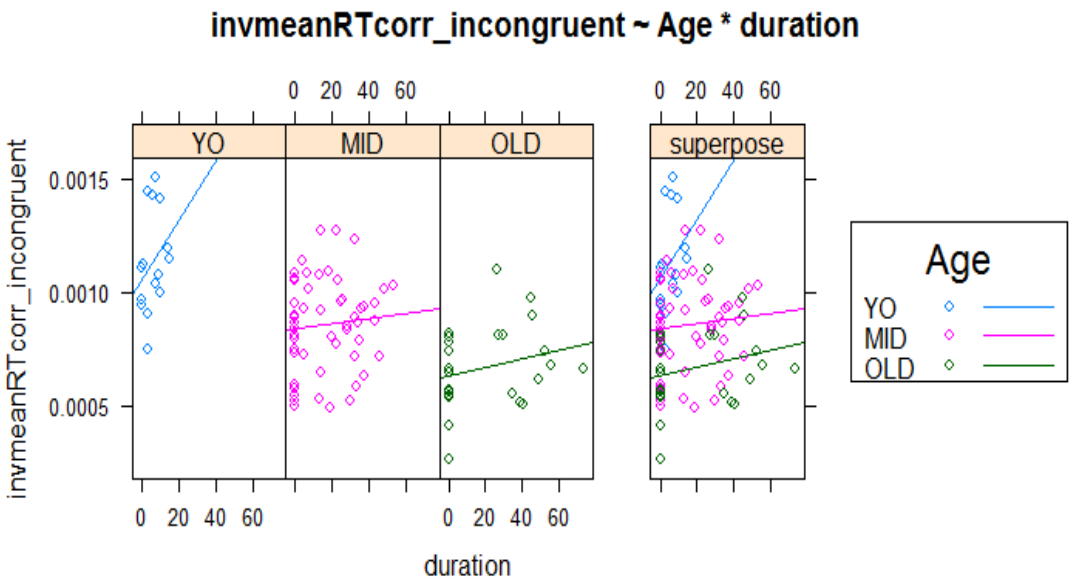
In ANCOVA Model 2, the dependent variable of Mean RT Congruent items was explored with the covariate of 'Duration of Active L2 use'. For the Mean RT Congruent condition there was also a significant main effect of Age, $F(2,76) = 24.15$, $p < 0.0001$. Older bilinguals again had slower RTs than younger ones, as demonstrated in Plot 34. See Table 2 in Appendix E for details.

Plot 34: **Stroop ANCOVA with Duration active L2 use and congruent mean RT**



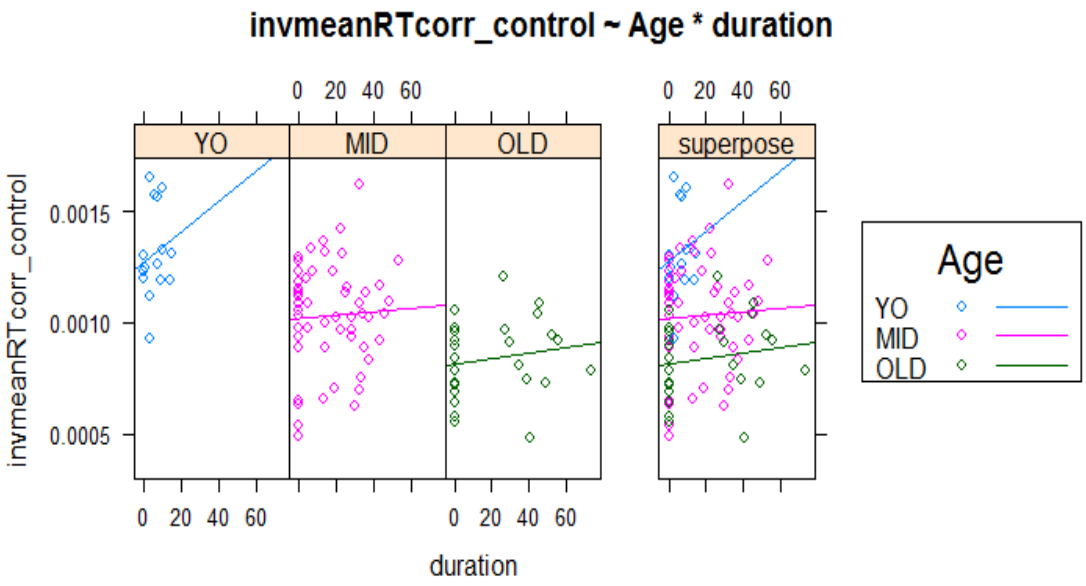
In ANCOVA Model 3, the dependent variable of Mean RT in the Incongruent items was explored with the covariate of Duration of Active L2 use. For the Mean RT in the Incongruent condition there was also a significant main effect of Age $F(2,76) = 24.92$, $p < 0.0001$. Results again revealed that older bilinguals had slower RTs as demonstrated in Plot 35. See Table 3 in Appendix E for details.

Plot 35: **Stroop ANCOVA with Duration active L2 use and incongruent mean RT**



In ANCOVA Model 4, the dependent variable of Mean RT Control items was explored with the covariate of 'Duration of Active L2 use'. For the Mean RT Congruent condition there was also a significant main effect of Age F (2,76) =22.02, $p < 0.0001$. Results for this condition also revealed that older bilinguals had slower RTs as compared to younger ones, as demonstrated in Plot 36. See Table 4 in Appendix E for results.

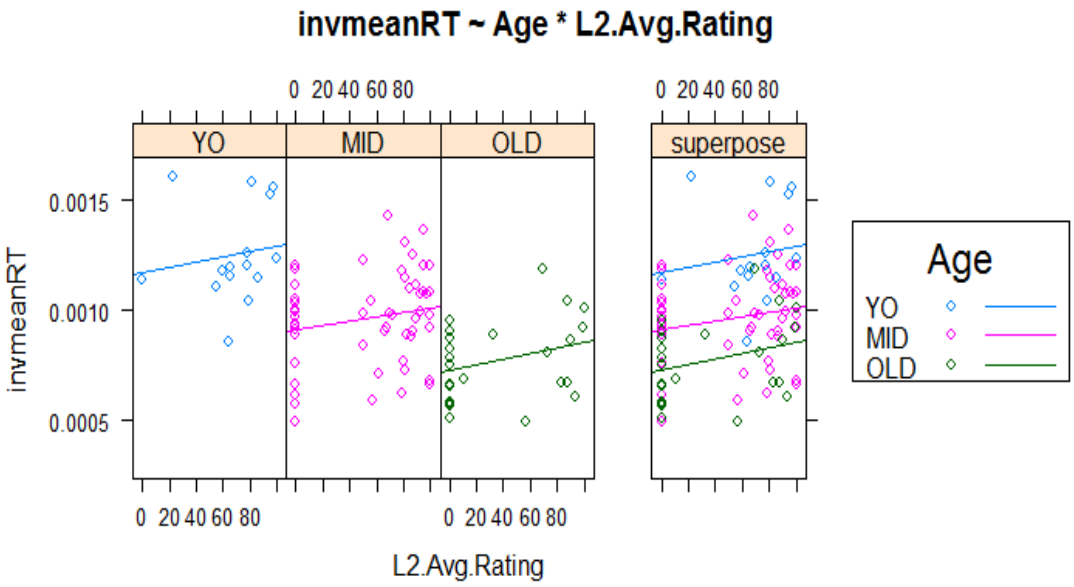
Plot 36: **Stroop ANCOVA with Duration active L2 use and mean RT control**



ANCOVA 2: Covariate: Self-rated average L2 proficiency

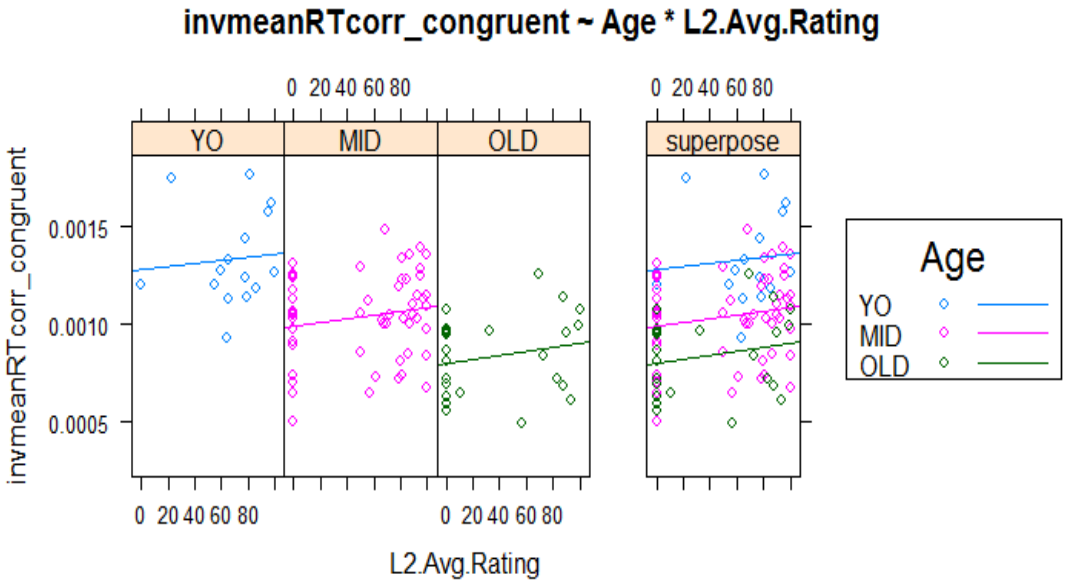
In ANCOVA Model 5, the covariate L2 Average Rating was analyzed with the dependent variable of mean RT. There was a significant main effect of age F (2,76) = 8.04, p = 0.0006, and of L2 Average Rating F (1,77) = 4.18, p = 0.04. These results revealed that older bilinguals have significantly slower reaction times. In addition, the L2 Average Rating effect was significant with a positive value estimation indicating reaction time decreases as L2 proficiency rating increases. Where this was charted in Plot 37, the slopes of lines were positive. The Age X L2 Average Rating interaction was not significant. See Table 5 in Appendix E for results.

Plot 37: **Stroop ANCOVA with Self-rated L2 proficiency and mean RT control**



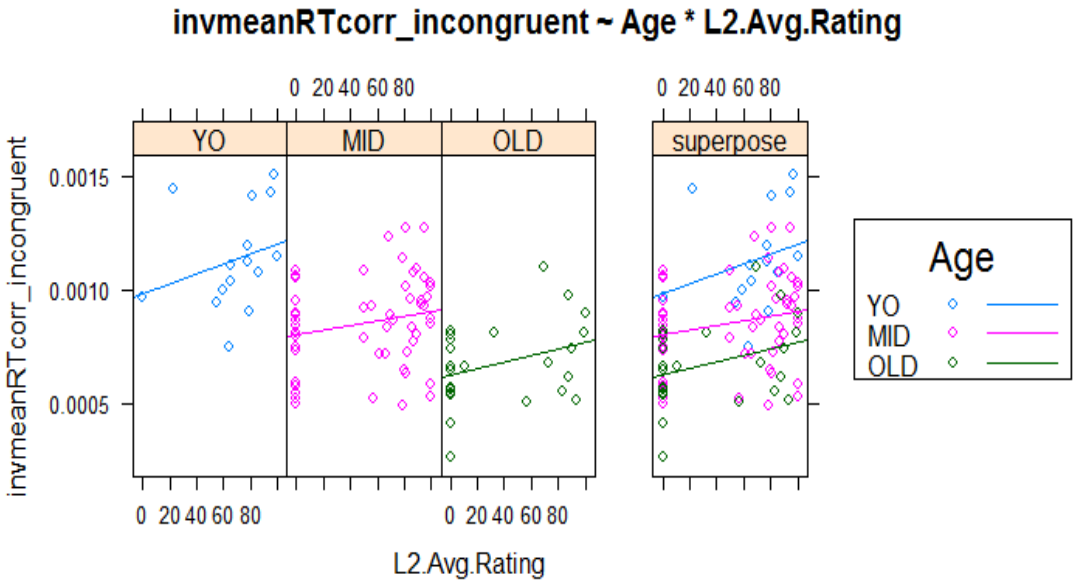
In ANCOVA Model 6, the covariate L2 Average Rating was analyzed with the dependent variable of Mean RT Congruent Items. There was a significant main effect of Age F (2,76) =25.84, p <0.0001). The L2 Average Rating F (1,77) = 2.71, p = 0.10 just missed significance. These results revealed that older bilinguals have significantly slower reaction times, as demonstrated in Plot 38. See Table 6 in Appendix E for details.

Plot 38: **Stroop ANCOVA with Self-rated L2 proficiency and mean RT congruent**



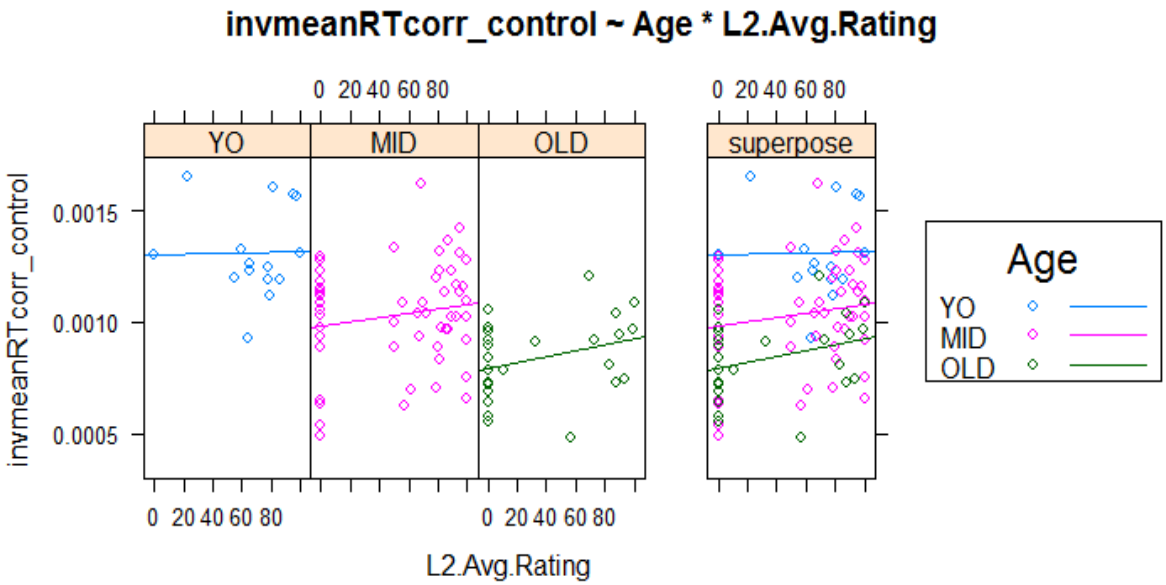
In ANCOVA Model 7, the covariate L2 Average Rating was analyzed with the dependent variable of mean RT for the Incongruent Items. There was a significant main effect of Age $F(2,76) = 25.82$, $p < 0.0001$, which revealed that older bilinguals had significantly slower reaction times. There was also a significant main effect of L2 Average Rating $F(1,77) = 5.96$, $p = 0.02$. Where this result was charted in Plot 39, the slopes of lines were positive, indicating that reaction time decreased as L2 proficiency rating increased. The Age X L2 Average Rating interaction was not significant, so these results were not significantly different across different Age groups. See Table 7 in Appendix E for results.

Plot 39: **Stroop ANCOVA with Self-rated L2 proficiency and mean RT incongruent**



In ANCOVA Model 8, the covariate L2 Average Rating was analyzed with the dependent variable of mean RT Control items. There was a significant main effect of Age F (2,76) =22.62 p < 0.0001, which revealed that older bilinguals had significantly slower reaction times than younger ones. The main effect of L2 Average Rating just missed significance, F (1,77) = 3.12, p = 0.08, indicating that reaction times tended to decrease as L2 proficiency self-ratings increased. Where this result was charted in Plot 40, the slopes of lines were positive. The Age X L2 Average Rating interaction was not significant. See Table 8 in Appendix E for results.

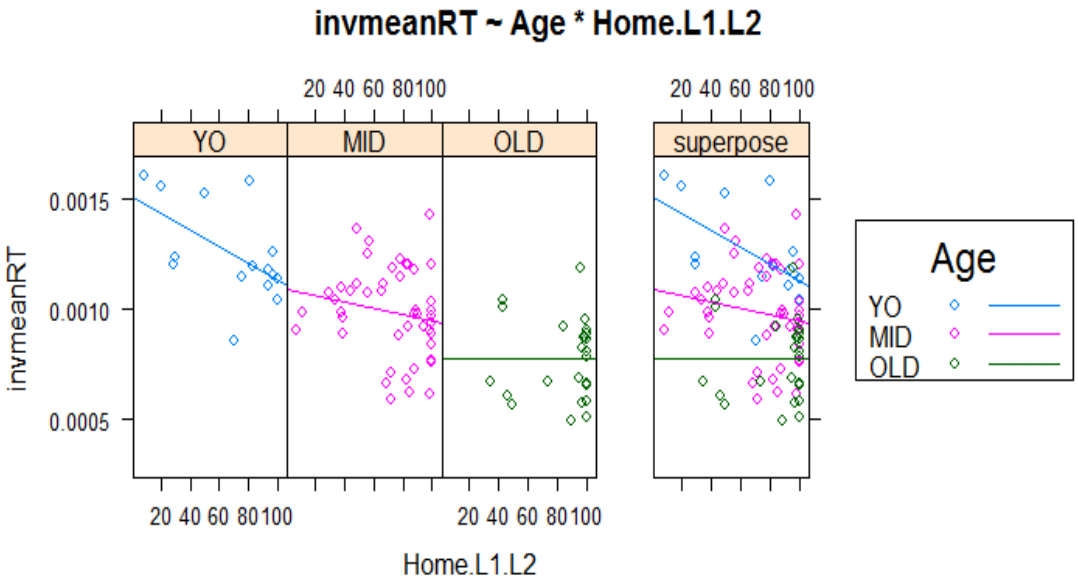
Plot 40: **Stroop ANCOVA with Self-rated L2 proficiency and mean RT control**



ANCOVA 3: Covariate: Daily L1- L2 home use

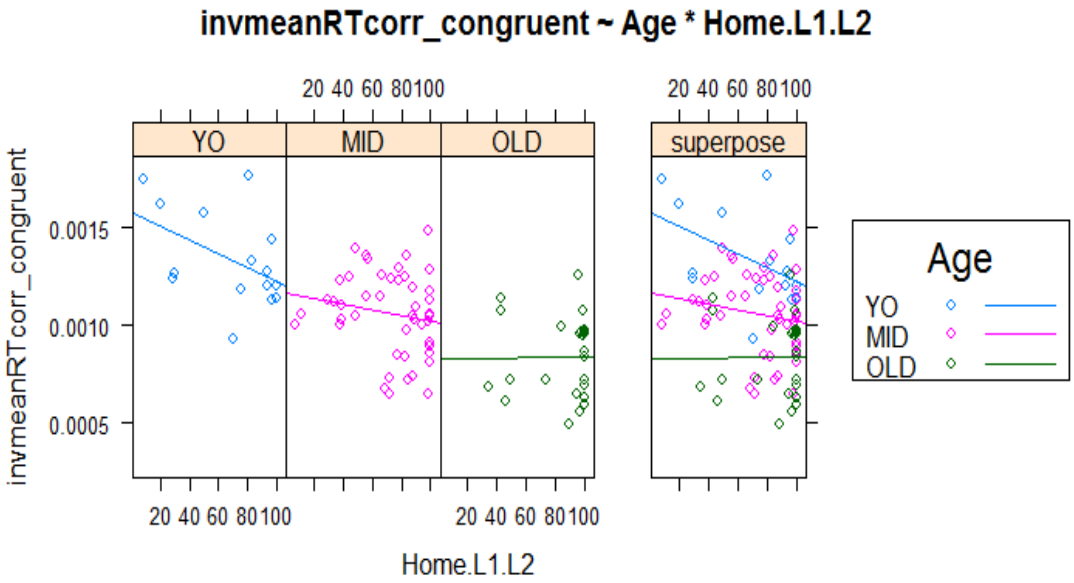
In ANCOVA Model 9, the covariate L1-L2 Home use with the dependent variable Mean RT revealed a significant main effect of Age F (2,76) = 27.89, $p < 0.0001$, and a significant main effect of L1-L2 Home use F (1,77) = 4.54, p=0.04. Where this result was charted in Plot 41 the line slopes were negative, indicating that the bilinguals reacted faster with more L2 use in the home. The Age X Home L1-L2 Use interaction was not significant. See Table 9 in Appendix E for results.

Plot 41: **Stroop ANCOVA with Daily L1-L2 home use and mean RT**



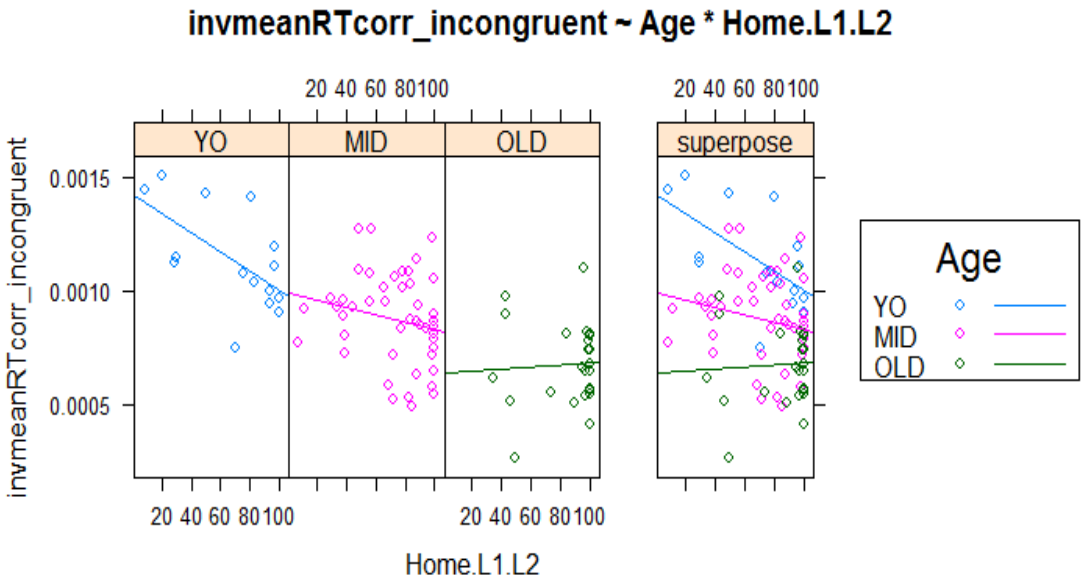
In ANCOVA Model 10, the covariate L1-L2 Home use with the dependent variable mean RT for congruent items revealed a significant main effect of age F (2,76) = 25.98, $p < 0.0001$, indicating that older bilinguals had significantly slower RTs. There main effect of L1-L2 Home use just missed significance, F (1,77) = 3.57, $p = 0.06$. Where this result was charted in Plot 42, line slopes were negative, which meant that reaction times decreased as a function of more frequent L2 use in the home environment. The Age X Home L1-L2 Use interaction was not significant. See Table 10 in Appendix E for results.

Plot 42: **Stroop ANCOVA with Daily L1-L2 home use and mean RT congruent**



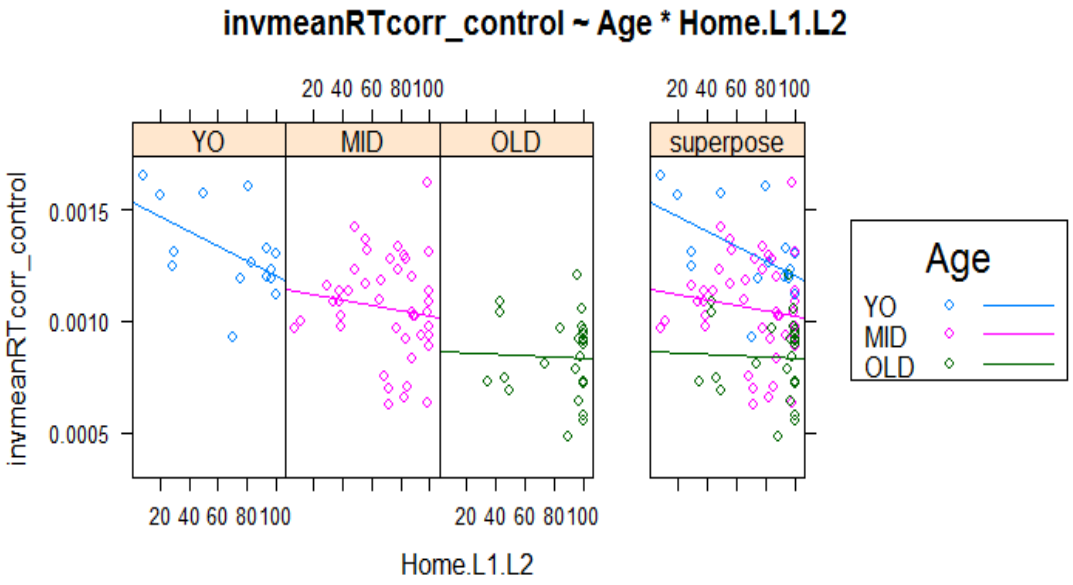
In ANCOVA Model 11, the covariate, L1-L2 Home use with the dependent variable of mean RT for incongruent items revealed a significant main effect of age F (2,76) = 26.76 , p < 0.0001, and a significant main effect of L1-L2 Home use F (1,77) = 5.23, p = 0.02. These results revealed that older bilinguals had significantly slower RTs, and that all bilinguals had faster RTs as a function of more L2 use in the home environment, as demonstrated in Plot 43. See Table 11 in Appendix E for results.

Plot 43: **Stroop ANCOVA with Daily L1-L2 home use and mean RT incongruent**



In ANCOVA Model 12, the covariate L1-L2 Home use with the dependent variable of mean RT for Control items revealed a significant main effect of age F (2,76) = 24.98, $p < 0.0001$. For the effect of L1-L2 Home use, F (1,77) = 3.19, p=0.08, there was a trend toward significance, as demonstrated in Plot 44. See Table 12 in Appendix E for results.

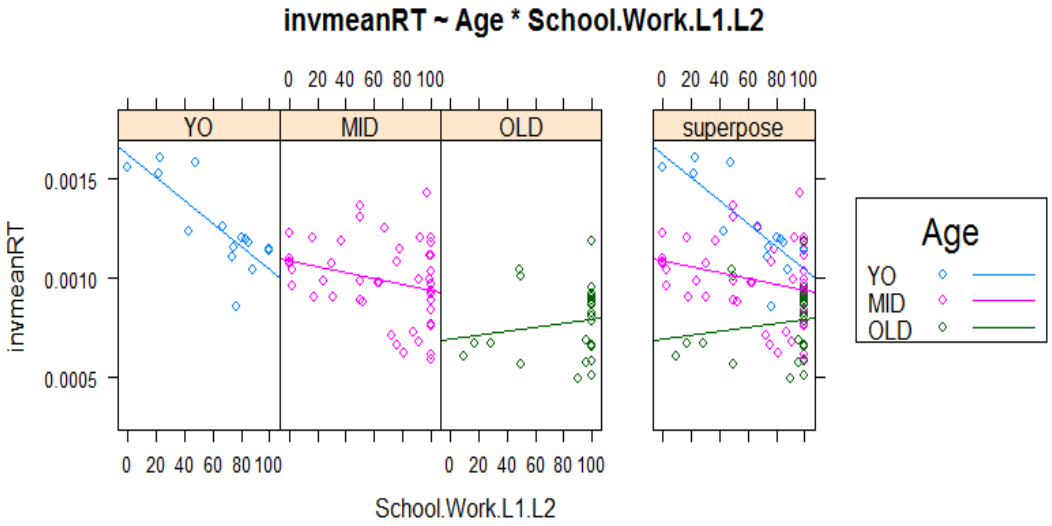
Plot 44: **Stroop ANCOVA with Daily L1-L2 home use and mean RT control**



ANCOVA 4: Covariate: L1-L2 School/Work Use

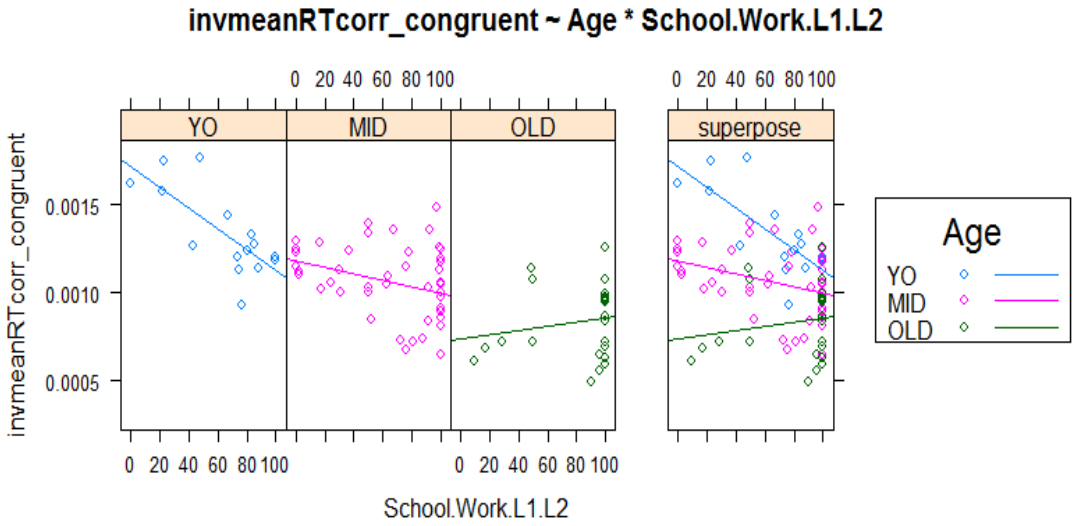
In ANCOVA Model 13, the covariate L1-L2 School/Work Use with the dependent variable of mean RT revealed a main effect of age F (2,76) = 31.19, $p < 0.0001$. There was also a significant main effect of L1-L2 School-Work Use $F(1,77) = 6.74$ $p=0.01$. Additionally, there was a significant age X School/Work Proportion L1-L2 Use interaction effect, $F(2,76) = 5.35$ $p=0.007$, as demonstrated in Plot 45. The interaction is likely due to the fact that unlike the younger and middle aged bilinguals, the older bilinguals were often not working or in school. See Table 13 in Appendix E for results.

Plot 45: **Stroop ANCOVA with L1-L2 school/work use and mean RT**



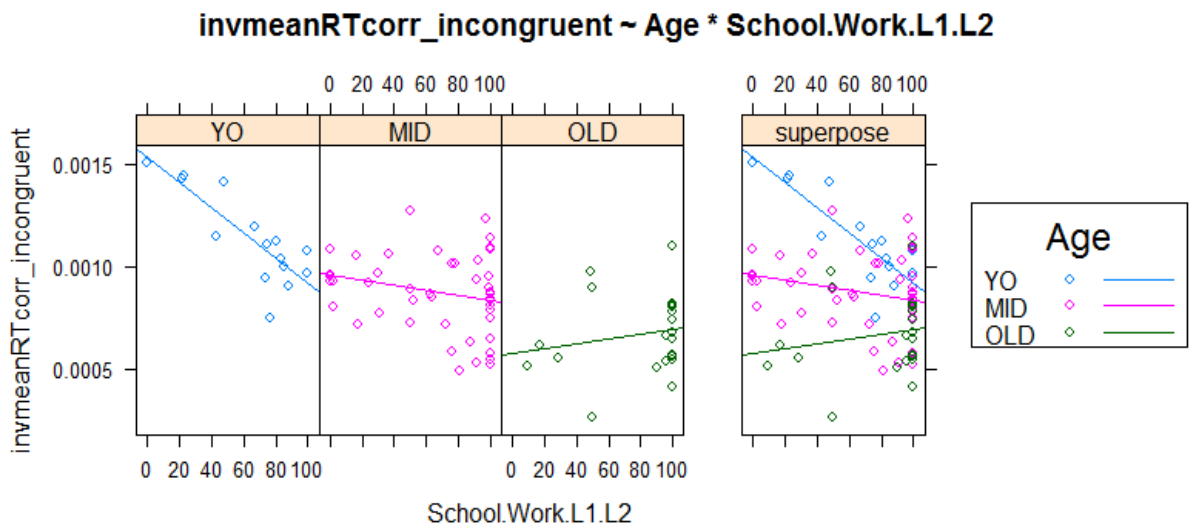
In ANCOVA Model 14, the covariate L1-L2 School/Work Use with the dependent variable of mean RT for Congruent items, there was a main effect of age F (2,76) = 29.63, p < 0.0001. There was also a significant main effect of L1-L2 School-Work Use F (1,77) = 7.01 p=0.0098. Additionally, there was a significant interaction effect for Age X School/Work Proportion L1-L2 Use, F(2,76) =5.21 p=0.007, as seen in Plot 46. As before, the interaction is likely due to the fact that unlike the younger and middle aged bilinguals, the older bilinguals were often not working or in school. See Table 14 in Appendix E for results.

Plot 46: **Stroop ANCOVA with L1-L2 school/work use and mean RT congruent**



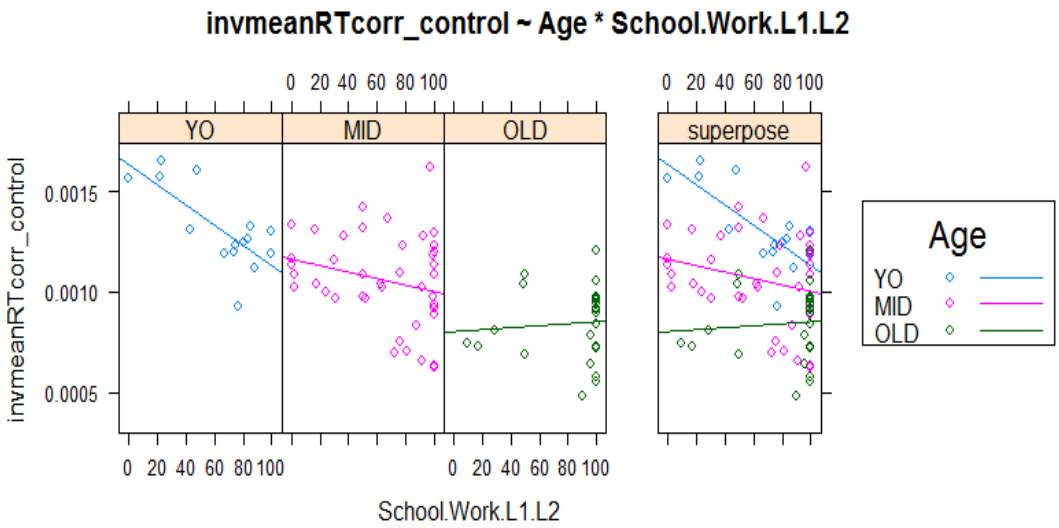
In ANCOVA Model 15, the covariate L1-L2 School/Work Use with the dependent variable of mean RT for incongruent items revealed a main effect of age $F(2,76) = 29.54$, $p < 0.0001$. There was also a significant main effect of L1-L2 School-Work Use $F(1,77) = 5.33$, $p=0.023$. Additionally, there was also a significant interaction effect of Age X School/Work Proportion L1-L2 Use $F(2,76) = 6.51$, $p=0.0024$, as seen in Plot 47. The interaction is again likely due to the fact that unlike the younger and middle aged bilinguals, the older bilinguals were often not working or in school. See Table 15 in Appendix E for results.

Plot 47: **Stroop ANCOVA with L1-L2 school/work use and mean RT incongruent**



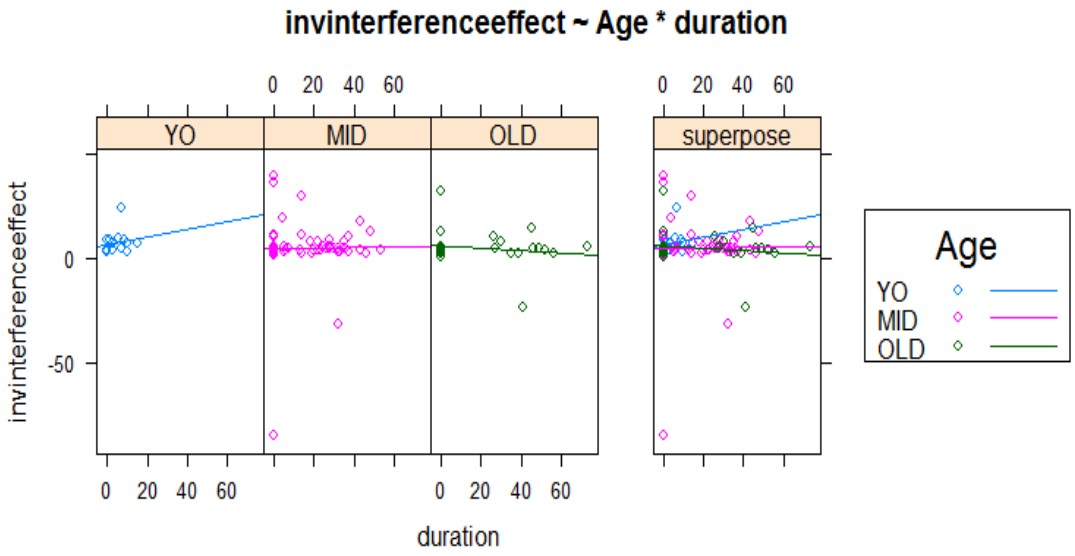
In ANCOVA Model 16 the covariate L1-L2 School/Work Use with the dependent variable of mean RT for control items revealed a main effect of age F (2,76) = 27.28, $p < 0.0001$. There was also a significant main effect of L1-L2 School-Work Use $F(1,77) = 6.29$, $p < 0.0001$. Additionally, there was a significant interaction effect of Age X School/Work Proportion L1-L2 Use F (2,76) = 3.17, p=0.048, as seen in Plot 48. The interaction is likely due to the fact that unlike the younger and middle aged bilinguals, the older bilinguals were often not working or in school. See Table 16 in Appendix E for results.

Plot 48: **Stroop ANCOVA with L1-L2 school/work use and mean RT control**



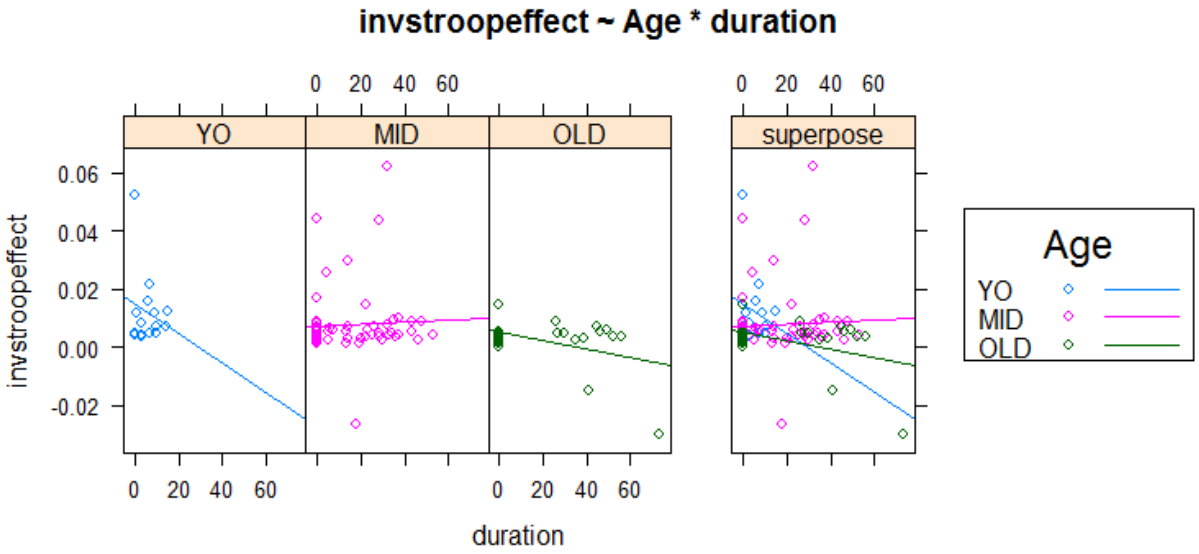
In ANCOVA Model 17, the Stroop interference effect (the difference between the incongruent and control condition) was the dependent variable explored with the covariate of Duration of Active L2 use. One outlier was removed from the dataset with 1/interference effect smaller than -100. No significant main or interaction effects were observed for this analysis, as seen in Plot 49. See Table 17 in Appendix E for results.

Plot 49: **Stroop ANCOVA with Duration active L2 use and interference effect**



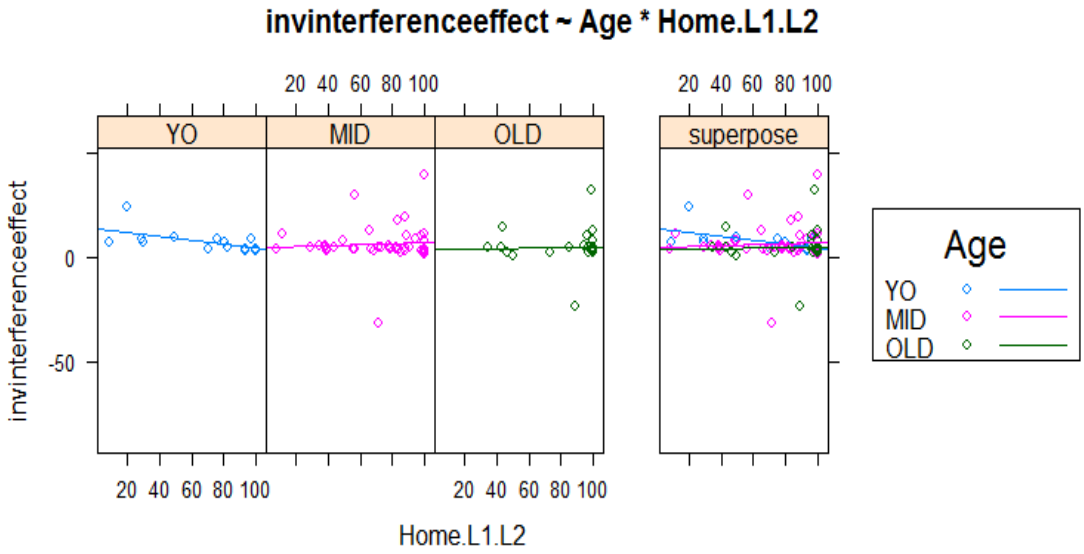
In ANCOVA Model 18 the Stroop effect (difference between incongruent and congruent RTs) was the dependent variable explored with the covariate of Duration of Active L2 use. There was a significant main effect of Age $F(2,76) = 3.66$, $p = 0.03$, which indicated that older bilinguals had a significantly larger Stroop Effect compared to younger ones. No other significant main or interaction effects were observed, as seen in Plot 50. See Table 18 in Appendix E for results.

Plot 50: **Stroop ANCOVA with Duration active L2 use and Stroop effect**



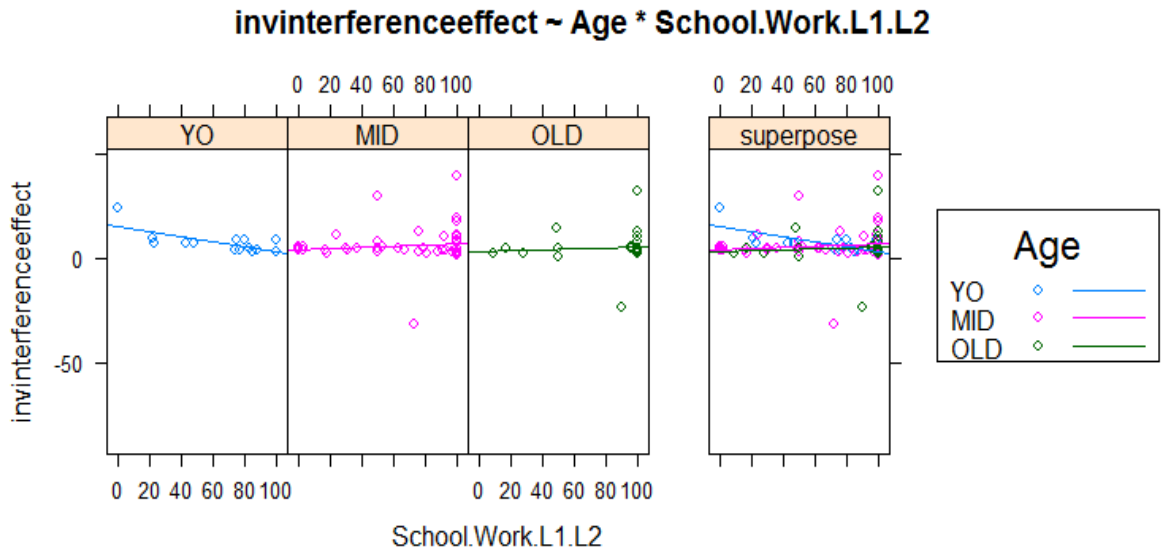
In ANCOVA Model 19, the Stroop interference effect was the dependent variable explored with the covariate of Home L1-L2 Use. One outlier was removed from the dataset with 1/interference effect smaller than -100. No significant main or interaction effects were observed for this analysis, as demonstrated in Plot 51. See Table 19 in Appendix E for details.

Plot 51: **Stroop ANCOVA with Daily L1-L2 home use and interference effect**



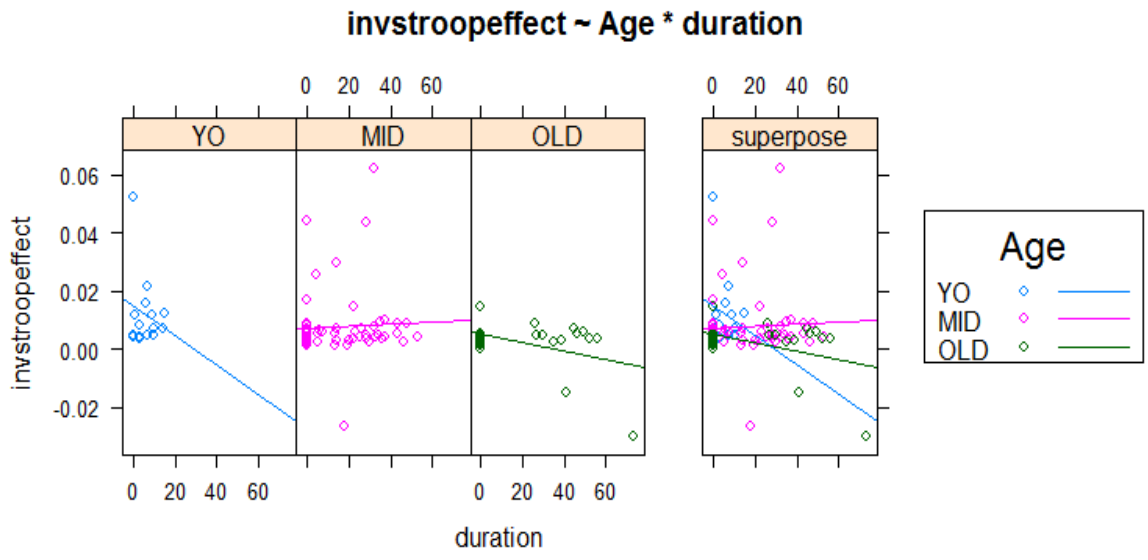
In ANCOVA Model 20, the Stroop interference effect was the dependent variable explored with the covariate of L1-L2 School/Work Use. One outlier was removed from the dataset with 1/interference effect smaller than -100. No significant main effects or interactions were observed for this analysis, as demonstrated in Plot 52. See Table 20 in Appendix E for results.

Plot 52: **Stroop ANCOVA L1-L2 School/work use and Stroop interference effect**



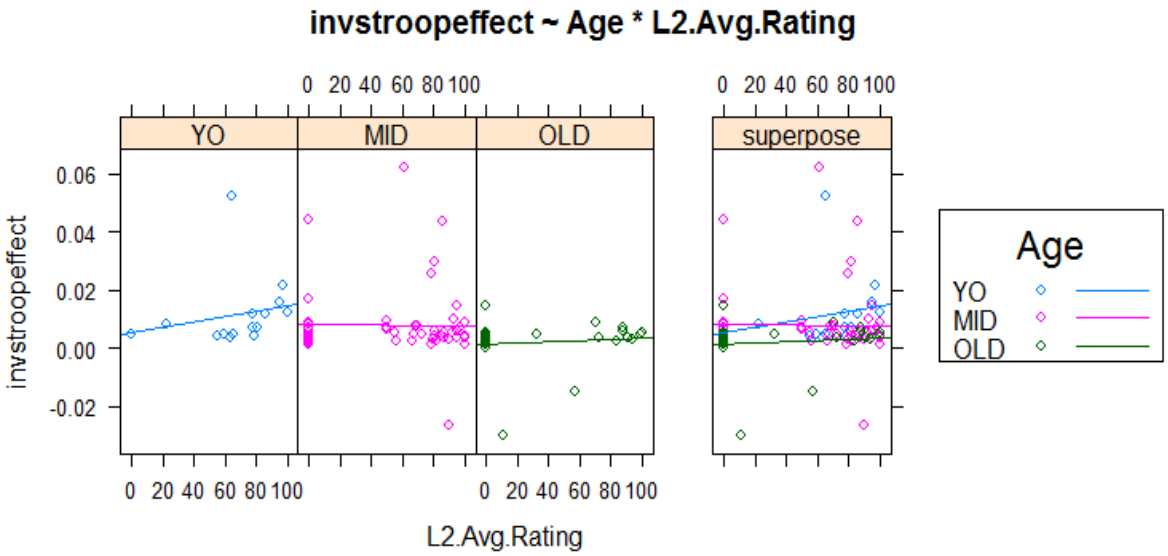
In ANCOVA Model 21, the Stroop effect was the dependent variable explored with the covariate of Duration active L2 use. There was a main effect of age $F(2,76) = 3.66$ p=0.03. No significant interaction effect was observed for this analysis, as demonstrated in Plot 53. See Table 21 in Appendix E for results.

Plot 53: **Stroop ANCOVA Duration active L2 use and Stroop effect**



In ANCOVA Model 22, the Stroop effect was the dependent variable explored with the covariate of L2 Average Rating. There was a significant main effect of Age F (2,76) =3.57, p = 0.03, which indicated that older bilinguals had a significantly larger Stroop effect compared to younger ones. Middle-aged bilinguals appeared to have smaller Stroop effects than younger bilinguals. No other significant main or interaction effects were observed, as demonstrated in Plot 54. See Table 22 Appendix E for results.

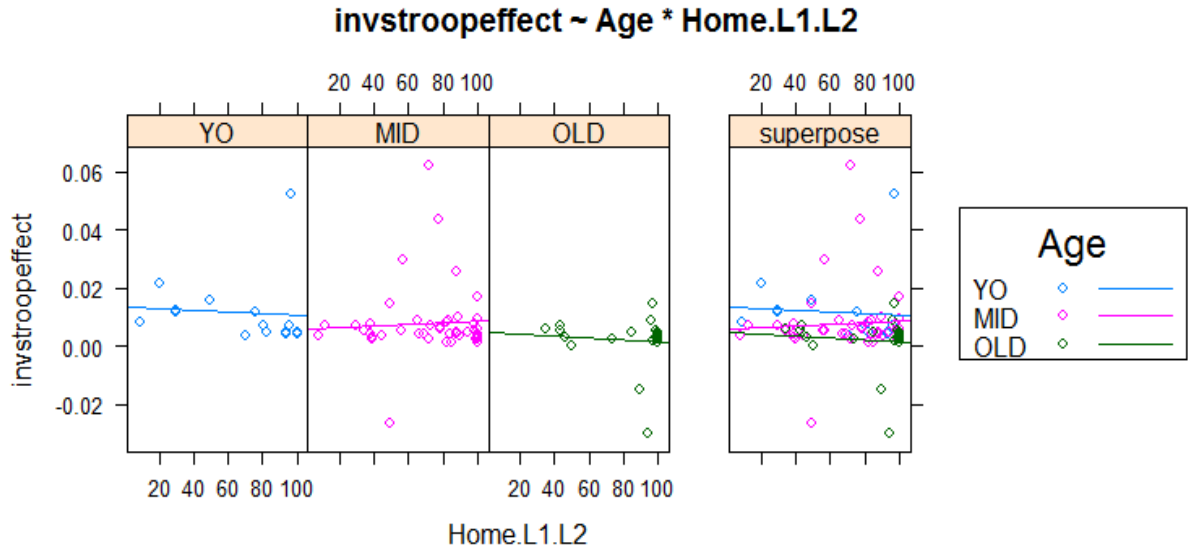
Plot 54: **Stroop ANCOVA with Self-rated average L2 proficiency and Stroop effect**



In ANCOVA Model 23, the Stroop effect was the dependent variable explored with the covariate of L1-L2 Home Use'. There was a significant main effect of age F(2,76) =3.47, p = 0.04, which indicated that older bilinguals had a significantly larger Stroop effect compared to younger bilinguals. No other significant main or interaction effects were observed for the

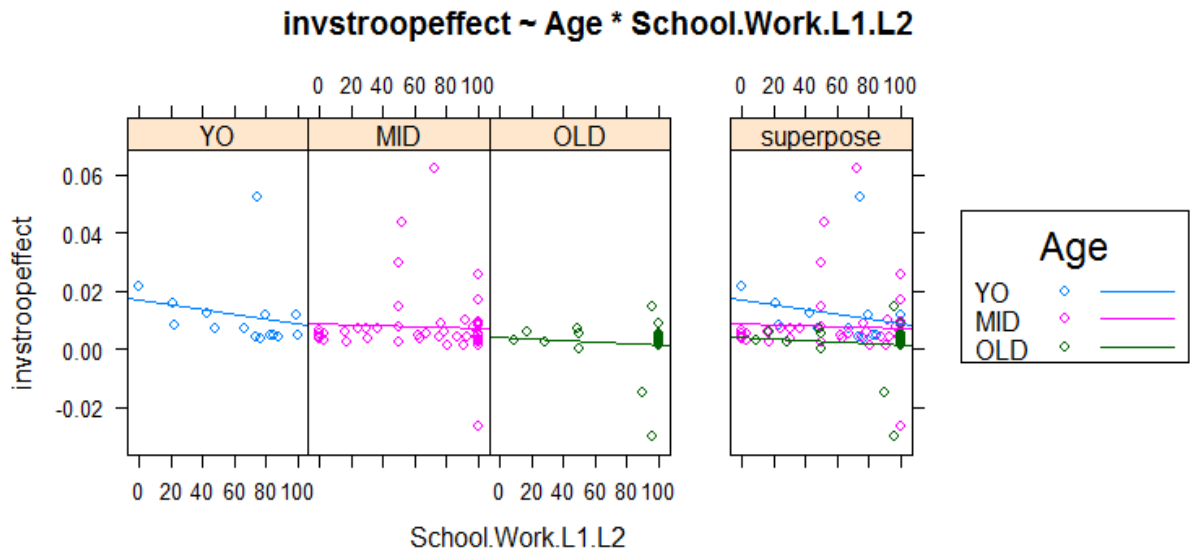
covariate, Home L1-L2 Home Use, as demonstrated in Plot 55. See Table 23 in Appendix E for results.

Plot 55: **Stroop ANCOVA with Daily L1-L2 home use and Stroop effect**



In ANCOVA Model 24, the Stroop effect was the dependent variable explored with the covariate of L1-L2 School/Work Use. There was a significant main effect of Age F (2,76) =3.49, p = 0.04 which indicated that older bilinguals had a significantly larger Stroop Effect. No other significant main or interaction effects were observed for the covariate, L1-L2 School/Work Use, as demonstrated in Plot 56. See Table 24 in Appendix E for results.

Plot 56: **Stroop ANCOVA with L1-L2 school/work use and Stroop effect**



Summary of Stroop ANCOVA Analysis:

For the Stroop ANCOVA analyses, the covariate Duration of active L2 use, revealed no significant or main effects with any of the dependent variables (overall mean RT, mean RT congruent condition, mean RT incongruent condition, mean RT control condition, mean RT interference effect, mean RT Stroop effect). For the covariate Self-rated average L2 proficiency, there was a significant main effect of age, and of self-rated average L2 proficiency for all the dependent variables, except for mean RT for the interference effect and the Stroop effect. This same result was observed for a main effect of the covariates, L1-L2 Home use, and L1-L2 School use with all the dependent variables except interference effect and Stroop effect. Therefore, it appears that the bilingualism covariates of Self-rated Average L2 use, L1-L2 Home Use, and L1-L2 School/Work use impact performance on the Stroop Task. Further exploration of

these covariates with the Stroop task would be warranted to further understand which aspects of these bilingualism covariates most impact cognitive performance and how.

For the Stroop task, the age effect was consistently revealed in most of the ANCOVA analyses and under most conditions, the same as for the Simon task analyses. In contrast, Duration of Active L2 use, did not have an effect for most Stroop conditions. It was noteworthy that the covariate Duration of Active L2 use, which had revealed a significant main effect of age and language for the Simon effect and clearly supporting a bilingual inhibitory control advantage, did not reveal any significant effects for the Stroop effect which presumably tests the same construct.

These results clearly highlight that bilingual variables are impacting cognitive performance, although from these results it is difficult to say exactly how. The fact that the same bilingual covariates did not produce comparable main effects for dependent variables in different tasks, even for measures thought to index the same construct (i.e. the Simon effect and the Stroop effect), highlights the complexity of exploring bilingualism and executive function. More research is needed to systematically explore each of these variables with the same tasks indexing executive function.

Chapter 5: Discussion and Conclusions

The goal of this study was to explore the BCA for inhibitory control by grounding it in the work of other researchers in the field, and more importantly to make a significant contribution by exploring bilingualism as a non-categorical variable. Bilingualism variables were systematically analyzed, and significant and impactful results were revealed. The following hypotheses were explored:

1. Younger participants will perform better than older participants. They will have faster processing and less interference when performing executive function tasks.
2. Older bilinguals will perform better on executive function tasks than older monolinguals.
3. Older and younger bilinguals with high levels of proficiency and consistent use of their two languages will perform better than their monolingual counterparts.
4. Bilingual language experience and language use profile will impact performance on executive function tasks.

Results from the analyses will be summarized. For the Simon Task ANOVA analyses, no statistically significant Simon Effect differences were found for the three age groups and two language groups in either the 2sq or 4sq conditions. There was no significant interaction effect between age and language for all four ANOVAs, which can be interpreted to indicate that the reaction time differences between bilingual and monolingual language groups were quite consistent across the different age groups. The only statistically significant difference was that older participants had significantly slower RTs in the control conditions, Center 2sq and Center 4sq compared to younger participants, which is in line with normal age-related declines in cognitive processing efficiency.

The results from the Stroop Task ANOVA analyses were comparable to the Simon analyses. When looking at mean raw RTs for Stroop conditions, bilinguals overall had smaller mean RTs compared to monolinguals in their age group. When the ANOVA was performed, however, there was no significant interaction effect between age and language. The interaction plots also confirmed this finding. The results can be interpreted to mean that the reaction time differences between bilingual and monolingual language groups were consistent across different age groups. As has previously been reported, older participants had significantly slower reaction times compared to younger participants. For the ANOVA analyses, no significant reaction time differences between monolingual and bilingual participants were observed. In addition, with the Stroop interference effect and Stroop effect, no significant age and language interactions were observed.

For the word fluency task results, the number of words generated for letter and category fluency was numerically larger for monolinguals versus bilinguals which is in line with previously reported findings. However, when ANOVAs for age and language effects were performed there were no statistically significant differences. This might be viewed as being consistent with other findings that did not find a lexical disadvantage when the task or analysis controlled for vocabulary knowledge (Bialystok et al. 2008b).

For the first working memory measure, The Corsi Block Task, the results revealed that monolingual and bilingual participants in comparable age groups had similar block span values. The ANOVA performed revealed that older adults had significantly smaller block span values than the young and middle aged groups.

For the Aospan results, the ANOVA analysis revealed that there was a significant interaction between age and language. Bilingual participants performed better than monolinguals

in the older and middle aged groups, while monolinguals and bilinguals alike had comparable performance in the young group. In addition, older adults had significantly smaller Aospan values. This result can be viewed as support for Hypothesis 2: Older bilinguals will perform better on executive function tasks than older monolinguals. It also supports the idea that the bilingual cognitive advantage goes beyond just an advantage in inhibitory control as a result of the bilingual having to consistently having to suppress one language. It may be that the bilingual cognitive advantage is more far reaching in nature, as suggested by the bilingual executive processing advantage BEPA (Hilchey & Klein, 2011). This would not discount the existence of a bilingual advantage in inhibitory control, but would instead suggest that the bilingual cognitive advantage might extend beyond this one specific component.

The results from the first series of ANOVA analyses for the Stroop and Simon Task, in addition to the other tasks, confirmed the first hypothesis in that younger participants consistently had faster RTs than older participants across task conditions. The performance on the block span task was as would have been expected, with older adults having significantly smaller block spans; this finding is in line with normal age-related declines in working memory and with more generally reduced cognitive efficiency associated with aging. From a linguistic perspective, when looking at raw scores, as would be expected the monolinguals generated more words than the bilinguals. Although these differences were not statistically significant, this can be taken as confirmation that for this study, this particular group of monolingual and bilingual participants was comparable to monolinguals and bilinguals in the general population. Otherwise, from the initial ANOVA analyses, no significant age and language performance differences were found between monolinguals and bilinguals for the Simon Task, the Stroop Task and the Corsi Block Span. These findings would lead one to initially refute the second hypothesis

that older bilinguals would perform better than older monolinguals on executive function tasks. From this, one might conclude that there is no evidence of a bilingual advantage in executive processing in general, and/or no bilingual cognitive advantage with respect to inhibitory control. However, there was evidence of a bilingual processing advantage whereby middle-aged and older bilinguals performed better than middle aged and older monolinguals on what was arguably the most cognitively challenging task of the protocol, namely the Aospan.

That evidence for this bilingual advantage might not appear until middle or older age might explain why some studies have concluded that there is no bilingual advantage: such studies (Paap & Greenberg, 2013; Paap et al. 2014; Kousaie & Phillips, 2012) have had younger monolingual and bilingual participants perform executive function tasks, and when no effects emerged, the conclusion was that the processing advantage does not exist. This was in fact the general finding among the younger participants in the present population. However, the bilingual cognitive advantage has been observed in younger adults when performing the classic 2 color Simon task with an increased number of experimental trials (Bialystok et al. 2005). So, although this study did not find strong support for a bilingual cognitive advantage with younger adults, there was unequivocal support for Hypothesis 1: Younger participants will perform better than older participants. They will have faster processing and less interference when performing executive function tasks. The age effect was consistently supported in almost every analysis in the majority of experimental conditions. From this, we can conclude that age definitely matters, especially for cognitive processing efficiency.

The interpretation here is not that the bilingual advantage does not exist, but that by virtue of being bilingual, younger bilinguals who are at the peak of their cognitive processing performance do not demonstrate an additional cognitive advantage as compared to younger

monolinguals. However, when bilingualism-related variables were taken into consideration, younger bilinguals who had higher ratings of L2 use at school performed better or faster than their bilingual peers who had lower ratings of L2 use at school. So, this confirms that bilingualism does matter. Moreover, as cognitive processing starts to decline in middle and older aged adults, this is where bilingualism serves as an advantage and allows for better cognitive performance as compared to monolinguals. The Aospan, which is a complex working memory task and which by design appeared last in the protocol, was again likely the most challenging task in it. It was striking that a bilingual advantage was found for this task. Only one other study has reported finding a bilingual advantage for working memory with older adults (Bialystok et al. 2014), and that was for spatial working memory rather than for verbal working memory. The Aospan was chosen and positioned last in the protocol because it was a cognitively challenging task and because although it contained letters and numbers, it was a complex non-verbal working memory measure.

In keeping with other studies which also did not find unequivocal evidence of a bilingual inhibitory control advantage (e.g., Kousaie & Phillips, 2012; Kousaie et al., 2014), the present study found no significant bilingual advantages in the Simon or Stroop Task indexing inhibitory control across all age groups with the ANOVA analyses, although it is noteworthy that for the Simon effect in the 4 square condition, significance was just missed. So although strong support for the BCA for inhibitory control was not found, there appeared to be indications that something was going on, given the effects of language which revealed trends and results which just missed significance. This resulted in a decision to conduct further analyses. By design, the study had set out to explore more than one component of executive function in addition to incorporating more

cognitively challenging tasks, like the Aospan task, in the hope of observing the bilingual advantage.

The main purpose of this project was to go beyond comparing monolinguals and bilinguals, and to systematically analyze the results as a function of key variables indexing bilingualism within the bilingual groups. Although there have been calls for exploring bilingualism in a more systematic and quantitative manner with respect to the bilingual cognitive advantage, no study to date has gone beyond reporting descriptive statistics for bilingualism-related variables and then speculating on how these variables might impact performance on cognitive tasks. Therefore, a series of ANCOVAs was carried out on the bilingual participants in order to explore bilingualism as a non-categorical variable and to see whether measurable differences in cognitive processing performance could be observed. Four key variables which had been identified as impacting performance on cognitive tasks were incorporated into subsequent analyses: Duration of Active L2 use, Self-rated Average L2 Proficiency, L1-L2 Home use, and L1-L2 School/work use.

When analyzing the results of the ANCOVAs with the bilingualism covariates, the most noteworthy finding which emerged was the significant main effect of Duration of Active L2 use $F(1,78) = 4.43$ $p=0.04$, for the Simon effect with two colors, a task and condition which have consistently been used to index inhibitory control function. This finding meant that the covariate itself had a significant effect on RT such that participants who had longer Duration of Active L2 use had a smaller Simon effect (See Table 2 in Appendix D for details). Strikingly, this effect was observed in the absence of a main effect of age, a variable which otherwise had been a significant predictor of RT in virtually every other analysis. This indicates that in the Simon effect 2 color condition, the bilingualism-related covariate Duration of Active L2 use, had a

significant effect on RT whereas age did not. This can be viewed as strong evidence of a bilingual cognitive advantage in inhibitory control irrespective of age. Furthermore, it is noteworthy that while the Simon effect typically increases with age (especially among older adults, as part of normal age-related cognitive processing declines), in this instance the Simon effect did not increase as a function of age; instead, only duration of active L2 use was significantly related to RT.

In addition, there were also results which suggested the possibility of a bilingual cognitive advantage as a function of the other bilingualism-related variables, namely Self-rated L2 proficiency and daily L1-L2 use at home and at work/school. Performance in various conditions improved with a higher self-rating of L2 proficiency and with a higher proportion of L1-L2 use in the home.

By completing additional analyses, digging deeper and incorporating bilingualism as a non-categorical variable, this second set of data provides positive evidence in support of Hypothesis 3: Older and younger bilinguals with high levels of proficiency and consistent use of their two languages will perform better than their monolingual counterparts, as well as positive evidence in support for Hypothesis 4: Bilingual language experience and language use profile will impact performance on executive function tasks.

These confirmations were obtained only after thorough and systematic analyses of variables indexing bilingualism. It is true that the bilingual performance advantages did not appear for every condition and as a function of every variable associated with bilingualism. However, there is positive evidence to support the claim that longer duration of active L2 use, higher levels of self-reported proficiency in L2 use, and higher proportions of L1-L2 use in home and work environments result in better or more efficient cognitive processing for middle aged

and older bilinguals. This study provides confirmation that, as operationalized by certain key variables, bilingual language experience significantly contributes to a difference in performance on executive function tasks. The fact that these processing advantages did not appear in every task condition as a function of each of the bilingualism variables highlights the complexity of bilingualism and how it is analyzed. Both factors may explain why the bilingual cognitive advantage is sometimes difficult to observe. There is clearly a need however for future research on the tasks and analyses used. This study has provided objective evidence that bilingualism variables matter, that they impact performance, and that it is crucial to operationalize them and include them in analyses versus just reporting them. Future research can continue to incorporate the bilingual variables used in this study, in addition to others, to explore how they impact performance on measures indexing executive function.

The results obtained for younger adults are in line with results obtained elsewhere, in that no bilingual cognitive advantages were observed. It may be that, given that younger adults are already functioning at the peak of their cognitive performance, being bilingual does not make a significant impact on cognitive performance when a person is relatively young, even in a task condition that is designed to be more challenging. By contrast, when cognitive processing starts to decline as a consequence of normal aging, the present findings suggest that cognitive performance may be maintained by virtue of being bilingual and having a higher proficiency in an L2, or a greater use of L2 at home and at work (recall that the Stroop ANCOVA analysis revealed significant main effects associated with all of these variables in all experimental conditions) or by virtue of longer periods of active L2 use (as demonstrated by the main effect of duration of L2 use in the ANCOVA for Simon effect 2sq condition). Compellingly, the present results support the notion that certain key components of a bilingual experience mitigated the

cognitive processing declines associated with aging. The results further suggest that future research should continue to explore bilingualism as a non-categorical variable.

Future research:

The possibilities for future research are practically limitless, but some possibilities include refining or revising aspects of the presently-used tasks that index executive function, while also identifying new tasks that index comparable executive function. It was noteworthy that with this population of bilinguals, a strong main effect of language appeared on the Aospan task, a task which moreover had not previously been used in protocols exploring the bilingual cognitive advantage. At a minimum, this would warrant a replication study with this measure. Another possibility for future research would be to further explore additional bilingual variables that may impact performance on tasks indexing executive function. The construct of self-reported language dominance could also be explored to see whether the degree to which participants said that they were dominant in one of their languages modulated performance on tasks such as those used in the present study. Exploring more subjective versus objective variables could also be an avenue for future research. In this study, duration of active L2 use could be viewed as a more objective measure of bilingualism as compared to self-rated L2 proficiency.

The results of this study suggest that knowing and using, and possibly also learning a second language can lead to better classroom performance in non-language areas, while at the same time imparting L2 literacy skills. This kind of ‘two-for-one’ implication would certainly be of interest to educators and could be pursued further in future research. For example, L2 middle school or high school students could be studied to assess the impact of L2 study and/or use upon both cognitive performance measures and classroom performance.

Incidentally, cultural differences were observed in this study with respect to what it means to be bilingual. Frequently, French participants understood that being bilingual meant actively using two languages from early childhood; as such, they may have provided lower self-rated average L2 proficiency ratings as compared to American participants, who often understood that being bilingual meant having the ability to hold a basic conversation in an L2 irrespective of when the language had been acquired or how long it had been used. What was confirmed in this study was that degree of bilingualism matters, and that this variable must be systematically and objectively addressed in future research. As a result of the findings of this study, we now know that 'Duration of Active L2 use' is important for observation of the bilingual cognitive advantage, but we still do not understand why this is so. That is, what is it about a longer active use of L2 that results in a bilingual cognitive advantage? There are many possibilities for future research that would systematically explore which aspects of active L2 use contribute to a bilingual cognitive advantage. More specifically, is the experience to some degree modality- or literacy-skill specific? Is the experience impacted by cultural variables associated with being bilingual?

These findings that demonstrated improved cognitive performance for bilinguals as a function of longer duration of active duration of L2 use, or greater use of the L2 at work or home suggest that the BCA may reflect a relatively short-term change in the brain rather than a permanent rewiring; much like physical exercise improves muscle strength and tone leading to improved physical function and performance which is not permanent, but rather requires ongoing exercise in order to be maintained. Future research would have to determine whether the BCA as observed here is more of a short-term vs. a permanent type of brain change, but findings here suggest that it is a change which is dependent on consistent use over time. It is also for future

research to determine the length and duration of L2 use which is required for improved cognitive performance, and also how much ongoing L2 use would be required to maintain gains in cognitive performance.

The ephemeral nature of the bilingual cognitive advantage, and the fact that one must look carefully and systematically to observe it, highlights the need for additional research with both behavioral and psychophysiological measures. As the present study has shown, to reduce bilingualism to a simple yes/no question is to miss its very essence.

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APPENDIX A

Simon Task ANOVA Tables

Table A1: Simon 4-way Anova

```
Response: Inverse Mean RT
              Df     Sum Sq    Mean Sq  F value    Pr(>F)
Language       1 3.9600e-07 3.9570e-07   3.6720 0.0559237
Age            2 1.8349e-05 9.1743e-06  85.1257 < 2.2e-16
color          1 1.5945e-05 1.5945e-05 147.9444 < 2.2e-16
position       1 1.5520e-06 1.5516e-06  14.3968 0.0001668
Language:Age   2 9.2100e-07 4.6050e-07   4.2727 0.0144743
Residuals    484 5.2163e-05 1.0780e-07


Contrast Coefficients(planned comparisons):
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)        2.247e-03  5.011e-05  44.842  < 2e-16
LanguageBI        -6.317e-05  6.322e-05  -0.999 0.318243
AgeMID            -4.192e-04  6.048e-05  -6.932 1.33e-11
AgeOLD            -6.183e-04  6.438e-05  -9.603  < 2e-16
colorc4           -3.600e-04  2.960e-05 -12.163  < 2e-16
positionincon     -1.123e-04  2.960e-05  -3.794 0.000167
LanguageBI:AgeMID  2.234e-04  7.831e-05   2.853 0.004520
LanguageBI:AgeOLD  1.003e-04  8.749e-05   1.146 0.252266
```

Table A2: RTs Center Control 2sq : (inverse transformed)

```
Response: Inverse Mean RT_Center/Control 2sq
              Df     Sum Sq    Mean Sq F value    Pr(>F)
Language       1 1.0300e-08 1.0290e-08  0.0651    0.7991
Age            2 5.0657e-06 2.5328e-06 16.0203 7.088e-07
Language:Age   2 2.0270e-07 1.0137e-07  0.6412    0.5285
Residuals    117 1.8498e-05 1.5810e-07
```

Table A2 cont'd.

Contrast Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	2.472e-03	1.103e-04	22.413	< 2e-16
LanguageBI	-9.873e-05	1.532e-04	-0.645	0.52042
AgeMID	-4.550e-04	1.465e-04	-3.106	0.00238
AgeOLD	-6.607e-04	1.560e-04	-4.237	4.55e-05
LanguageBI:AgeMID	2.141e-04	1.897e-04	1.129	0.26140
LanguageBI:AgeOLD	1.235e-04	2.119e-04	0.583	0.56130

Table A3: Simon Effect 2sq

Response: Inverse Simon effect 2sq

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Language	1	57.6	57.647	0.5692	0.4521
Age	2	62.3	31.136	0.3075	0.7359
Language:Age	2	33.7	16.844	0.1663	0.8470
Residuals	117	11848.5	101.269		

Simon effect 2sq condition: 1/(RT Incongruent 2sq – RT Congruent 2sq)

Contrast Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-0.07086	2.79105	-0.025	0.980
LanguageBI	0.08947	3.87601	0.023	0.982
AgeMID	0.04647	3.70769	0.013	0.990
AgeOLD	0.08940	3.94714	0.023	0.982
LanguageBI:AgeMID	2.21602	4.80075	0.462	0.645
LanguageBI:AgeOLD	-0.06188	5.36381	-0.012	0.991

Table A4: RTs Center 4sq

Response: Inverse MeanRT Center 4sq

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Language	1	5.4300e-08	5.4320e-08	0.4517	0.5029
Age	2	3.7712e-06	1.8856e-06	15.6795	9.268e-07
Language:Age	2	1.3130e-07	6.5630e-08	0.5457	0.5809
Residuals	117	1.4070e-05	1.2026e-07		

Constrast Coefficients (planned comparisons)

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.868e-03	9.618e-05	19.418	< 2e-16
LanguageBI	-6.049e-05	1.336e-04	-0.453	0.6515
AgeMID	-3.131e-04	1.278e-04	-2.450	0.0158
AgeOLD	-5.522e-04	1.360e-04	-4.060	8.92e-05
LanguageBI:AgeMID	1.707e-04	1.654e-04	1.032	0.3043
LanguageBI:AgeOLD	8.657e-05	1.848e-04	0.468	0.6404

Table A5: ANOVA Simon effect for the 4sq condition

Response: Inverse Simon Effect 4 square

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Language	1	1.301	1.30092	2.7304	0.1011
Age	2	1.026	0.51278	1.0763	0.3442
Language:Age	2	1.402	0.70089	1.4711	0.2339
Residuals	117	55.745	0.4764		

Table A5 cont'd.

Constrast Coefficients (planned comparisons)

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-0.5621	0.1914	-2.936	0.0040
LanguageBI	0.5793	0.2659	2.179	0.0313
AgeMID	0.5404	0.2543	2.125	0.0357
AgeOLD	0.4804	0.2707	1.774	0.0786
LanguageBI:AgeMID	-0.5442	0.3293	-1.653	0.1011
LanguageBI:AgeOLD	-0.4920	0.3679	-1.337	0.1838

Table A6: Simon ANOVA for Working Memory Costs

Response: Inverse mean RT

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Language	1	0.00010	0.00009703	0.0505	0.8224
Age	2	0.00012	0.00005823	0.0303	0.9702
position	1	0.00005	0.00004694	0.0244	0.8760
Language:Age	2	0.00062	0.00031110	0.1618	0.8507
Language:position	1	0.00000	0.00000183	0.0010	0.9754
Age:position	2	0.00047	0.00023426	0.1219	0.8853
Language:Age:position	2	0.00099	0.00049325	0.2566	0.7739
Residuals					

Contrast Coefficients (Planned Comparisons):

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.0082141	0.0121602	0.675	0.500
LanguageBI	-0.0006788	0.0168872	-0.040	0.968
AgeMID	-0.0001660	0.0161539	-0.010	0.992
AgeOLD	-0.0019926	0.0171971	-0.116	0.908
positionside	-0.0094079	0.0171971	-0.547	0.585

Table A6 cont'd.

LanguageBI:AgeMID	0.0022458	0.0209162	0.107	0.915
LanguageBI:AgeOLD	0.0013946	0.0233693	0.060	0.952
LanguageBI:positionside	0.0129869	0.0238821	0.544	0.587
AgeMID:positionside	0.0126862	0.0228450	0.555	0.579
AgeOLD:positionside	0.0108603	0.0243204	0.447	0.656
LangBI:AgeMID:positionside	-0.0205285	0.0295799	-0.694	0.488
LangBI:AgeOLD:positionside	-0.0086139	0.0330492	-0.261	0.795

Table A7: Simon Effect ANOVA Working memory Costs

Response: inverse mean RT

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Language	1	38.1	38.134	0.7496	0.3875
Age	2	36.2	18.118	0.3561	0.7008
color	1	58.0	58.014	1.1404	0.2867
Language:Age	2	13.3	6.674	0.1312	0.8771
Language:color	1	20.8	20.814	0.4091	0.5230
Age:color	2	27.1	13.531	0.2660	0.7667
Language:Age:color	2	21.7	10.870	0.2137	0.8078
Residuals	234	11904.3	50.873		

Contrast Coefficients (Planned comparisons):

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-0.07086	1.97821	-0.036	0.971
LanguageBI	0.08947	2.74719	0.033	0.974
AgeMID	0.04647	2.62789	0.018	0.986
AgeOLD	0.08940	2.79761	0.032	0.975
colorc4	-0.49120	2.79761	-0.176	0.861
LanguageBI:AgeMID	2.21602	3.40262	0.651	0.516

Table A7 cont'd.

LanguageBI:AgeOLD	-0.06188	3.80170	-0.016	0.987
LanguageBI:colorc4	0.48987	3.88512	0.126	0.900
AgeMID:colorc4	0.49390	3.71640	0.133	0.894
AgeOLD:colorc4	0.39097	3.95641	0.099	0.921
LanguageBI:AgeMID:colorc4	-2.76022	4.81203	-0.574	0.567
LanguageBI:AgeOLD:colorc4	-0.43009	5.37641	-0.080	0.936

APPENDIX B

Stroop Task ANOVA Tables

Table B1: Stroop ANOVA mean RT

Response: Inverse mean RT

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Language	1	3.0000e-09	2.9600e-09	0.0609	0.8055
Age	2	3.2507e-06	1.6253e-06	33.3864	2.414e-12
Language:Age	2	1.8700e-08	9.3700e-09	0.1925	0.8252
Residuals	125	6.0853e-06	4.8680e-08		

Contrast Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.157e-03	4.815e-05	24.024	< 2e-16
LanguageBI	1.039e-04	7.613e-05	1.364	0.17486
AgeMID	-2.395e-04	7.087e-05	-3.379	0.00097
AgeOLD	-4.251e-04	7.787e-05	-5.459	2.47e-07
LanguageBI:AgeMID	-5.920e-05	9.754e-05	-0.607	0.54502
LanguageBI:AgeOLD	-4.820e-05	1.114e-04	-0.433	0.66593

Graph B1

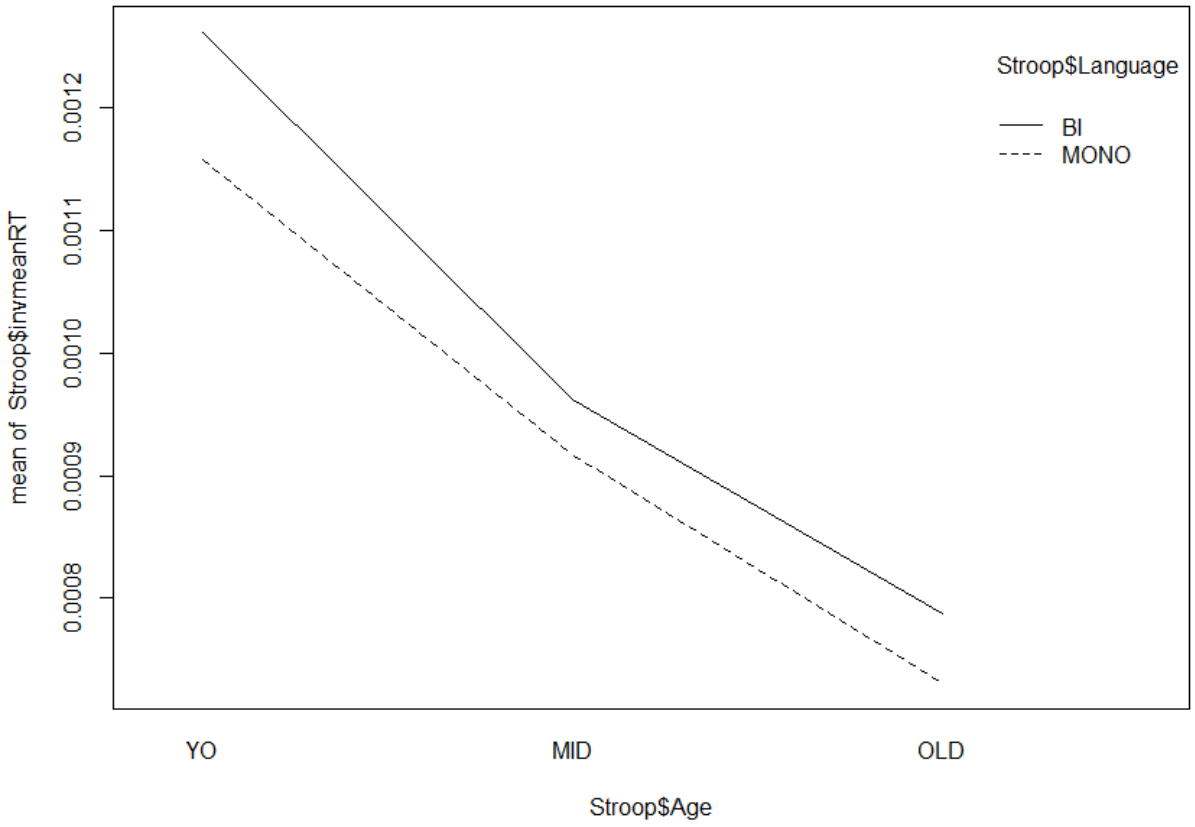

Stroop$Language
BI
MONO
mean of Stroop$invmeanRT
0.0008
0.0009
0.0010
0.0011
0.0012
YO
MID
OLD
Stroop$Age

Table B2: Stroop ANOVA mean RT congruent

Response: Inverse mean RT congruent

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Language	1	7.5000e-09	7.5100e-09	0.1375	0.7115
Age	2	3.8166e-06	1.9083e-06	34.9074	9.026e-13
Language:Age	2	9.9000e-09	4.9400e-09	0.0904	0.9136
Residuals	125	6.8335e-06	5.4670e-08		

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.270e-03	5.102e-05	24.899	< 2e-16
LanguageBI	7.294e-05	8.067e-05	0.904	0.367650
AgeMID	-2.731e-04	7.510e-05	-3.637	0.000402
AgeOLD	-4.637e-04	8.251e-05	-5.619	1.19e-07
LanguageBI:AgeMID	-3.941e-05	1.034e-04	-0.381	0.703618
LanguageBI:AgeOLD	-4.280e-05	1.180e-04	-0.363	0.717511

Graph B2

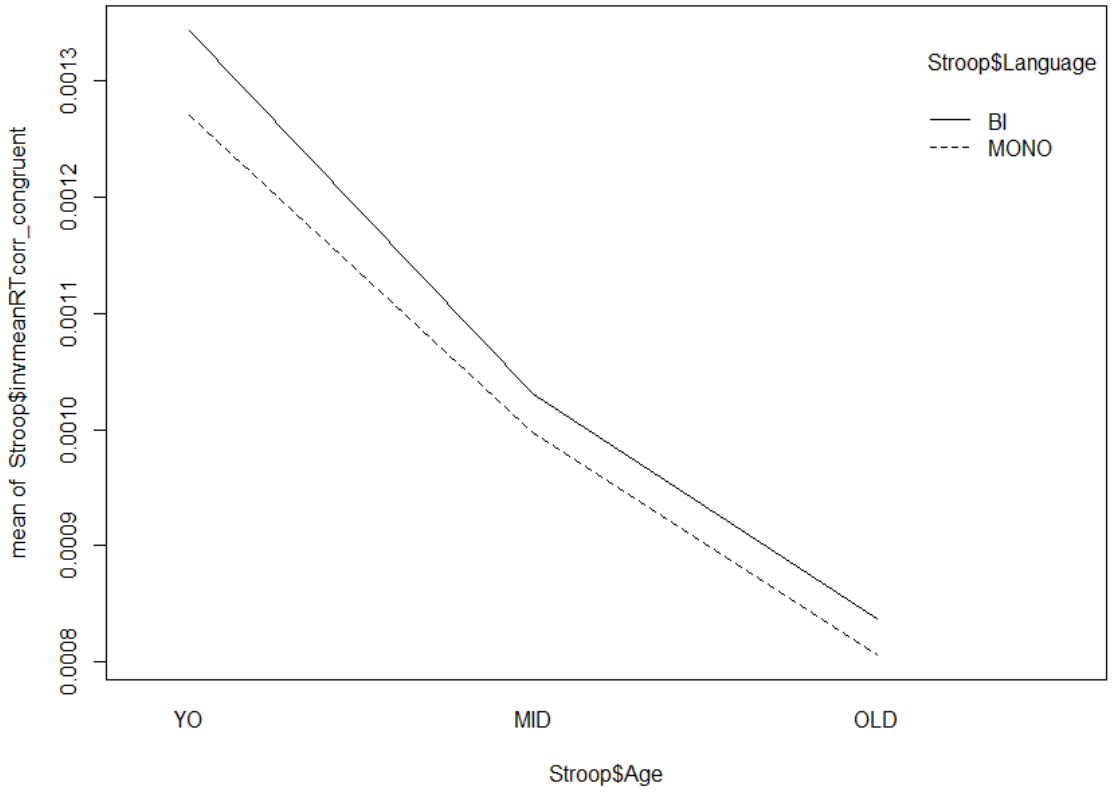


Table B3: Stroop ANOVA mean RT Incongruent

```
Response: Inverse meanRT Incongruent
              Df     Sum Sq    Mean Sq F value    Pr(>F)
Language       1 2.9500e-08 2.9520e-08  0.6389    0.4256
Age            2 2.9383e-06 1.4691e-06 31.7960    6.866e-12
Language:Age   2 2.7200e-08 1.3590e-08  0.2942    0.7457
Residuals    125 5.7756e-06 4.6210e-08


Contrast Coefficients:
                   Estimate     Std. Error     t value    Pr(>|t|)
(Intercept)        1.020e-03    4.691e-05      21.745    < 2e-16
LanguageBI         1.274e-04    7.417e-05      1.718       0.08825
AgeMID            -2.201e-04     6.904e-05     -3.187      0.00182
AgeOLD            -4.067e-04    7.586e-05      -5.361      3.85e-07
LanguageBI:AgeMID -7.286e-05    9.503e-05      -0.767      0.44470
LanguageBI:AgeOLD -4.228e-05    1.085e-04      -0.390      0.69741
```

Graph B3

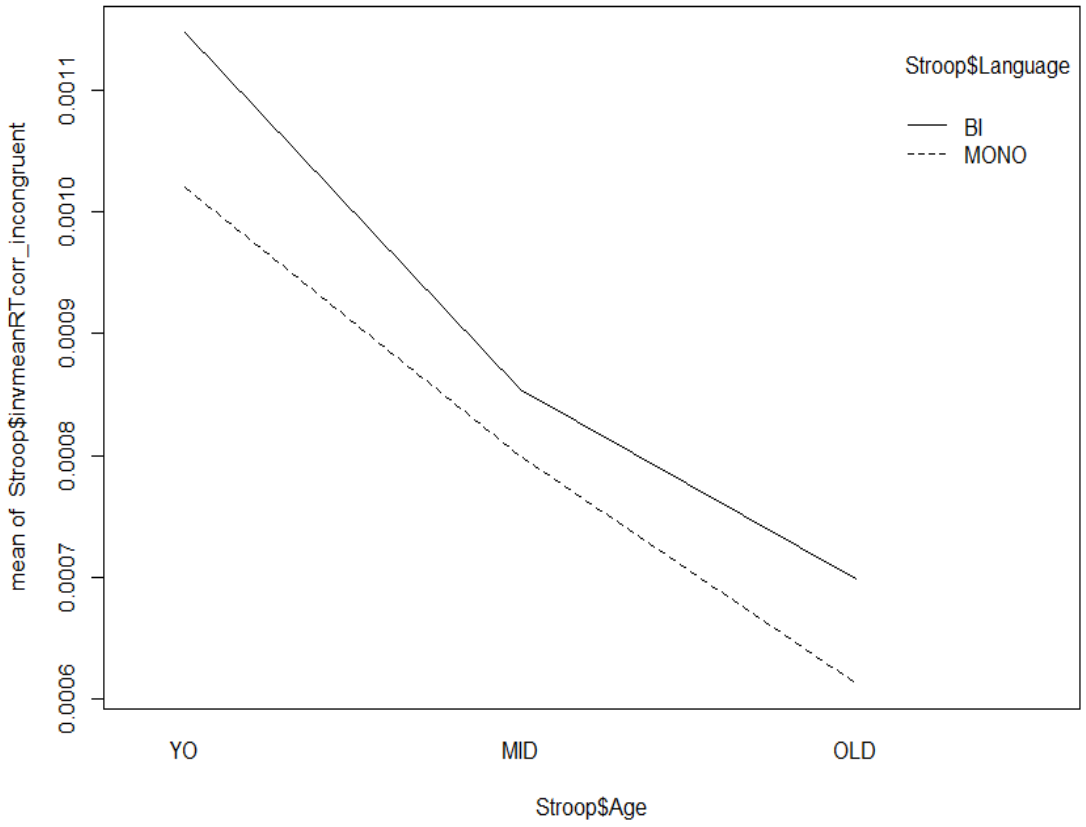

Stroop$Language
BI
MONO
mean of Stroop$invmeanRTcorr_incongruent
0.0006
0.0007
0.0008
0.0009
0.0010
0.0011
YO
MID
OLD
Stroop$Age

Table B4: Stroop ANOVA mean RT control

```
Response: Inverse MeanRT control
              Df     Sum Sq    Mean Sq  F value    Pr(>F)
Language       1 3.6000e-09 3.5700e-09   0.0670    0.7961
Age            2 3.0438e-06 1.5219e-06 28.5977    5.933e-11
Language:Age   2 2.7000e-08 1.3490e-08   0.2535    0.7765
Residuals    125 6.6521e-06 5.3220e-08
```

```
Contrast Coefficients:
                   Estimate    Std. Error     t value        Pr(>|t|)
(Intercept)         1.204e-03   5.034e-05      23.922         < 2e-16
LanguageBI          1.089e-04   7.960e-05       1.368         0.1739
AgeMID             -2.179e-04   7.410e-05      -2.941         0.0039
AgeOLD             -4.091e-04    8.141e-05     -5.025         1.7e-06
LanguageBI:AgeMID -7.148e-05   1.020e-04      -0.701         0.4846
LanguageBI:AgeOLD -5.586e-05    1.164e-04     -0.480         0.6323
```

Graph B4

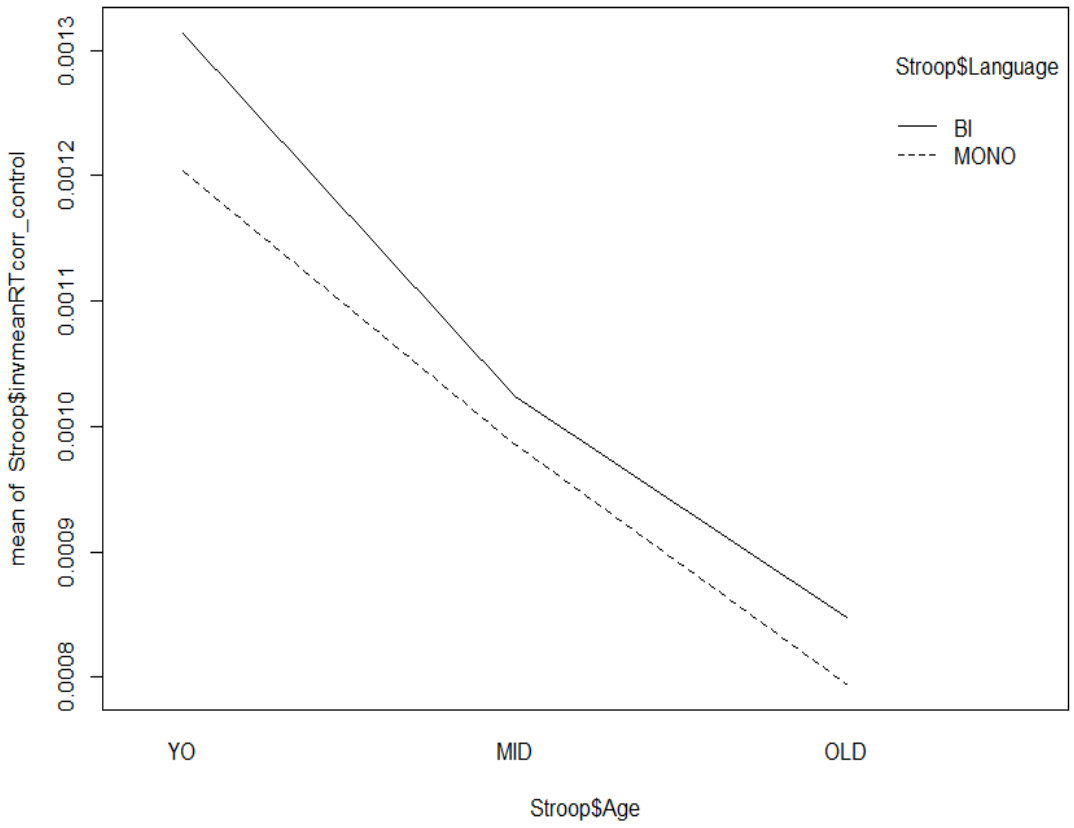


Table B5: Stroop ANOVA Interference effect

Response: Inverse Interference effect

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Language	1	2	2.15	0.0022	0.9623
Age	2	3365	1682.54	1.7585	0.1765
Language:Age	2	1134	567.02	0.5926	0.5544
Residuals	125	119598	956.78		

Contrast Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-0.6675	6.7499	-0.099	0.921
LanguageBI	-12.3070	10.6725	-1.153	0.251
AgeMID	4.3842	9.9356	0.441	0.660
AgeOLD	7.0404	10.9160	0.645	0.520
LangBI:AgeMID	14.8668	13.6744	1.087	0.279
LangBI:AgeOLD	9.8112	15.6135	0.628	0.531

Graph B5

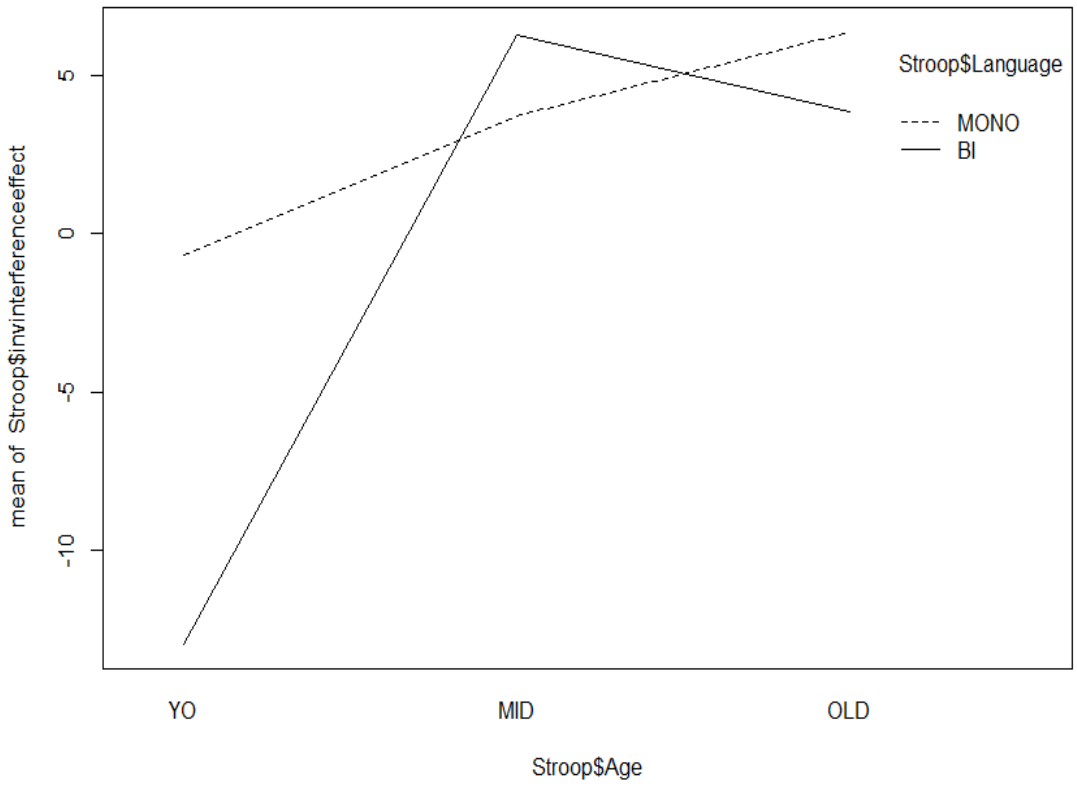
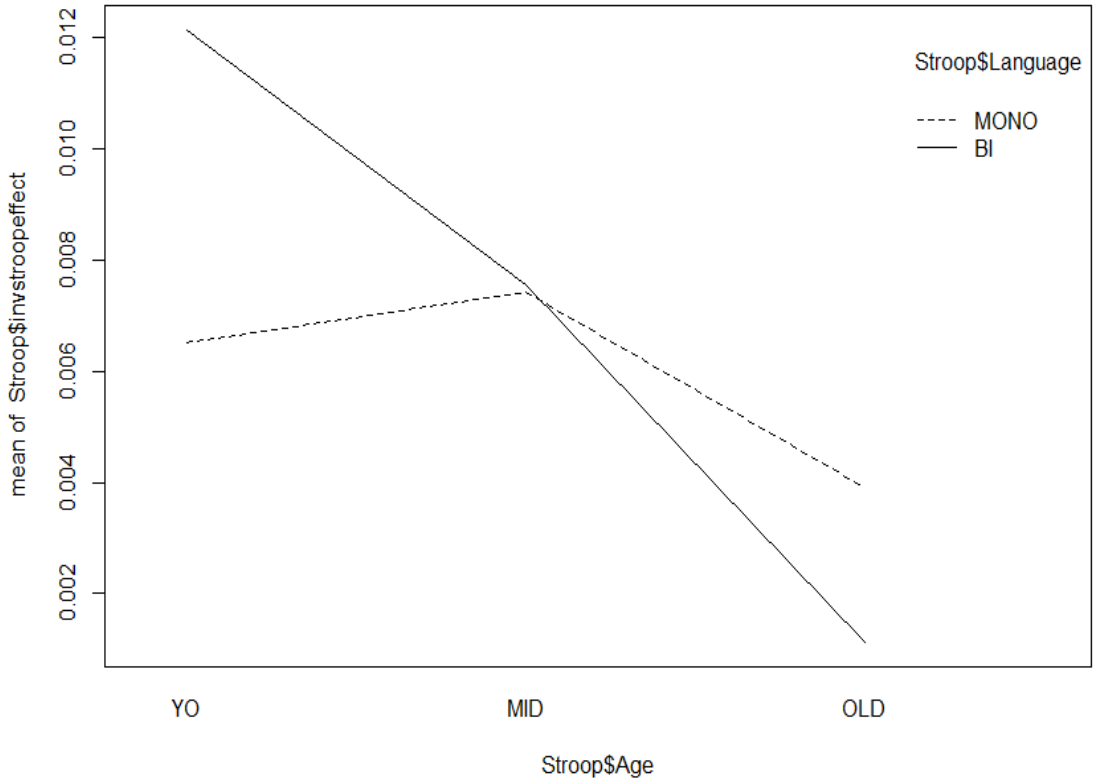


Table B6: Stroop effect ANOVA

```
Response: Inverse Stroop effect
              Df    Sum Sq    Mean Sq  F value  Pr(>F)
Language       1 0.0000206 0.00002055  0.2015   0.65427
Age            2 0.0007733 0.00038664  3.7910   0.02521
Language:Age   2 0.0002935 0.00014674  1.4388   0.24111
Residuals    125 0.0127485 0.00010199

Contrast Coefficients:
                    Estimate   Std. Error     t value        Pr(>|t|)
(Intercept)        0.0065259   0.0022038       2.961         0.00367
LanguageBI         0.0056133   0.0034845       1.611         0.10971
AgeMID             0.0008912   0.0032439       0.275         0.78396
AgeOLD            -0.0026132   0.0035640      -0.733         0.46479
LanguageBI:AgeMID -0.0054674   0.0044646      -1.225         0.22302
LanguageBI:AgeOLD -0.0083917   0.0050976      -1.646         0.10224
```

Graph B6


mean of Stroop$invstroopeffect
0.002
0.004
0.006
0.008
0.010
0.012
YO
MID
OLD
Stroop$Age
Stroop$Language
MONO
BI

APPENDIX C

Verbal Fluency Test, Corsi Block Task and Aospan ANOVA Tables

Table C1: ANOVA Table Letter Fluency

Response: FAS estimate total

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Language	1	1555	1554.67	1.7829	0.1844
Age	2	545	272.65	0.3127	0.7321
Language:Age	2	1514	757.06	0.8682	0.4224
Residuals	115	100276	871.96		

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	72.368	6.774	10.683	<2e-16
LanguageBI	-14.168	10.199	-1.389	0.167
AgeMID	-3.806	10.020	-0.380	0.705
AgeOLD	-15.599	10.629	-1.468	0.145
LanguageBI:AgeMID	4.815	13.372	0.360	0.719
LanguageBI:AgeOLD	19.266	15.140	1.272	0.206

Table C2: ANOVA Table Category Fluency

Response: Word count: Animals

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Language	1	249.3	249.299	2.1234	0.1478
Age	2	203.7	101.858	0.8676	0.4227
Language:Age	2	72.6	36.317	0.3093	0.7345
Residuals	115	13501.5	117.405		

Table C2 cont'd.

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	30.3684	2.4858	12.217	<2e-16
LanguageBI	-3.2351	3.7425	-0.864	0.389
AgeMID	-0.7434	3.6765	-0.202	0.840
AgeOLD	-5.2915	3.9000	-1.357	0.178
LanguageBI:AgeMID	-0.8550	4.9066	-0.174	0.862
LanguageBI:AgeOLD	3.1582	5.5556	0.568	0.571

Table C3: ANOVA Corsi Block Span

Response: Blockspan

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Language	1	1.373	1.373	0.7855	0.3773
Age	2	67.954	33.977	19.4349	5.061e-08
Language:Age	2	0.402	0.201	0.1151	0.8914
Residuals	118	206.294	1.74		

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	6.2105	0.3033	20.474	< 2e-16
LanguageBI	0.1895	0.4567	0.415	0.6790
AgeMID	-1.0105	0.4567	-2.213	0.0288
AgeOLD	-2.2105	0.4759	-4.645	8.91e-06
LanguageBI:AgeMID	0.2014	0.6040	0.333	0.7394
LanguageBI:AgeOLD	0.3105	0.6635	0.468	0.6406
LangBI:AgeMID	0.2014	0.6040	0.333	0.7394
LangBI:AgeOLD	0.3105	0.6635	0.468	0.6406

Table C4: ANOVA Aospan

Response: Aospan score

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Language	1	5107	5106.9	12.853	0.0004883
Age	2	9958	4978.9	12.531	1.142e-05
Residuals	120	47680	397.3		

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	41.893	3.805	11.011	< 2e-16
LanguageBI	12.176	3.786	3.216	0.00167
AgeMID	-1.292	4.428	-0.292	0.77089
AgeOLD	-21.506	4.967	-4.330	3.11e-05

APPENDIX D

Simon Task ANCOVA Tables

Table D1: Simon ANCOVA with Duration active L2 use and mean RT

```
      Response: Inverse meanRT_A
                   Df    Sum Sq   Mean Sq F value   Pr(>F)
      Age           2 2.705e-06 1.353e-06   7.945 0.000669
      duration      1 2.400e-08 2.420e-08   0.142 0.707064
      Age:duration  2 4.300e-08 2.140e-08   0.126 0.881849
      Residuals    89 1.515e-05 1.703e-07

(Intercept)     AgeMID          AgeOLD        duration
2.289583e-03   -2.003058e-04   -4.593518e-04  1.045518e-05

AgeMID:duration AgeOLD:duration
-9.004136e-06  -1.035340e-05
```

Table D2: Simon ANCOVA with Duration active L2 use and Simon effect 2sq

```
      Response: Inverse Simon effect
                   Df  Sum Sq  Mean Sq  F value  Pr(>F)
      Age           2 0.00587 0.002935  0.1021 0.90301
      duration      1 0.12729 0.127289  4.4298 0.03817
      Age:duration  2 0.00957 0.004787  0.1666 0.84681
      Residuals    88 2.52866 0.028735


(Intercept)     AgeMID          AgeOLD         duration
4.838497e-03   -2.646261e-02    6.034973e-03   1.633047e-03

AgeMID:duration   AgeOLD:duration
1.201287e-03      -4.337346e-05
```

Table D3: Simon ANCOVA with Duration active L2 use and mean RT 4sq

```
      Response: Inverse meanRT_C
                   Df     Sum Sq    Mean Sq  F value    Pr(>F)
      Age           2 2.0068e-06 1.0034e-06  7.7971 0.0007582
      duration      1 9.6900e-08 9.6920e-08  0.7531 0.3878174
      Age:duration  2 1.8730e-07 9.3670e-08  0.7279 0.4857750
      Residuals    89 1.1454e-05 1.2869e-07
(Intercept)     AgeMID          AgeOLD           duration
 1.648070e-03   -3.489912e-05   -3.036483e-04    2.494716e-05   AgeMID:durati
on   AgeOLD:duration
-2.312645e-05     -2.353405e-05
```

Table D4: Simon ANCOVA with Duration active L2 use and Simon effect 4sq

```
Response: Inverse Simon effect4sq
              Df   Sum Sq    Mean Sq  F value Pr(>F)
Age            2 0.002301 0.00115054  0.6111 0.5451
duration       1 0.000060 0.00005963  0.0317 0.8592
Age:duration   2 0.000377 0.00018859  0.1002 0.9048
Residuals     85 0.160031 0.00188271
```

```
(Intercept)       AgeMID           AgeOLD           duration
0.0069972204     0.0101894935     0.0036723283     0.0005262960

AgeMID:duration AgeOLD:duration
-0.0003834115   -0.0006076490
```

Table D5: Simon ANCOVA with Self-rated average L2 proficiency and mean RT

```
 Response: Inverse meanRT
                   Df     Sum Sq    Mean Sq  F value    Pr(>F)
Age                 2 2.7053e-06 1.3527e-06  8.0465 0.0006135
L2.Avg.Rating       1 2.2390e-07 2.2395e-07  1.3322 0.2515075
Age:L2.Avg.Rating   2 3.4700e-08 1.7360e-08  0.1033 0.9019837
Residuals          89 1.4961e-05 1.6811e-07
```

```
(Intercept)       AgeMID           AgeOLD           L2.Avg.Rating
2.146801e-03      -9.095465e-05   -3.591571e-04   2.987842e-06

AgeMID:L2.Avg.Rating   AgeOLD:L2.Avg.Rating
-1.932714e-06          -1.719176e-06
```

Table D6: Simon ANCOVA with Self-rated average L2 proficiency and Simon effect 2sq

```
Response: Inverse Simon effect2sq
                   Df  Sum Sq  Mean Sq  F value Pr(>F)
Age                 2 0.00587 0.002935  0.0995 0.9054
L2.Avg.Rating       1 0.06716 0.067159  2.2770 0.1349
Age:L2.Avg.Rating   2 0.00280 0.001399  0.0474 0.9537
Residuals          88 2.59556 0.029495
```

```
(Intercept)        AgeMID           AgeOLD          L2.Avg.Rating
-0.0167256921      0.0100190151     0.0245360391   0.0004558877

AgeMID:L2.Avg.Rating   AgeOLD:L2.Avg.Rating
0.0001678755           0.00044190
```

Table D7: Simon ANCOVA with Self-rate average L2 proficiency and mean RT 4sq

```
      Response: Inverse mean RT center 4sq

                        Df     Sum Sq    Mean Sq  F value    Pr(>F)
      Age                2 2.0068e-06 1.0034e-06  7.7987 0.0007571
      L2.Avg.Rating      1 2.7970e-07 2.7967e-07  2.1737 0.1439199
      Age:L2.Avg.Rating  2 7.0000e-09 3.5100e-09  0.0273 0.9731181
      Residuals         89 1.1451e-05 1.2866e-07


(Intercept)         AgeMID           AgeOLD        L2.Avg.Rating
1.646910e-03        -7.431679e-05    -3.284173e-04 2.159300e-06

AgeMID:L2.Avg.Rating   AgeOLD:L2.Avg.Rating
- 8.597785e-07        -6.982026e-07
```

Table D8: Simon ANCOVA with Self-rated average L2 proficiency and Simon effect 4sq

```
      Response: Inverse Simon effect 4sq
                        Df   Sum Sq    Mean Sq  F value Pr(>F)
      Age                2 0.002301 0.00115054  0.6163 0.5423
      L2.Avg.Rating      1 0.001099 0.00109929  0.5889 0.4450
      Age:L2.Avg.Rating  2 0.000690 0.00034513  0.1849 0.8315
      Residuals         85 0.158678 0.00186680

(Intercept)          AgeMID           AgeOLD        L2.Avg.Rating
-0.0103206023        0.0235036248     0.0193478915  0.0002903549

AgeMID:L2.Avg.Rating   AgeOLD:L2.Avg.Rating
-0.0001750803          -0.0002867769
```

Table D9: Simon ANCOVA with Daily L1-L2 home use and mean RT

```
        Response: Inverse meanRT center 2sq
                       Df     Sum Sq    Mean Sq  F value    Pr(>F)
      Age               2 2.6061e-06 1.3030e-06  9.5677 0.0001881
      Home.L1.L2        1 1.3128e-06 1.3128e-06  9.6389 0.0026343
      Age:Home.L1.L2    2 8.1200e-08 4.0620e-08  0.2982 0.7429405
      Residuals        80 1.0895e-05 1.3619e-07
(Intercept)         AgeMID           AgeOLD           Home.L1.L2
2.803835e-03        -3.322785e-04    -6.895190e-04    -6.620484e-06
AgeMID:Home.L1.L2      AgeOLD:Home.L1.L2
2.042694e-06           3.437683e-06
```

Table D10: Simon ANCOVA with Daily L1-L2 home use and Simon effect 2sq

```
      Response: Inverse Simon effect 2sq
                     Df  Sum Sq  Mean Sq  F value  Pr(>F)
      Age             2 0.00939 0.004696  0.1832 0.83295
      Home.L1.L2      1 0.00567 0.005670  0.2212 0.63942
      Age:Home.L1.L2  2 0.23509 0.117544  4.5854 0.01306
      Residuals      79 2.02512 0.025634

(Intercept)         AgeMID            AgeOLD         Home.L1.L2
0.0386471328        -0.1463135669     0.2675777872   -0.0003541544

AgeMID:Home.L1.L2      AgeOLD:Home.L1.L2
0.0024019579           -0.0027412185
```

Table D11: Simon ANCOVA with Daily L1-L2 home use and mean RT 4sq

```
      Response: Inverse meanRT_control 4sq
                     Df     Sum Sq    Mean Sq  F value    Pr(>F)
      Age             2 1.9887e-06 9.9435e-07  8.5697 0.0004244
      Home.L1.L2      1 1.6400e-07 1.6401e-07  1.4135 0.2379863
      Age:Home.L1.L2  2 1.1970e-07 5.9870e-08  0.5160 0.5988836
      Residuals      80 9.2825e-06 1.1603e-07

(Intercept)           AgeMID          AgeOLD          Home.L1.L2
2.068007e-03          -2.897331e-04   -6.905296e-04   -3.999066e-06

AgeMID:Home.L1.L2      AgeOLD:Home.L1.L2
2.701038e-06           4.073302e-06
```

Table D12: Simon ANCOVA with Daily L1-L2 home use and Simon effect 4sq

```
      Response: Inverse Simon effect 4sq
                     Df   Sum Sq    Mean Sq  F value Pr(>F)
      Age             2 0.001780 0.00089014  0.5477 0.5805
      Home.L1.L2      1 0.000380 0.00038047  0.2341 0.6299
      Age:Home.L1.L2  2 0.005266 0.00263324  1.6203 0.2045
      Residuals      77 0.125135 0.00162513
(Intercept)           AgeMID          AgeOLD          Home.L1.L2
-0.0292601783         0.0671125042    0.0498903263    0.0005608675
AgeMID:Home.L1.L2      AgeOLD:Home.L1.L2
-0.0008339193          -0.000709971
```

Table D13: Simon ANCOVA with L1-L2 school/work use and mean RT 2sq

```
      Response: Inverse MeanRT_Center 2sq Control
                           Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age                   2 2.6061e-06 1.3030e-06 10.8657  6.69e-05
      School.Work.L1.L2     1 1.9650e-06 1.9650e-06 16.3855  0.0001186
      Age:School.Work.L1.L2 2 7.3060e-07 3.6530e-07  3.0461  0.0530947
      Residuals            80 9.5939e-06 1.1992e-07

(Intercept)    AgeMID         AgeOLD         School.Work.L1.L2
3.036260e-03   -5.968589e-04  -1.103427e-03  -1.066953e-05

AgeMID:School.Work.L1.L2      AgeOLD:School.Work.L1.L2
6.150085e-06                  9.578108e-06
```

Table D14: Simon ANCOVA with L1-L2 school/work use and Simon effect 2sq

```
      Response: Inverse Simon Effect 2sq
                           Df  Sum Sq  Mean Sq  F value Pr(>F)
      Age                   2 0.00939 0.004696  0.1725  0.8419
      School.Work.L1.L2     1 0.00797 0.007965  0.2926  0.5901
      Age:School.Work.L1.L2 2 0.10702 0.053508  1.9653  0.1469
      Residuals            79 2.15090 0.027227

(Intercept)    AgeMID         AgeOLD         School.Work.L1.L2
0.0443008778   -0.0335499916  0.1791238011   -0.0004652077
AgeMID:School.Work.L1.L2      AgeOLD:School.Work.L1.L2
0.0009270883                  -0.0017285289
```

Table 15: Simon ANCOVA with L1-L2 school/work use and mean RT 4sq

```
      Response: Inverse Mean RT_Center
                           Df     Sum Sq    Mean Sq  F value    Pr(>F)
      Age                   2 1.9887e-06 9.9435e-07  9.3324 0.0002276
      School.Work.L1.L2     1 5.9240e-07 5.9241e-07  5.5600 0.0208176
      Age:School.Work.L1.L2 2 4.5000e-07 2.2500e-07  2.1117 0.1277281
      Residuals            80 8.5238e-06 1.0655e-07
(Intercept)    AgeMID         AgeOLD         School.Work.L1.L2
2.237778e-03   -3.762385e-04  -9.027436e-04  -6.902207e-06

AgeMID:School.Work.L1.L2      AgeOLD:School.Work.L1.L2
4.227596e-06                  7.491720e-06
```

Table D16: Simon ANCOVA with L1-L2 school/work use and mean RT 4sq

```
Response: Inverse Simon effect4sq
                       Df   Sum Sq   Mean Sq  F value  Pr(>F)
Age                     2 0.001780 0.0008901  0.5602 0.57342
School.Work.L1.L2       1 0.000184 0.0001841  0.1158 0.73452
Age:School.Work.L1.L2   2 0.008240 0.0041202  2.5929 0.08132
Residuals              77 0.122357 0.0015891
```

```
(Intercept)     AgeMID          AgeOLD          School.Work.L1.L2
-0.0464161586  0.0666836718    0.0666788075    0.0008651381

AgeMID:School.Work.L1.L2       AgeOLD:School.Work.L1.L2
-0.0008984570                  -0.0010147809
```

Table D17: Simon ANCOVA with Duration active L2 use and Simon congruent 2sq

```
Response: Inverse meanRT_Congruent2sq
               Df     Sum Sq    Mean Sq F value    Pr(>F)
Age             2 3.1180e-06 1.5590e-06 10.7171    6.757e-05
duration        1 9.9400e-08 9.9410e-08  0.6834    0.4106
Age:duration    2 2.0500e-08 1.0270e-08  0.0706    0.9319
Residuals      89 1.2947e-05 1.4547e-07
```

```
(Intercept)     AgeMID          AgeOLD          duration
2.174964e-03   -2.146238e-04   -5.300320e-04   9.602721e-06

AgeMID:duration        AgeOLD:duration
-7.771163e-06          -7.668277e-06
```

Table D18: Simon ANCOVA with Duration active L2 use and Simon incongruent 2sq

```
      Response: Inverse meanRT_Incongruent2sq
                   Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age           2 3.1828e-06 1.5914e-06 12.5369    1.596e-05
      duration      1 1.2950e-07 1.2946e-07  1.0199    0.3153
      Age:duration  2 2.9000e-09 1.4700e-09  0.0115    0.9885
      Residuals    89 1.1297e-05 1.2694e-07

(Intercept)    AgeMID          AgeOLD        duration
2.098393e-03   -3.472357e-04   -6.221629e-04 -4.889458e-07

AgeMID:duration        AgeOLD:duration
2.699618e-06           2.904756e-06
```

Table D19: Simon ANCOVA with Duration active L2 use and Simon congruent 4sq

```
      Response: Inverse meanRT_congruent 4sq

                   Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age           2 2.2522e-06 1.1261e-06 12.3231    1.887e-05
      duration      1 8.0800e-08 8.0810e-08  0.8843    0.3496
      Age:duration  2 1.7660e-07 8.8280e-08  0.9661    0.3845
      Residuals    89 8.1329e-06 9.1380e-08

(Intercept)          AgeMID          AgeOLD        duration
1.737795e-03        -2.469611e-04   -4.208168e-04  4.404377e-06

AgeMID:duration        AgeOLD:duration
-2.699221e-07          -5.587446e-06
```

Table D20:
Simon ANCOVA with Duration active L2 use and Simon incongruent condition 4sq

```
      Response: Inverse meanRT Incongruent4sq
                   Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age           2 2.3806e-06 1.1903e-06 11.8550    2.726e-05
      duration      1 9.4100e-08 9.4130e-08  0.9375    0.3355
      Age:duration  2 8.1800e-08 4.0890e-08  0.4072    0.6667
      Residuals    89 8.9360e-06 1.0040e-07
(Intercept)           AgeMID          AgeOLD        duration
1.704423e-03          -2.481752e-04   -4.777374e-04 -1.404440e-06

AgeMID:duration        AgeOLD:duration
4.974294e-06           1.419028e-06
```

Table D21:
Simon ANCOVA with Self-rated L2 proficiency and Simon congruent condition 2sq

```
      Response: Inverse meanRT congruent2sq
                        Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age                2 3.1180e-06 1.5590e-06 11.1460   4.788e-05
      L2.Avg.Rating      1 6.1200e-07 6.1197e-07  4.3752   0.03932
      Age:L2.Avg.Rating  2 6.2000e-09 3.1100e-09  0.0222   0.97805
      Residuals         89 1.2449e-05 1.3987e-07

(Intercept)            AgeMID               AgeOLD           L2.Avg.Rating
2.137807e-03           -2.675822e-04        -5.309931e-04    1.368522e-06

AgeMID:L2.Avg.Rating   AgeOLD:L2.Avg.Rating
8.164676e-07           7.065787e-07
```

Table D22:
Simon ANCOVA with Self-rated L2 proficiency and Simon incongruent condition 2sq

```
      Response: Inverse meanRT_Incongruent2sq
                        Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age                2 3.1828e-06 1.5914e-06 12.6174    1.499e-05
      L2.Avg.Rating      1 1.6150e-07 1.6148e-07  1.2803    0.2609
      Age:L2.Avg.Rating  2 4.3000e-08 2.1480e-08  0.1703    0.8437
      Residuals         89 1.1225e-05 1.2613e-07

(Intercept)            AgeMID          AgeOLD          L2.Avg.Rating
2.124252e-03          -3.860906e-04   -6.651078e-04   -4.205084e-07

AgeMID:L2.Avg.Rating   AgeOLD:L2.Avg.Rating
1.352528e-06           2.140043e-06
```

Table D23:
Simon ANCOVA with Self-rated L2 proficiency and Simon congruent condition 4sq

```
      Response: Inverse meanRT_congruent 4sq
                        Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age                2 2.2522e-06 1.1261e-06 12.9755   1.135e-05
      L2.Avg.Rating      1 3.6070e-07 3.6069e-07  4.1561   0.04445
      Age:L2.Avg.Rating  2 3.0560e-07 1.5281e-07  1.7607   0.17786
      Residuals         89 7.7239e-06 8.6790e-08

(Intercept)            AgeMID         AgeOLD         L2.Avg.Rating
1.957053e-03          -5.347288e-04  -6.898611e-04   2.831217e-06

AgeMID:L2.Avg.Rating    AgeOLD:L2.Avg.Rating
-5.361371e-06           3.650646e-06
```

Table D24:
Simon ANCOVA with Self-rated L2 proficiency and Simon incongruent condition 4sq

```
      Response: Inverse meanRT_Incongruent4sq
                        Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age                2 2.3806e-06 1.1903e-06 12.1435    2.172e-05
      L2.Avg.Rating      1 2.0590e-07 2.0588e-07  2.1004    0.1508
      Age:L2.Avg.Rating  2 1.8230e-07 9.1150e-08  0.9299    0.3984
      Residuals         89 8.7237e-06 9.8020e-08

(Intercept)            AgeMID         AgeOLD         L2.Avg.Rating
1.865734e-03          -4.493753e-04  -6.682670e-04   2.481832e-06
AgeMID:L2.Avg.Rating   AgeOLD:L2.Avg.Rating
-4.323458e-06          3.324083e-06
```

Table 25:
Simon ANCOVA with Daily L1-L2 home use and Simon congruent condition 2sq

```
      Response: Inverse meanRT_congruent2sq
                       Df     Sum Sq    Mean Sq F value  Pr(>F)
      Age               2 2.9403e-06 1.4702e-06 11.8539  3.098e-05
      Home.L1.L2        1 1.0193e-06 1.0193e-06  8.2188  0.005297
      Age:Home.L1.L2    2 4.6900e-08 2.3430e-08  0.1889  0.828257
      Residuals        80 9.9219e-06 1.2402e-07

(Intercept)            AgeMID            AgeOLD              Home.L1.L2
2.621611e-03           -3.520943e-04     -5.651345e-04       -5.705374e-06
AgeMID:Home.L1.L2      AgeOLD:Home.L1.L2
2.183540e-06           1.460111e-06
```

Table D26:
Simon ANCOVA with Daily L1-L2 home use and Simon incongruent condition 2sq

```
      Response: Inverse meanRT_Incongruent 2sq
                     Df     Sum Sq    Mean Sq F value   Pr(>F)
      Age             2 3.0700e-06 1.5350e-06 12.5906   1.762e-05
      Home.L1.L2      1 4.8860e-07 4.8859e-07  4.0076   0.04868
      Age:Home.L1.L2  2 6.6000e-08 3.3000e-08  0.2707   0.76357
      Residuals      80 9.7532e-06 1.2192e-07

(Intercept)            AgeMID            AgeOLD              Home.L1.L2
2.399338e-03          -4.625579e-04     -5.730792e-04       -4.441000e-06

AgeMID:Home.L1.L2      AgeOLD:Home.L1.L2
2.477985e-06           9.013695e-07
```

Table D27:
Simon ANCOVA with Daily L1-L2 home use and Simon congruent condition 4sq

```
      Response: Inverse meanRT_congruent4sq
                     Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age             2 2.2909e-06 1.1454e-06 14.3678    4.664e-06
      Home.L1.L2      1 1.4750e-07 1.4752e-07  1.8504    0.1776
      Age:Home.L1.L2  2 2.8000e-08 1.3980e-08  0.1753    0.8395
      Residuals      80 6.3778e-06 7.9720e-08

(Intercept)            AgeMID            AgeOLD              Home.L1.L2
1.901333e-03          -1.593441e-04     -5.783112e-04       -2.012816e-06

AgeMID:Home.L1.L2      AgeOLD:Home.L1.L2
5.733581e-08           1.753283e-06
```

Table D28:
Simon ANCOVA with Daily L1-L2 home use and Simon congruent incondition 4sq

```
      Response: Inverse meanRT_Incongruent4sq
                     Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age             2 2.3812e-06 1.1906e-06 13.2788   1.048e-05
      Home.L1.L2      1 2.4970e-07 2.4974e-07  2.7853   0.09904 .
      Age:Home.L1.L2  2 1.0710e-07 5.3530e-08  0.5970   0.55291
      Residuals      80 7.1731e-06 8.9660e-08
(Intercept)            AgeMID            AgeOLD              Home.L1.L2
1.973514e-03          -2.873058e-04     -7.392425e-04      -4.053879e-06

AgeMID:Home.L1.L2      AgeOLD:Home.L1.L2
2.082178e-06           4.011029e-06
```

Table D29:
Simon ANCOVA with L1-L2 school/work use and Simon congruent condition 2sq

```
Response: Inverse meanRT_congruent2sq
                          Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age                  2 2.9403e-06 1.4702e-06 13.4125 9.477e-06
      School.Work.L1.L2    1 1.7208e-06 1.7208e-06 15.6993 0.0001603
      Age:School.Work.L1.L2  2 4.9830e-07 2.4917e-07  2.2732 0.1095971
      Residuals           80 8.7689e-06 1.0961e-07

(Intercept)            AgeMID         AgeOLD         School.Work.L1.L2
2.850252e-03           -5.693343e-04  -1.005428e-03  -9.636001e-06

AgeMID:School.Work.L1.L2      AgeOLD:School.Work.L1.L2
5.614072e-06                  7.812727e
```

Table D30:
Simon ANCOVA with L1-L2 school/work use and Simon incongruent condition 2sq

```
      Response: Inverse meanRT_incongruentB
                          Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age                  2 3.0700e-06 1.5350e-06 12.8552   1.442e-05
      School.Work.L1.L2    1 4.2630e-07 4.2635e-07  3.5706   0.06243
      Age:School.Work.L1.L2  2 3.2900e-07 1.6449e-07  1.3776   0.25810
      Residuals           80 9.5525e-06 1.1941e-07

(Intercept)            AgeMID         AgeOLD         School.Work.L1.L2
2.534940e-03           -6.487613e-04  -8.947074e-04   -6.840928e-06

AgeMID:School.Work.L1.L2      AgeOLD:School.Work.L1.L2
5.458062e-06                  5.436175e-06
```

Table D31:
Simon ANCOVA with L1-L2 school/work use and Simon congruent condition 4sq

```
      Response: Inverse mean RT_congruent 4sq
                            Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age                    2 2.2909e-06 1.1454e-06 14.6773    3.716e-06
      School.Work.L1.L2      1 1.5710e-07 1.5714e-07  2.0135    0.1598
      Age:School.Work.L1.L2  2 1.5280e-07 7.6410e-08  0.9791    0.3801
      Residuals             80 6.2434e-06 7.8040e-08

(Intercept)            AgeMID         AgeOLD         School.Work.L1.L2
2.014590e-03          -3.242193e-04  -7.525025e-04  -3.906951e-06

AgeMID:School.Work.L1.L2      AgeOLD:School.Work.L1.L2
2.547645e-06                  4.375481e-06
```

Table D32:
Simon ANCOVA with L1-L2 school/work use and Simon incongruent condition 4sq

```
      Response: Inverse mean RT_incongruent D

                            Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age                    2 2.3812e-06 1.1906e-06 13.8035   7.079e-06
      School.Work.L1.L2      1 3.8960e-07 3.8957e-07  4.5165   0.03666
      Age:School.Work.L1.L2  2 2.3990e-07 1.1995e-07  1.3906   0.25487
      Residuals             80 6.9004e-06 8.6250e-08

(Intercept)            AgeMID         AgeOLD        School.Work.L1.L2
 2.042387e-03          -3.611377e-04 -8.200924e-04  -5.389783e-06

AgeMID:School.Work.L1.L2      AgeOLD:School.Work.L1.L2
3.309134e-06                  5.490295e-06
```

APPENDIX E

Stroop Task ANCOVA Tables

Table E1: Stroop ANCOVA with Duration active L2 use and mean RT

```
Response: Inverse meanRT
              Df     Sum Sq   Mean Sq F value    Pr(>F)
Age            2 2.1401e-06 1.070e-06 25.1510    2.295e-09
duration       1 3.4400e-08 3.444e-08  0.8096    0.3707
Age:duration   2 4.0400e-08 2.021e-08  0.4751    0.6234
Residuals     88 3.7439e-06 4.254e-08

(Intercept)            AgeMID          AgeOLD        duration
1.183417e-03           -2.298364e-04   -4.309610e-04 1.177459e-05
AgeMID:duration        AgeOLD:duration
-1.091604e-05          -1.067797e-05
```

Table E2: Stroop ANCOVA with Duration active L2 use and congruent mean RT

```
Response: Inverse mean RT congruent
              Df     Sum Sq    Mean Sq F value    Pr(>F)
Age            2 2.3512e-06 1.1756e-06 24.1547    4.346e-09
duration       1 8.5000e-09 8.5000e-09  0.1746    0.6770
Age:duration   2 7.8100e-08 3.9030e-08  0.8019    0.4517
Residuals     88 4.2829e-06 4.8670e-08

(Intercept)            AgeMID          AgeOLD          duration
1.244098e-03           -2.139117e-04   -4.135126e-04    1.534139e-05
AgeMID:duration        AgeOLD:duration
-1.478345e-05          -1.517150e-05
```

Table E3: Stroop ANCOVA with Duration active L2 use and incongruent mean RT

```
Response: Inverse meanRT Incongruent
              Df     Sum Sq    Mean Sq F value    Pr(>F)
Age            2 2.0067e-06 1.0034e-06 24.9242    2.652e-09
duration       1 7.3000e-08 7.3030e-08  1.8142    0.1815
Age:duration   2 4.9800e-08 2.4910e-08  0.6189    0.5409
Residuals     88 3.5426e-06 4.0260e-08

(Intercept)            AgeMID          AgeOLD                duration
1.058403e-03           -2.200982e-04   -4.237151e-04         1.307953e-05

AgeMID:duration        AgeOLD:duration
-1.196360e-05          -1.124296e-05
```

Table E4: Stroop ANCOVA with Duration active L2 use and mean RT control

```
Response: invmeanRTcorr_control
              Df     Sum Sq    Mean Sq F value    Pr(>F)
Age            2 2.1032e-06 1.0516e-06 22.0191    1.764e-08
duration       1 3.3600e-08 3.3640e-08  0.7044    0.4036
Age:duration   2 1.3000e-08 6.5100e-09  0.1363    0.8728
Residuals     88 4.2027e-06 4.7760e-08

(Intercept)            AgeMID          AgeOLD                duration
1.272537e-03           -2.515328e-04   -4.599090e-04         6.745426e-06

AgeMID:duration        AgeOLD:duration
-5.971270e-06           -5.461849e-06
```

Table E5: Stroop ANCOVA with Self-rated L2 proficiency and mean RT control

```
Response: Inverse meanRT
                   Df     Sum Sq    Mean Sq F value   Pr(>F)
Age                 2 2.1401e-06 1.0700e-06 25.8435 1.48e-09
L2.Avg.Rating       1 1.7300e-07 1.7301e-07  4.1786  0.04393
Age:L2.Avg.Rating   2 2.2000e-09 1.0900e-09  0.0263  0.97407
Residuals          88 3.6436e-06 4.1400e-08

(Intercept)            AgeMID          AgeOLD          L2.Avg.Rating
1.172551e-03           -2.591912e-04   -4.429246e-04   1.170198e-06

AgeMID:L2.Avg.Rating   AgeOLD:L2.Avg.Rating
-1.560573e-07           1.167311e
```

Table E6: Stroop ANCOVA with Self-rated L2 proficiency and mean RT congruent

```
Response: Inverse mean RT_congruent
                   Df     Sum Sq    Mean Sq F value   Pr(>F)
Age                 2 2.3512e-06 1.1756e-06 24.4088 3.69e-09
L2.Avg.Rating       1 1.3030e-07 1.3029e-07  2.7051   0.1036
Age:L2.Avg.Rating   2 9.0000e-10 4.3000e-10  0.0088   0.9912
Residuals          88 4.2383e-06 4.8160e-08

(Intercept)            AgeMID          AgeOLD          L2.Avg.Rating
1.279768e-03           -2.903878e-04   -4.834720e-04   7.953206e-07

AgeMID:L2.Avg.Rating   AgeOLD:L2.Avg.Rating
1.345606e-07            2.720573e
```

Table E7: Stroop ANCOVA with Self-rated L2 proficiency and mean RT incongruent

```
      Response: Inverse meanRT_incongruent
                        Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age                2 2.0067e-06 1.0034e-06 25.8199 1.503e-09
      L2.Avg.Rating      1 2.3150e-07 2.3146e-07  5.9563   0.01667
      Age:L2.Avg.Rating  2 1.4300e-08 7.1500e-09  0.1840   0.83223
      Residuals         88 3.4197e-06 3.8860e-08

(Intercept)            AgeMID         AgeOLD         L2.Avg.Rating
9.839923e-04           -1.849270e-04  -3.634770e-04  2.212407e-06

AgeMID:L2.Avg.Rating   AgeOLD:L2.Avg.Rating
-1.134987e-06          -7.362545e-07
```

Table E8: Stroop ANCOVA with Self-rated L2 proficiency and mean RT control

```
      Response: Inverse meanRT_control
                        Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age                2 2.1032e-06 1.0516e-06 22.6223 1.182e-08
      L2.Avg.Rating      1 1.4500e-07 1.4502e-07  3.1196   0.08082
      Age:L2.Avg.Rating  2 1.3700e-08 6.8500e-09  0.1475   0.86311
      Residuals         88 4.0906e-06 4.6480e-08

(Intercept)              AgeMID       AgeOLD         L2.Avg.Rating
1.303655e-03           -3.209670e-04  -5.126085e-04   1.237593e-07

AgeMID:L2.Avg.Rating   AgeOLD:L2.Avg.Rating
8.285096e-07            1.237467e
```

Table E9: Stroop ANCOVA with Daily L1-L2 home use and mean RT

```
      Response: Inverse meanRT
                       Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age               2 2.1121e-06 1.0561e-06 27.8757 6.913e-10
      Home.L1.L2        1 1.7203e-07 1.7203e-07  4.5409    0.0362
      Age:Home.L1.L2    2 1.0057e-07 5.0280e-08  1.3273    0.2710
      Residuals        79 2.9929e-06 3.7880e-08
(Intercept)              AgeMID         AgeOLD         Home.L1.L2
1.511320e-03           -4.158939e-04  -7.373185e-04  -3.783376e-06
AgeMID:Home.L1.L2      AgeOLD:Home.L1.L2
2.317187e-06           3.808975e-06
```

Table E10: Stroop ANCOVA with Daily L1-L2 home use and mean RT congruent

```
Response: Inverse meanRT_congruent
               Df     Sum Sq    Mean Sq F value    Pr(>F)
Age             2 2.3216e-06 1.1608e-06 25.9796 2.135e-09
Home.L1.L2      1 1.5970e-07 1.5969e-07  3.5739   0.06236
Age:Home.L1.L2  2 8.8200e-08 4.4090e-08  0.9868   0.37730
Residuals      79 3.5299e-06 4.4680e-08

(Intercept)            AgeMID         AgeOLD         Home.L1.L2
1.574854e-03         -4.044408e-04  -7.478731e-04  -3.519204e-06

AgeMID:Home.L1.L2      AgeOLD:Home.L1.L2
2.016498e-06           3.615479e-06
```

Table E11: Stroop ANCOVA with Daily L1-L2 home use and mean RT incongruent

```
Response: Inverse meanRT Incongruent
               Df     Sum Sq    Mean Sq F value    Pr(>F)
Age             2 1.9827e-06 9.9133e-07 26.7452 1.349e-09
Home.L1.L2      1 1.9371e-07 1.9371e-07  5.2261   0.02493
Age:Home.L1.L2  2 1.4608e-07 7.3040e-08  1.9705   0.14618
Residuals      79 2.9282e-06 3.7070e-08

(Intercept)            AgeMID         AgeOLD         Home.L1.L2
1.423165e-03         -4.289117e-04  -7.881145e-04  -4.210265e-06

AgeMID:Home.L1.L2      AgeOLD:Home.L1.L2
2.580615e-06           4.656773e-06
```

Table E12: Stroop ANCOVA with Daily L1-L2 home use and mean RT control

```
Response: Inverse meanRT control
               Df     Sum Sq    Mean Sq F value    Pr(>F)
Age             2 2.0681e-06 1.0341e-06 24.9793 3.922e-09
Home.L1.L2      1 1.3220e-07 1.3224e-07  3.1944   0.07773
Age:Home.L1.L2  2 7.0500e-08 3.5270e-08  0.8519   0.43047
Residuals      79 3.2703e-06 4.1400e-08

(Intercept)            AgeMID           AgeOLD           Home.L1.L2
1.539958e-03         -3.989346e-04    -6.759819e-04    -3.330579e-06

AgeMID:Home.L1.L2      AgeOLD:Home.L1.L2
2.166679e-06           3.067646e-06
```

Table E13: Stroop ANCOVA with L1-L2 school/work use and mean RT

```
      Response: Inverse meanRT
                           Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age                   2 2.1121e-06 1.0561e-06 31.1925 1.036e-10
      School.Work.L1.L2     1 2.2833e-07 2.2833e-07  6.7441   0.01121
      Age:School.Work.L1.L2 2 3.6251e-07 1.8126e-07  5.3537   0.00660
      Residuals            79 2.6747e-06 3.3860e-08

(Intercept)            AgeMID         AgeOLD         School.Work.L1.L2
1.625116e-03          -5.346485e-04  -9.274733e-04  -5.801056e-06

AgeMID:School.Work.L1.L2      AgeOLD:School.Work.L1.L2
4.263615e-06                  6.750237e-06
```

Table E14: Stroop ANCOVA with L1-L2 school/work use and mean RT congruent

```
      Response: Inverse meanRT_congruent

                           Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age                   2 2.3216e-06 1.1608e-06 29.6317 2.502e-10
      School.Work.L1.L2     1 2.7462e-07 2.7462e-07  7.0100  0.009782
      Age:School.Work.L1.L2 2 4.0831e-07 2.0415e-07  5.2113  0.007483
      Residuals            79 3.0948e-06 3.9170e-08

(Intercept)            AgeMID         AgeOLD         School.Work.L1.L2
1.716512e-03          -5.343947e-04  -9.801681e-04  -5.953468e-06

AgeMID:School.Work.L1.L2      AgeOLD:School.Work.L1.L2
4.124501e-06                  7.148128e-06
```

Table E15: Stroop ANCOVA with L1-L2 school/work use and mean RT incongruent

```
      Response: Inverse Mean RT_Incongruent
                           Df     Sum Sq    Mean Sq F value    Pr(>F)
      Age                   2 1.9827e-06 9.9133e-07 29.5358 2.643e-10
      School.Work.L1.L2     1 1.7912e-07 1.7912e-07  5.3368  0.023490
      Age:School.Work.L1.L2 2 4.3733e-07 2.1867e-07  6.5150  0.002405
      Residuals            79 2.6515e-06 3.3560e-08

(Intercept)            AgeMID         AgeOLD        School.Work.L1.L2
1.532818e-03          -5.737794e-04  -9.590955e-04  -6.191203e-06
AgeMID:School.Work.L1.L2      AgeOLD:School.Work.L1.L2
4.930458e-06                  7.393115e-06
```

Table E16: Stroop ANCOVA with L1-L2 school/work use and mean RT control

```
  Response: Inverse meanRT_control
                       Df     Sum Sq    Mean Sq F value    Pr(>F)
Age                     2 2.0681e-06 1.0341e-06 27.2773 9.834e-10
School.Work.L1.L2       1 2.3828e-07 2.3828e-07  6.2856   0.01422
Age:School.Work.L1.L2   2 2.4000e-07 1.2000e-07  3.1656   0.04759
Residuals              79 2.9948e-06 3.7910e-08

(Intercept)            AgeMID          AgeOLD          School.Work.L1.L2
1.634621e-03           -4.729393e-04   -8.321938e-04   -5.020933e-06

AgeMID:School.Work.L1.L2       AgeOLD:School.Work.L1.L2
3.429451e-06                   5.493390e-06
```

Table E17: Stroop ANCOVA with Duration active L2 use and interference effect

```
Response: Inverse Interference Effect
             Df  Sum Sq Mean Sq F value Pr(>F)
Age           2    76.5  38.249  0.2190 0.8038
duration      1    15.7  15.731  0.0901 0.7648
Age:duration  2    50.1  25.048  0.1434 0.8666
Residuals    87 15196.1 174.668

(Intercept)            AgeMID          AgeOLD         duration
6.5396541              -1.6621794      -0.3135388     0.1902104
AgeMID:duration        AgeOLD:duration
-0.1796128             -0.2532123
```

Table E18: Stroop ANCOVA with Duration active L2 use and Stroop effect

```
Response: Inverse Stroop Effect
             Df    Sum Sq    Mean Sq F value  Pr(>F)
Age           2 0.0009637 0.00048187  3.6641 0.02961 *
duration      1 0.0001046 0.00010463  0.7956 0.37484
Age:duration  2 0.0002965 0.00014827  1.1274 0.32851
Residuals    88 0.0115731 0.00013151
(Intercept)            AgeMID          AgeOLD         duration
0.0146239239           -0.0071302568   -0.0093757878   -0.0005070189

AgeMID:duration        AgeOLD:duration
0.0005414352           0.0003600230
```

Table E19: Stroop ANCOVA with Daily L1-L2 home use and interference effect

```
Response: Inverse Interference effect
                Df Sum Sq Mean Sq F value Pr(>F)
Age              2   66.5  33.229  0.4393 0.6461
Home.L1.L2       1    8.6   8.623  0.1140 0.7365
Age:Home.L1.L2   2  128.0  63.975  0.8458 0.4331
Residuals       78 5899.8  75.639
```

```
(Intercept)            AgeMID            AgeOLD      Home.L1.L2
13.93159180            -8.82468266       -9.92211826 -0.09614146

AgeMID:Home.L1.L2      AgeOLD:Home.L1.L2
0.11290832             0.10651072
```

Table E20: Stroop ANCOVA L1-L2 School/work use and Stroop interference effect

```
Response: Inverse interference effect
                       Df Sum Sq Mean Sq F value Pr(>F)
Age                     2   66.5  33.229  0.4474 0.6409
School.Work.L1.L2       1    4.5   4.543  0.0612 0.8053
Age:School.Work.L1.L2   2  238.3 119.172  1.6045 0.2076
Residuals              78 5793.5  74.276
```

```
(Intercept)    AgeMID         AgeOLD         School.Work.L1.L2
15.1758118     -10.8137070    -11.9549281    -0.1191641

AgeMID:School.Work.L1.L2      AgeOLD:School.Work.L1.L2
0.1488371                     0.1393947
```

Table E21: Stroop ANCOVA Duration active L2 use and Stroop effect

```
Response: Inverse Stroop effect
             Df    Sum Sq    Mean Sq F value  Pr(>F)
Age           2 0.0009637 0.00048187  3.6641 0.02961
duration      1 0.0001046 0.00010463  0.7956 0.37484
Age:duration  2 0.0002965 0.00014827  1.1274 0.32851
Residuals    88 0.0115731 0.00013151
```

Table E21 cont'd.

```
(Intercept)            AgeMID          AgeOLD         duration
0.0146239239           -0.0071302568   -0.0093757878   -0.0005070189

AgeMID:duration        AgeOLD:duration
0.0005414352           0.0003600230
```

Table E22: Stroop ANCOVA with Self-rated average L2 proficiency and Stroop effect

```
      Response: Inverse Stroop Effect
                        Df    Sum Sq    Mean Sq F value  Pr(>F)
      Age                2 0.0009637 0.00048187  3.5720 0.03225
      L2.Avg.Rating      1 0.0000157 0.00001568  0.1162 0.73401
      Age:L2.Avg.Rating  2 0.0000870 0.00004349  0.3224 0.72528
      Residuals         88 0.0118716 0.00013490

(Intercept)            AgeMID          AgeOLD          L2.Avg.Rating
5.426016e-03         2.823680e-03     -3.904198e-03  9.109633e-05

AgeMID:L2.Avg.Rating   AgeOLD:L2.Avg.Rating
-9.417025e-05          -7.205357e-05
```

Table E23: Stroop ANCOVA with Daily L1-L2 home use and Stroop effect

```
      Response: Inverse Stroop Effect
                     Df    Sum Sq    Mean Sq F value  Pr(>F)
      Age             2 0.0009220 0.00046101  3.4700 0.03594 *
      Home.L1.L2      1 0.0000000 0.00000000  0.0000 0.99824
      Age:Home.L1.L2  2 0.0000415 0.00002074  0.1561 0.85574
      Residuals      79 0.0104956 0.00013286

 (Intercept)            AgeMID            AgeOLD              Home.L1.L2
 1.329189e-02           -7.336071e-03     -8.280502e-03       -2.400894e-05

 AgeMID:Home.L1.L2      AgeOLD:Home.L1.L2
 4.947066e-05           -9.701065e-06
```

Table E24: Stroop ANCOVA with L1-L2 school/work use and Stroop effect

```
      Response: Inverse Stroop Effect
                            Df    Sum Sq    Mean Sq F value  Pr(>F)
      Age                    2 0.0009220 0.00046101  3.4944 0.03514
      School.Work.L1.L2      1 0.0000572 0.00005719  0.4335 0.51221
      Age:School.Work.L1.L2  2 0.0000574 0.00002870  0.2175 0.80500
      Residuals             79 0.0104225 0.00013193
(Intercept)            AgeMID         AgeOLD         School.Work.L1.L2
1.716267e-02           -8.547351e-03  -1.310679e-02  -8.583178e-05

AgeMID:School.Work.L1.L2      AgeOLD:School.Work.L1.L2
7.370945e-05                  6.259087e-05
```

APPENDIX F

Materials

Recruitment Message:



ILLINOIS

The University of Illinois at Urbana-Champaign

CALL for participants:
Dear Sir/Madam:
Hello! You are invited to participate in a research project about language processing in bilinguals and monolinguals (French-ˇEnglish). Your participation will make a significant contribution to the body of research exploring language processing, and will advance knowledge in the areas of language and cognition. Your participation is voluntary and there are no anticipated risks. Please contact Henrietta Boudros, boudros2@illinois.edu or henrietta.boudros@gmail.com, if you would like more information, or to participate. Thank you.

Cher(e) Monsieur/Madame:
Bonjour! Vous êtes invité(e) à participer à un projet de recherche dans le domaine de la psycholinguistique concernant les monolingues et les bilingues (français et anglais). Avec votre participation vous aurez la possibilité de faire une contribution importante dans le domaine linguistique pour l'avancement de nos connaissances en linguistique et en sciences cognitives. Votre participation est volontaire et il n'y a pas de risques prévus. S'il vous plaît contactez Henrietta Boudros, boudros2@illinois.edu ou bien henrietta.boudros@gmail.com, si vous souhaitez en savoir plus ou participer. Merci.

Consent Forms: French and English Versions

FORMULAIRE DE CONSENTEMENT : Le Bilinguisme et la Cognition

Nous vous invitons à participer à une étude conçue pour augmenter nos connaissances sur le traitement de la parole et de la cognition à travers le bilinguisme. Nous vous demandons d'accomplir des tâches variées en français, en anglais et dans les deux langues. Il n' y a priori pas de risques qui résulteraient de votre participation. Cette étude est dirigée par Henrietta Boudros sous la direction de Kiel Christianson, PhD, du département de Educational Psychology et Cognitive Science de l'Université d'Illinois à Champaign-Urbana.

Si vous acceptez de participer à cette étude, nous vous demandons de participer à une séance de recherche qui durera entre une heure et une heure et demie, à un endroit qui vous convient. On vous demandera de compléter un historique de votre bilan linguistique et d'éffectuer des tâches linguistiques et cognitives. Pendant la séance nous ferons tout pour assurer votre comfort et réduire la fatigue au maximum.

Les donnés et l'information obtenues par moi pour cette étude seront-elles confidentielles?

Oui, mais pas toujours. En général, nous ne parlerons à personne de vos informations privées. Quand cette recherche sera incluse dans une discussion ou dans une publication, personne ne saura que vous aviez participé à l'étude. Néanmoins, la règlementation universitaire pourrait nous obliger à divulger vos informations. Par exemple, si la loi ou règlementation universitaire, l'exige, les données de recherche qui vous identifient et le formulaire de consentement que vous signez pourraient être vus ou copiés par les personnes ou groupes suivantes:

-La commission universitaire et le bureau qui révise et approuve les études de recherche: Institutional Review Board (IRB) and Office for Protection of Research Subjects;

-Les contrôleurs de gestion de l'Université d'Illinois et de l'état d'Illinois, et les départements universitaires responsables de la supervision de recherche.

Si vous acceptez d'y participer, toute l'information obtenue pour cette étude sera confidentielle. Votre nom n'apparaîtra jamais dans aucun rapport, publication ou présentation de cette étude.

Nous vous serions très reconnaissants de votre participation à cette étude; toutefois, elle est entièrement volontaire. Si vous décidez d'y participer et vous changez d'avis plus tard, vous pouvez vous retirer de cette étude à tout moment sans aucune pénalité. Votre participation nous aidera a mieux comprendre les différences linguistiques et cognitives entre les monolingues et les bilingues qui porteront sur des décisions importantes dans les domaines clinique, educatif et reglementaire.

Il n'y aucun risque prévu de votre participation dans cette étude au déla des risques qui existent dans la vie quotidienne. Votre décision de participer, de décliner ou de vous retirer de cette étude n'aura aucun effet sur vos relations actuelles ou éventuelles avec L'Université d'Illinois.

Si vous avez des questions concernant ce projet, vous pouvez les adresser à, Henrietta Boudros au US: 312 217-5602/FR: 06.31.88.63.16, et par courriel boudros2@illinois.edu. Vous pouvez la contacter avant, durant et après votre participation. Vous pouvez aussi adresser vos questions au directeur du projet, Dr. Kiel Christianson, PhD, kiel@illinois.edu or 217-265-6558.

Je vous remercie par avance de votre coopération et de votre participation.Vous avez le droit de demander une copie de ce formulaire.

En témoignage de notre gratitude pour votre participation, si vous accomplissez toutes les tâches prevues, vous aurez la possibilité de recevoir comme cadeau la somme de $50.00 par loterie.

Si vous cliquez ci-dessous cela signifie que vous avez lu ce formulaire, que vous avez au moins 18 ans, que vous comprenez le but de cette étude, et que vous acceptez d'y participer volontairement.

La secrétaire exécutive de UIUC Institutional Review Board peut répondre à toutes questions concernant les droits des participants en recherche au 217-333-2760.

J'ACCEPTE DE PARTICIPER JE N'ACCEPTE PAS DE PARTICIPER

English Consent Form:

Online Consent Document

Bilingualism and cognition across the lifespan: How does consistently interacting in more than one language influence cognitive-linguistic processing?

You are invited to participate in a research study on cognitive and linguistic processing in monolinguals and bilinguals. This study conducted by Henrietta Boudros under the direction of Kiel Christianson, PhD, of the Educational Psychology and Cognitive Science Department from the University of Illinois Urbana Champaign.

This study will take approximately one to two hours of your time. You will be asked to complete an online survey about language use and background history, and various linguistic and cognitive processing tasks.

Your decision to participate or decline participation in this study is completely voluntary and you have the right to terminate your participation at any time without penalty. You may skip any questions you do not wish to answer. If you do not wish to participate in this study just close your browser.

Will my study-related information be kept confidential?

Yes, but not always. In general, we will not tell anyone any information about you. When this research is discussed or published, no one will know that you were in the study. However, laws and university rules might require us to disclose information about you. For example, if required by laws or University Policy, study information which identifies you and the consent form signed by you may be seen or copied by the following people or groups:

The university committee and office that reviews and approves research studies, the Institutional Review Board (IRB) and Office for Protection of Research Subjects;

University and state auditors, and Departments of the university responsible for oversight of research;

Your participation in this research will be completely confidential and data will be averaged and reported in aggregate. Possible outlets of dissemination may be journal articles, book chapters or conference presentations. Although your participation in this research may not benefit you personally, it will help us understand cognitive and linguistic processing differences in monolinguals and bilinguals which can impact clinical, educational and policy decisions.

There are no risks to individuals participating in this survey beyond those that exist in daily life. Your decision to participate, decline, or withdraw from participation will have no effect on your current status or future relations with the University of Illinois.

If you have questions about this project, you may contact Henrietta Boudros, MA, at boudros2@illinois.edu or US: 312-217-5602/FR: 06-31-88-63-16. Kiel Christianson, PhD, at kiel@illinois.edu or 217-265-6558.

If you have any questions about your rights as a participant in this study or any concerns or complaints, please contact the University of Illinois Institutional Review Board at 217-333-2670 (collect calls will be accepted if you identify yourself as a research participant) or via email at irb@illinois.edu.

As a token of appreciation for your participation, upon completion of the research protocol you will be entered into a drawing to win a $50.00 gift card. Six gift cards will be awarded.

Please print a copy of this consent form for your records, if you so desire.

I have read and understand the above consent form, I certify that I am 18 years old or older and, by clicking the submit button to participate in the study, I indicate my willingness voluntarily take part in the study.

SUBMIT

Language and Social Background Questionnaire (Adapted from Luk & Bialystok, 2013)

1. Participant ID: _____
2. Today's Date:_____
3. Sex: Male Female
4. Handedness: Left-Handed Right-Handed
5. Date of birth: _____
6. On average, how many hours do you spend working on a computer every day? _____

7a. Do you play video games? Yes No

7b. If yes, how many hours do you play in a week? _____

8. Do you speak any languages in addition to English? If yes, please specify the language(s):

---

9. Do you need to speak/read/write in the non-English language everyday? YES NO

10. Have you ever lived in a place where the non-English language is the dominant communicating language? YES NO

11. If yes, where and for how long? Where:_____ How long:_____

12. Were you born in the US? YES NO (If, yes, skip question 13)

13. a. If No, where were you born? _____
b. WHEN, did you first move to the US: _____

14. What is the first language that you have acquired? _____
15. What is the second language that you have acquired?_____
16. What is your dominant language for the last 5 years? _____
17. A. Do you speak any other language(s)? YES NO
B. If yes, what are the language(s)? _____ _____

18. Where did you learn your second language? HOME SCHOOL COMMUNITY

19. a. At what age did you first start learning your second language informally at home?

_____

19 b. At what age did you first start learning your second language formally at school?

_____

19c. At what age did you first start using your second language actively? _____

In each of the scales below, indicate the proportion of use for English and your other language in daily life. These scales are set up for different activities at home or at school/work. On one end of the continuum you have 100 which indicates that the particular activity in that environment is carried out in ALL ENGLISH. On the other end, you have 0 which indicates you do not use English at all to carry out the activity.

AT HOME

SPEAKING 0 x x x 100

No English All English

LISTENING 0 x x x 100

No English All English

READING 0 x x x 100

No English All English

WRITING 0 x x x 100

No English All English

WATCHING TV 0 x x x 100

No English All English

LISTENING TO RADIO

0 x x x 100

No English All English

AT SCHOOL/WORK

SPEAKING 0 x x x 100

No English All English

LISTENING 0 x x x 100

No English All English

READING 0 x x x 100

No English All English

WRITING 0 x x x 100

No English All English

Relative to a native speaker's performance, rate your proficiency level on a scale of 0-100 for the following activities conducted in your first and second language.

LANGUAGE #1: _____(please indicate)

22a. Speaking 0 x x x 100

Non-native-like Native-like

22b. Understanding 0 x x x 100

(comprehension) Non-native-like Native-like

22c. Reading 0 x x x 100

Non-native-like Native-like

22d. Writing 0 x x x 100

Non-native-like Native-like

LANGUAGE #2: _____(please indicate)

23a. Speaking 0 x x x 100

Non-native-like Native-like

23b. Understanding 0 x x x 100

(comprehension) Non-native-like Native-like

23c. Reading 0 x x x 100

Non-native-like Native-like

23d. Writing 0 x x x 100

Non-native-like Native-like