ABSTRACT

Title of dissertation: AN INVESTIGATION OF INHIBITORY CONTROL IN BILINGUAL APHASIA

Monica Sampson, Doctor of Philosophy, 2015

Dissertation directed by: Yasmeen Faroqi-Shah, Ph.D.

Department of Hearing and Speech Sciences

Speaking involves selecting words and syntactic structures from among numerous competing options. It has been suggested that constant practice in using inhibitory control (IC) to limit within and cross-language competition may be associated with better lexical-semantic IC in proficient bilingual speakers relative to monolingual speakers. This advantage is also theorized to generalize to IC advantages in non-linguistic tasks (bilingual advantage hypothesis; BAH; Bialystok, 2001). However, conflicting evidence with regard to bilingual IC advantages abound, and the nature of relationship between linguistic and domain-general inhibitory control abilities is poorly understood. Since IC is proposed to be critical for lexical retrieval, it is important to understand the nature of IC engaged in individuals with lexical retrieval deficits (aphasia).

Bilingual speakers with aphasia provide an ideal platform to examine the relationship between language processing and IC because there are seemingly contradictory effects at play: while bilingualism may render an IC advantage, acquired brain injury may be associated with less efficient IC. These contrasting effects allow one to tease apart the effects of bilingualism on IC, the domain generality of the bilingual IC

advantage, and relationship between bilingualism, IC and lexical selection. It is important to examine these effects relative to matched monolingual controls to understand (i) if there is a bilingual advantage in lexically based IC and, (ii) the domain generality of any bilingual IC advantage.

To address these aims, IC engaged in (i) lexical retrieval (semantically blocked cyclic naming task), (ii) linguistic processing (Stroop task), and (iii) non-linguistic processing (flanker task) was compared in ten each of bilingual (Tamil-English) and monolingual (English) neurologically healthy speakers and participants with aphasia. Results from neurologically healthy participants revealed a bilingual advantage in the blocked cyclic naming task (lexical IC) but no advantages in the non-lexical Stroop and flanker tasks. Results from participants with aphasia revealed no support for the proposed bilingual advantages in all three experiments. Furthermore, there was no significant association between inhibitory control measures in the three experimental tasks for all participants. Contrary to the predictions of the BAH, the collective results of this study indicate that there is insufficient evidence for the role of bilingualism in modulating non-lexical IC advantages. This lack of consistent support for BAH questions the influence of bilingual experience in modulating non-linguistic inhibitory control. These findings also reveal that the relationship between inhibitory control and lexical retrieval is not influenced by language background (monolingual versus bilingual) in persons with aphasia.

AN INVESTIGATION OF INHIBITORY CONTROL IN BILINGUAL APHASIA

by

Monica Sampson

Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2015

Advisory Committee:

Professor Yasmeen Faroqi-Shah, Chair
Professor Yi Ting Huang
Professor Rochelle Newman
Professor Robert Slevc
Professor Min Wang (Dean's Representative)

Dedication

To my mother

Did you ever know that you're my hero

And everything I would like to be?

I can fly higher than an eagle

For you are the wind beneath my wings

(Bette Midler)

ACKNOWLEDGEMENTS

Looking back on the years leading to this dissertation, I realize that the people whom I am grateful to for their support and inspiration are simply too numerous to acknowledge in such a short space. I am sure I will forget some people here, probably even important ones, and I apologize to them for this. I can only hope I have been able to convey my appreciation to them for the positive impact they have had on me during this journey.

To my advisor, Dr. Yasmeen Faroqi-Shah – your input and guidance throughout my academic tenure at University of Maryland is appreciated. Thank you for all the learning opportunities you have provided. I am also grateful to my dissertation committee members (Drs. Yi Ting Huang, Rochelle Newman, Robert Slevc and Min Wang) for your feedback and encouragement. Special thanks to Dr. Rochelle Newman – your support has been invaluable in many ways.

To Dr. Nan Ratner – thank you for believing in me and encouraging me.

To all my friends and lab mates at UMD – you made a huge difference. Special thanks to Cathy Eaton – you laughed with me, cried with me, cheered me on and celebrated every milestone along the way. You are an amazing woman, my friend! Giovanna Morini, Peitzu Tsai, Arifi Waked, Lisa Pyun – you were all vital parts of this journey at different times and I appreciate your friendship.

To my faculty from Sri Ramachandra University (specifically Prof. Roopa Nagarajan and Dr. Prakash Boominathan) – you encouraged me to never settle and saw the potential in me even when I didn’t.

To the faculty and staff at West Chester University (Drs. Michael Weiss, Cheryl Gunter, Mareile Koenig, Jennifer Means as well as Christine Smith & Gail Toland) – you adopted me into the West Chester family. Your encouragement started me on my academic training in the United States. Each of you has impacted my life in amazing ways!

To my colleagues at the American Speech-Language-Hearing Association – you made the last two years more fun than I could’ve ever imagined. Janet Brown and Gennith Johnson – you both believed in me and stood by me these past two years. I am so lucky to call you both my teammates and friends. Janet – thank you for all your leadership and mentoring. Phyllis Bonelli– thank you for being my friend, my encourager and my consultant. You enrich my time at ASHA.

To my family – My dear father, Jacob Nargunam: you have unconditionally believed in me since the day I was born. I would not be half the person I am without your love, your prayers and your example. What a blessing it is to call you my appa! To my amazing mother, Mallika Jacob: Amma, I would give anything to have you share the end of this journey with me. I hope I have made you proud. Thank you being an inspiration and a wonderful example of a wife and mother. You mean the world to me and I miss you every day. To Preman and Lois – your love and prayers make a huge difference. To

Sheila Sampson - the most amazing mother-in-law a girl could ever be blessed with. You have loved me, cooked for me, cared for me, helped with participant recruitment, data collection/analysis, editing and literally everything else. I can never even begin to thank you enough. I am proud to be your daughter (in-law). To my father-in-law (Rajaseelan Sampson), my sisters (Annie and Esther) – thank you for all the encouragement, the laughs and support. You are incredible! To my extended family and friends around the world – your prayers and your inspiration are much appreciated.

Most importantly and above all, to my husband Josh – You have loved me, encouraged me, prayed for me and picked me up every time I faltered in this journey. I could not have started or finished this without you. You believed I could do this and never hesitated to speak truth in my life. You have sacrificed much during this process – I am deeply grateful for it all. Thank you for being my voice of reason, my sounding board and my rock. You have brought balance to my life. You are an incredible man and I am so blessed to be your wife.

I am grateful that God gave me the opportunity to engage in this endeavor. I am so much more blessed than I deserve!

TABLE OF CONTENTS

LIST OF TABLES xi

LIST OF FIGURES xiv

CHAPTER 1: INTRODUCTION........ 1

CHAPTER 2: REVIEW OF LITERATURE 8

Inhibitory Control........ 8

Domain Generality/Specificity of Inhibitory Control........ 10

Lexical Inhibitory Control in Neurologically Healthy Speakers 15

Competition and inhibition in bilingual lexical retrieval. 20

Lexical-semantic inhibition in monolingual versus bilingual neurologically healthy speakers........ 34

Non-Lexical Inhibitory Control in Monolingual and Bilingual Neurologically Healthy Speakers 35

Linguistic inhibitory control. 35

Non-linguistic inhibitory control. 39

Comparison of lexical and non-lexical IC: Bilingual advantage hypothesis. 42

Inhibitory Control and Aphasia 47

Lexical Inhibitory Control in Individuals with Aphasia 48

IC in monolingual speakers with aphasia. 49

Inhibitory control in bilingual speakers with aphasia. 51

Lexical inhibitory control in monolingual versus bilingual speakers. 54

Non-lexical (linguistic and non-linguistic) inhibitory control in individuals with aphasia 55
Monolingual aphasia. 55
Bilingual aphasia. 56
Monolingual versus bilingual aphasia. 57
Association Between Lexical and Non-Lexical Inhibitory Control in Individuals with aphasia 58
Summary and Statement of the Problem 59
Statement of Purpose 61
CHAPTER 3: RESEARCH QUESTIONS 63
Relevance of the study 68
CHAPTER 4: GENERAL METHODS 71
Participants 71
Participants with aphasia 71
Neurologically healthy Speakers. 85
Design and Analyses 86
CHAPTER 5: AN INVESTIGATION OF LEXICAL-SEMANTIC INHIBITION . 89
Research Question and Hypotheses 91
Method 92
Participants 92
Procedure. 93

Scoring. 96

Analyses. 97

Results 98

Neurologically Healthy Speakers 98

Persons with aphasia 103

Discussion. 110

Lexical retrieval in aphasia 110

Bilingual lexical retrieval 115

CHAPTER 6: AN INVESTIGATION OF LINGUISTICALLY BASED INHIBITORY CONTROL 119

Research Question 120

Hypotheses 120

Task 121

Method 122

Participants. 122

Stimuli. 122

Procedure. 124

Analyses 126

Results 127

Neurologically Healthy Speakers 128

Participants with aphasia 135

Discussion. 141

CHAPTER 7: AN INVESTIGATION OF NON-LEXICAL NON-LINGUISTIC INHIBITORY CONTROL 150

Research Question 150

Hypotheses 151

Task 151

Method 151

Stimuli. 152

Procedure. 152

Analyses 154

Results 154

Neurologically Healthy Speakers 154

Persons with aphasia 158

Discussion 160

CHAPTER 8: ASSOCIATION BETWEEN LEXICALLY, LINGUISTICALLY AND NON-LINGUISTICALLY BASED INHIBITORY CONTROL: AN INDIVIDUAL DIFFERENCES APPROACH 165

Research Question and Hypotheses 166

Analysis Procedure 167

Results 167

Neurologically Healthy Speakers 168

Individuals with aphasia 168

Discussion 171

CHAPTER 9: GENERAL DISCUSSION **177**

Lexical Inhibitory Control **177**

Global and Local Inhibitory Control 179

Non-Lexical Inhibitory Control **181**

Implications for Theories of Bilingualism **184**

Implications for aphasia **188**

Methodological Considerations **190**

Limitations of the Present Study **192**

Directions for Future Research **193**

Conclusions **195**

APPENDIX A **196**

APPENDIX B **200**

APPENDIX C **201**

APPENDIX D **203**

REFERENCES **204**

LIST OF TABLES

Table Number	Title	Page
1	Brain areas implicated in inhibitory control and lexical retrieval in monolingual speakers	13
2	Vowel inventory of Tamil and English (based on Wiltshire and Harnsberger, 2006)	31
3	Consonant inventory of Tamil and English (based on Wiltshire and Harnsberger, 2006)	32
4	Demographic profiles of monolingual and bilingual participants with aphasia	74
5	Self-reported pre- and post-stroke Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfield & Kaushanskaya, 2007) scores of bilingual participants with aphasia	76
6	Background test scores of participants with aphasia	78
7	Normed mean scores (reference values) of working memory subtests (de Renzi & Nichelli, 1975)	82
8	Apraxia test scores of participants with aphasia	84
9	Demographic and language profiles of monolingual and bilingual neurologically healthy participants	88

10	Sample order of stimulus presentation in the homogenous and mixed blocks of the semantic blocking picture naming task	94
11	Mean accuracy (%) and latency (ms) values and SIE (homogenous – mixed) in cycle 1 of the semantically blocked cyclic picture naming task for each participant group	100
12	Results of mixed model repeated measures ANOVA using (transformed) mean semantic interference effects (SIE) in accuracy and latency as dependent variables	102
13	Stimuli and testing conditions used in the computerized non-verbal Stroop task	123
14	Mean response accuracy (%) and latency (ms) in interference and facilitation effects in neurologically healthy speakers and participants with aphasia for each condition of the Stroop task	128
15	Summary of results of mixed model analyses of Stroop interference and facilitation effects in neurologically healthy participants.	130
16	Summary of results of mixed model analyses of accuracy and latency of participants with aphasia in the Stroop tasks	135

17	*Z*-scores of Stroop interference effects (response latency) across participant groups	147
18	Stimuli used in the computerized non-verbal flanker task	151
19	Mean response accuracy (%) and latency (ms) interference and facilitation effects in neurologically healthy participants and individuals with aphasia for each condition of the flanker task	154
20	Summary of results of mixed model analyses of accuracy and latency measures of neurologically healthy speakers and participants with aphasia in the flanker task	156
21	*Z*-scores of Stroop interference effects across participant groups	158
22	The interference effects of bilingual and monolingual participants with and without aphasia in semantically blocked cyclic naming, Stroop and flanker tasks	168
23	Spearman's correlation coefficients (r_s) between interference effects in the semantically blocked cyclic naming, Stroop and flanker tasks in neurologically healthy speakers and individuals with aphasia	170

LIST OF FIGURES

Figure Number	Title	Page
1	Revised hierarchical model of bilingual memory	22
2	Explanatory sketch of Green's IC model (based on Green, 1998)	26
3	SIE across cycles within each blocking condition in a semantically blocked picture naming task. (adapted from Crowther and Martin, 2014)	90
4	Schematic representation of stimulus presentation in the semantically blocked picture naming task	96
5	Mean naming latency (ms) and interference effect (ms; mean difference between homogenous and mixed conditions) on the semantically blocked cyclic picture naming task by repetition cycle in monolingual neurologically healthy speakers (Figure a), bilingual speakers in L1 (Figure b), and bilingual speakers in L2 (Figure c)	99
6	Mean naming accuracy (%) and interference effect (%; mean difference between homogenous and mixed conditions) on the semantically blocked cyclic picture naming task by repetition cycle in monolingual	106

	individuals with aphasia (Figure a), bilingual individuals with aphasia in L1 (Figure b), and bilingual individuals with aphasia in L2 (Figure c)	
7	Mean naming latency (ms) and interference effect (ms; mean difference between homogenous and mixed conditions) on the semantically blocked cyclic picture naming task by repetition cycle in monolingual individuals with aphasia (Figure a), bilingual individuals with aphasia in L1 (Figure b), and bilingual individuals with aphasia in L2 (Figure c)	108
8	Schematic representation of stimulus presentation in the Stroop task in English	125
9	Mean response latency (ms) of monolingual and bilingual neurologically healthy (NH) speakers and persons with aphasia (PWA) in each response language in a computerized adaptation of the color-word Stroop task (Stroop, 1945)	132

CHAPTER 1: INTRODUCTION

The nature of inhibitory control (IC) in bilingual persons with aphasia (BPWA) is the central focus of this dissertation. Bilingualism has been commonly used in scientific and lay terminology to refer to the knowledge and/or use of two or more languages, though the specifics of the definition have been widely debated (e.g., Altarriba & Heredia, 2008; De Groot & Kroll, 1997; Grosjean, 2010). One half (Grosjean, 2010) to two-thirds (Walraff, 2000) of all people in the world has been estimated to routinely use more than one language in everyday communicative contexts. Given this global linguistic profile, it has been suggested that a substantial number of people with communication difficulties post-brain injury (aphasia) are likely to be bilingual (Ansaldo, Marcotte, Scherer & Raboyeau, 2008; Centeno, 2009). Aphasia is marked by impairments in comprehension and/or production of language in one or more modalities, despite relatively preserved intellect. In speakers of two or more languages, the condition is called bilingual aphasia.

The projected incidence of bilingual aphasia is at least 45,000 new cases per year in just the United States (Paradis, 2001). Despite the large numbers of bilingual speakers with aphasia, our understanding of the condition is largely informed by empirical evidence from monolingual aphasia, which is not always relevant or applicable (Lorenzen & Murray, 2008). Rapidly changing demographics and paucity of studies that have directly examined language processing in bilingual speakers highlight the critical need for investigating the nature of deficits in bilingual aphasia. This study helps to address this by providing much needed evidence to inform our understanding of inhibitory control in bilingual speakers with and without aphasia.

A large body of evidence from psycholinguistic and neurolinguistic investigations suggests that when bilingual speakers attempt to retrieve a word in one language, lexical representations in both languages may be activated, and that even highly proficient bilingual speakers cannot effectively deactivate the language not in use (e.g., Bijeljac-Babic, Biardeau, & Grainger, 1997; Colomé, 2001; Hermans, Bongaerts, De Bot, & Schreuder, 1998; Jared & Kroll, 2001; van Hell & Dijkstra, 2002; for a review, see Kroll, Sumutka, & Schwartz, 2005). Some consequences of bilingualism that have been previously reported in literature include a smaller vocabulary in each language than monolinguals have in one language (Bialystok, Craik, & Luk, 2008; Portocarrero, Burright, & Donovick, 2007), reduced verbal fluency (e.g., Bialystok et al., 2008), more word retrieval errors (e.g., Gollan, Fennema-Notestine, Montoya, & Jernigan, 2007), and increased reaction times in lexical decision tasks due to interference (Bialystok, Craik, Green & Gollan, 2009; Gollan, Montoya, Cera, & Sandoval, 2008). Additionally, the "weaker links" hypothesis proposes that bilingual speakers have slower lexical retrieval relative to monolingual speakers because they divide frequency-of-use of the lexical entries between two languages (Gollan & Silverberg, 2001; Gollan & Acenas, 2004; Gollan, Bonanni, et al., 2005; Gollan et al., 2005, 2008).

The dual lexical activation in bilingual speakers suggests that they need to be equipped with cognitive mechanisms necessary to differentially control the production of the target language during specific communication needs. But there is an ongoing debate as to whether activated items in the two languages compete for selection and, if they do, by what mechanism this competition is resolved (e.g., Bloem, van den Boogaard, & La Heij, 2004; Costa, Santesteban & Ivanova, 2006; Finkbeiner, Gollan, & Caramazza, 2006; Kroll, Bobb, Misra, & Guo, 2008). One proposed mechanism for the resolution of this competition is inhibitory control (IC; e.g., Green, 1998; Kroll et al., 2008; Linck, Kroll, & Sunderman, 2009; Meuter & Allport, 1999). IC is an executive function that helps to produce a target response by suppressing the processing or expression of information that would disrupt the efficient completion of the goal at hand (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Dempster, 1992; Kerns et al., 2004; Miyake et al., 2000). Some proposals suggest a top-down IC mechanism regulated by task schemas and contextual demands (e.g., Green, 1998), while other suggest local inhibition between competing lexical candidates (Djikstra & vanHeuven, 1998). Psycholinguistic evidence from tasks engaging IC indicates that neurologically healthy bilingual speakers rely on IC to limit cross-language interference and within language lexical competition during language production (e.g., Costa, Caramazza, & Sebastián-Gallés, 2000; Costa, Roelstraete, & Hartsuiker, 2006; Hermans et al., 1998; Hoshino & Kroll, 2008). Several proposals indicate an amplified role of IC in bilingual speakers due to increased between-language competition in addition to within-language lexical competition (e.g., Green, 1998; Bialystok, 2009). But existing evidence is inadequate to conclusively determine if and how the IC employed in bilingual language processing is different from monolingual language processing.

Furthermore, it has also been suggested that this IC mechanism may not be unique to language processing (irrespective of language background), but is rather a domain-general mechanism that is used to limit interference in any conflict task (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004; Costa, Hernandez, & Sebastian-Galles, 2008). Increasing evidence from neuroimaging research also provides converging evidence that inhibitory mechanisms used to resolve competition among bilingual lexical competitors may involve the same brain regions that have been implicated in the resolution of interference during non-lexical tasks such as Stroop and Simon tasks (e.g., Peterson et al., 2002). Taken together, the currently available data raise the possibility that similar inhibitory mechanisms may support cognitive control in non-lexical tasks and bilingual language control. Consequently, it has been proposed that "if the mechanisms used by bilinguals to control attention to their two language systems recruit the same control processes as those needed to solve nonverbal tasks of executive control, then the experience of constant use should make bilinguals more efficient than monolingual speakers when these processes are required in a variety of tasks and situations." (bilingual advantage hypothesis; BAH; Craik & Bialystok, 2006). The BAH provides the theoretical framework for this study.

While lexical retrieval is proposed to rely on IC, the relationship between lexical retrieval deficits and IC is as yet unresolved. Lexical retrieval deficits are particularly common in individuals with aphasia, who often make errors such as saying *chair* for *table* (semantic paraphasia) suggesting the possibility of inadequate inhibition of competing lexical entries. While factors such as bilingualism have been proposed to render IC advantages, acquired brain injury has been reported to be associated with less efficient IC that may influence lexical retrieval in at least some individuals with aphasia, mostly those with damage to the left inferior frontal gyrus (Biegler, Crowther & Martin, 2008; Green et al., 2010, 2011; Scott & Wilshire, 2010; Wilshire & McCarthy, 2002). So, given that (i) IC has been proposed to be central to bilingual lexical retrieval, (ii) bilingualism has been proposed to provide IC advantages, and (iii) overlapping neural regions have been identified for both language and IC, a systematic investigation of IC in bilingual persons with aphasia (BPWA) provides an ideal platform to test the bilingual advantage hypothesis.

Our understanding of the BAH is currently informed by data from comparisons of only bilingual and monolingual *neurologically healthy* (NH) adults and children on a variety of linguistic and non-linguistically based conflict resolution tasks. Together, results of these data (reviewed in Chapter 2) reveal that (i) there are no studies at the present time that have compared lexical-semantic inhibition (IC engaged in lexical retrieval) within a single language in bilingual and monolingual NH speakers; (ii) on the linguistically based IC tasks such as the Stroop task, irrespective of age, some highly proficient bilingual speakers demonstrate better IC as evidenced by smaller interference effects on conflict trials when compared to matched monolingual speakers (e.g., Bialystok, Craik & Ryan, 2006; Bialystok, Craik & Luk, 2008; Costa et al., 2008; Costa, Hernandez, Costa-Faidella, Sebastian-Galles, 2009; Hernández, Costa, Fuentes, Vivas & Sebastián-Gallés, 2010; Martin-Rhee & Bialystok, 2008). However, these reported bilingual advantages in the Stroop task have not been reliably replicated and their interpretation has been influenced by task and methodological biases (reviewed by Hilchey & Klein, 2011); (iii) bilingual advantages have also been found in a variety of non-linguistic tasks such as the dimensional card-sort task (Bialystok, 1999; Bialystok & Martin, 2004; Carlson & Meltzoff, 2008), the flanker task (Costa et al., 2008; Yang & Lust, 2004), the Simon task (Bialystok et al., 2004; Martin-Rhee & Bialystok 2008), and a modified visual antisaccade task (Bialystok, Craik, & Ryan, 2006). Similar to the Stroop task, this reported bilingual advantage on the non-linguistic tasks has not been consistently replicated (Costa et al., 2008; Emmorey, Luk, Pyers & Bialystok, 2009; Luk, Anderson, Craik, Grady & Bialystok, 2010; Paap & Greenberg, 2013); (iv) despite evidence from neuroimaging data, the association between linguistic and non-linguistic IC cannot be reliably established in monolingual and bilingual adults in behavioral studies (Fan, Flombaum, McCandliss, Thomas, & Posner, 2003; Kousaie & Phillips, 2012; Paap & Greenberg, 2013; Sommer, Fossella, Fan, & Posner, 2003; Stins, Polderman, Boomsma, & de Geus, 2005; Unsworth & Spillers, 2010); (v) and finally, the bilingual advantage hypothesis has not been systematically examined until this point in individuals with aphasia.

Taken together, findings from extant literature highlight the need to examine the bilingual advantage in inhibitory control in lexical retrieval tasks (since this is the basis of the proposed advantage) and in non-lexical tasks that are both linguistically and non-linguistically based. Dissociating the specific context (lexical-semantic, linguistic, non-linguistic processing) that impacts IC in bilingual and monolingual speakers is important because it will aid in understanding the relationship between lexical retrieval deficits and

IC in PWA. Additionally, it will also assist in systematically testing the basis and nature of the proposed bilingual advantage (Green, 1998; Mahon, Costa, Peterson, Vargas, & Caramazza, 2007). For example, though parallel language activation during lexical retrieval has been cited as a potential source of bilingual IC advantage (e.g., Kroll et al., 2008), a direct link between demands in lexical retrieval and IC in bilingual versus monolingual speakers has not yet been established. Studying individuals with language impairment (aphasia) provides a particularly relevant opportunity to examine the linguistic basis of the IC advantages proposed by BAH. That is, if differences in processing context and acquired language impairment lead to differential impact on IC in bilingual versus monolingual speakers, this can contribute to understanding how the proposed control mechanisms interface with language processing.

Therefore, the main aims of this study are to test the bilingual advantage hypothesis and its generality across domains, particularly in the context of damage to left hemisphere language networks. To address these aims, inhibitory control engaged in (i) lexical retrieval (using semantically blocked cyclic naming task), (ii) linguistic processing (using Stroop task), and (iii) non-linguistic processing (using flanker task) was compared in bilingual (Tamil-English) and monolingual (English) NH speakers and PWA. The following chapter provides the theoretical background of the current study and reviews currently available evidence relating to BAH in neurologically healthy speakers and individuals with aphasia.

CHAPTER 2: REVIEW OF LITERATURE

This review of current literature includes discussions of inhibition as an executive function, lexical IC in monolingual and bilingual NH speakers and PWA, and non-lexical (linguistic and non-linguistic) IC in monolingual and bilingual speakers with and without aphasia. Finally the association between lexical-semantic and non-lexical inhibition is discussed within the context of the bilingual advantage hypothesis (BAH).

Inhibitory Control

Inhibitory control (IC) is an executive function that helps to produce a target response by suppressing the processing or expression of information that would disrupt the efficient completion of the goal at hand (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Dempster, 1992; Kerns et al., 2004; Miyake et al., 2000). The role of inhibitory control is not unique to verbal communication; rather, it is vital for almost all everyday activities such as reaching for an object, walking and driving. IC has been found to be critical for processing sensory (auditory/visual), motor and linguistic stimuli and deficits in IC have been implicated in several neuropsychiatric conditions including addictions, schizophrenia, attention deficit hyperactivity disorder, Parkinson's disease, dementia and obsessive-compulsive disorders (e.g., Maruff et al., 2009; Walton et al., 2014). IC deficits impacting various life skills have also been frequently reported in pre-frontal cortex damage and traumatic brain injury (e.g., Elsinger, Zappalà, Chakara, & Barrett, 2011). A small body of evidence has also reported IC deficits in some individuals with aphasia (discussed later in this chapter). Individuals with aphasia provide a particularly unique platform to examine the interaction between IC and language, since unlike the other neuropsychiatric conditions, they have isolated deficits in language processing with relatively spared cognitive functioning.

According to Sinopoli and Dennis's (2012) framework, inhibitory control has four components: (i) *interference control* - suppression of interference from distracting or competing stimuli, (ii) *response flexibility* - ability to shift among the features of a stimulus which an individual will respond to, (iii) *cancellation* - cessation of an already initiated or ongoing action, and (iv) *restraint or response inhibition* – withholding a prepotent response before it is initiated. Additionally, May, Hasher and Kane (1999) also proposed a vital *deletion* component which removes information that is no longer relevant from the working memory in order to facilitate task completion without interference from previously activated representations. All these components of IC have been suggested to be critical for verbal communication (Douglas, 2010) and several non-linguistic tasks (e.g., Aron, Robbins & Poldorack, 2014). The tasks engaged in this study engage all these components to different extents, along with other executive functions such as attention and memory. The behavioral consequence of impaired IC is interference from the non-target information. As a result of interference, the task at hand is likely to take longer to complete (increased response latency) and often with less precision (reduced accuracy; Macleod 1991, 2005). For example, when presented with a semantically related distractor while attempting to name a picture, the interference from the distractor leads individuals to take longer to name the target picture and make more errors (e.g., Schriefers, Meyer &, Levelt, 1990).

Review of available neurobehavioral and psycholinguistic evidence reveals that IC has been frequently examined within the contexts of three domains: (i) lexical-semantic (IC engaged while during word retrieval such as spontaneous speech or picture naming), (ii) linguistic (IC engaged during performance of tasks that do not require explicit lexical processing, but nonetheless utilize linguistic stimuli, such as the Stroop task), and (iii) non-linguistic (IC engaged during performance of tasks that are entirely dissociated from processing any linguistic information, such as the flanker and Simon tasks). Lexical-semantic and linguistic inhibitory control tasks specifically differ in the extent to which they engage semantic processing (greater lexical-semantic processing in naming tasks; Augustinova & Ferrand, 2014) and the extent to which response inhibition is engaged (lesser response inhibition in naming tasks; Augustinova & Ferrand, 2014; Finkbeiner & Caramazza, 2006). Currently available evidence does not conclusively indicate if the same (domain-general) neuro-cognitive mechanisms are engaged when utilizing IC in these different processing situations, or if domain-specific mechanisms are engaged. Recently, support for domain-general nature of IC has been obtained from some evidence that suggests that routine use of lexical IC (such as by bilingual speakers) may lead to IC benefits in other tasks that engage linguistic or non-linguistic processing (Bialystok, 1999, 2007). The following review of literature provides the framework for discussion of these findings.

Domain Generality/Specificity of Inhibitory Control

The extent to which the inhibitory neural and cognitive mechanisms that are recruited for a task are unique to the cognitive processes engaged by that task has been much debated. IC in lexical processing has sometimes been described as a sub-set of domain-general control mechanisms and similar to IC engaged in resolving competition in attentional or perceptual processing (Green, 1998). Brain areas implicated in domain-general IC include bilateral inferior and medial frontal cortex, the caudate and the anterior cingulate (Robbins, 2007; Stuss, 2011), and include those related to language control (left inferior frontal gyrus, the left caudate, the left inferior parietal lobe and the anterior cingulate; Table 1). For example, several studies have indicated that processing incongruent trials on the Stroop (e.g., Milham et al. 2003) and flanker (e.g., van Veen, Cohen, Botvinick, Stenger, & Carter, 2001; Ye & Zhou, 2009) tasks activates Broca's area. Similar activation in the Broca's area has also been identified in word-level lexical retrieval tasks such as picture-naming (e.g., Kan & Thompson-Schill 2004; Schnur et al. 2009) and verb generation (Thompson-Schill et al., 1997) suggesting possibly shared neural resources in resolving competition via inhibition. Similar to monolingual speakers, investigations of bilingual language control (typically involving translation paradigms, language switching paradigms, or language selection paradigms; see Abutalebi & Green, 2008, for a review) have revealed that the brain regions activated during these tasks, which include the prefrontal cortex, the anterior cingulate (e.g., Hernandez, Martinez, & Kohnert, 2000; Rodriguez-Fornells et al., 2005) and the subcortical basal ganglia control circuits (see review by Stocco, Yamasaki, Natalenko & Prat, 2014), highly overlap with those observed in nonlinguistic cognitive control tasks, such as the Stroop and flanker tasks.

These shared neural activations implicated in neuroimaging studies support Abutalebi and Green's (2008) proposal that a domain-general network for IC is also recruited during bilingual tasks. This has been proposed to be the basis of the purported bilingual advantage in IC relative to monolingual speakers (Green, 1998, 2005). It is critical to point out here that not only has activation in similar brain areas been reported for lexical and non-lexical processing, but similar areas are also engaged in monolingual and bilingual speakers during these tasks. This implies that for the bilingual advantage hypothesis to hold true, despite similar neural engagement, some aspect of the bilingual experience needs to hone the IC system differently in bilingual speakers relative to their monolingual counterparts. The BAH suggests that this advantage is endowed by increased practice in regular use of this neural network in bilingual speakers which increases its efficiency (due to constant need to limit interference from non-target language).

Table 1

Brain areas implicated in inhibitory control and lexical retrieval in monolingual speakers

Primary brain regions implicated in inhibitory control (Abutalebi, 2008; Abutalebi & Green, 2007; Crinion et al; 2006; Keil & Kasniak, 2002; Wiecki & Frank, 2013)	Primary brain regions implicated in monolingual lexical retrieval (Abrahams et al., 2003; Indefrey & Levelt, 2004; Spalek & Thompson-Schill, 2008; Whitney, Grossman & Kircher, 2009)
- Bilateral prefrontal and frontal lobes (including the inferior frontal gyrus – Broca's area)	- Left frontal lobe (including the inferior frontal gyrus – Broca's area)
- Parts of parietal and temporal lobes	- Pre-central gyrus
- Limbic cortex	- Parts of temporal lobe (superior, middle temporal gyri)
- Anterior cingulate cortex	- Anterior cingulate cortex
- Basal ganglia	- Basal Ganglia
- Thalamus	- Thalamus
- Hypothalamus	- Cerebellum
- Midbrain	- Fusiform gyrus
	- Insula

Behavioral evidence for domain generality (reviewed later in this chapter) is less conclusive. Several models of IC have proposed inhibition to be a component within the broader framework of executive function (e.g., Miyake et al., 2000; Munakata, Herd, Chatham, Depue, Banich, et al., 2011; Sinopoli and Dennis, 2012). Miller and Cohen

(2001) proposed that, to provide top-down support for language control, processes such as attention, working memory, response selection, and inhibition function as different modules of the same domain-general executive function. Consistent with this, a recent review of the behavioral evidence supporting domain generality and BAH concluded that bilingual and monolingual speakers might not differ in IC per se, but any domain-general executive functioning advantages observed may reflect overall processing efficiency in utilizing monitoring or attentional resources when competition demands are high (Hilchey & Klein, 2011). Hence, experiences and tasks that repeatedly engage, and consequently possibly hone, executive function (such as bilingual lexical retrieval) may impact several components of executive function engaged by these tasks such as attentional control, working memory, metalinguistic awareness, and abstract and symbolic representational skills, in addition to inhibition. However, at this point there is little agreement on whether there is partial or full overlap of bilingual lexical IC with domain-general control mechanisms (e.g., Abutalebi & Green, 2007; Abutalebi, Rosa, Tettamanti, Green & Cappa, 2009; Calbria, Hernandez, Branzi & Costa, 2012).

The proposal of domain-generality of inhibitory control is particularly relevant in the study of language impairments and inhibitory control. If IC is domain-general, then it suggests two important implications. First, it implies that linguistic processing may involve neural and cognitive networks that employ both inhibition and other control-related components of executive function, such as attention and working memory that are common to processing modalities. Secondly, it also suggests that impairment in one domain (such as language processing) could also impact non-linguistic IC. These potential implications of the relationship between lexical retrieval and domain-general IC guide the discussion of IC in the following sections.

Lexical Inhibitory Control in Neurologically Healthy Speakers

***Competition and inhibition in monolingual lexical retrieval*.** The process of selecting and encoding intended words from the mental lexicon during speech production is referred to as *lexical retrieval* (Caramazza, 1997; Levelt, 1989, 2001). Most authors agree that lexical retrieval is a multi-stage process proceeding from conceptual activation to articulatory programming. However, there are different views about the number and nature of intervening stages (e.g., lemma selection, phonological encoding, phonetic encoding, articulation) and whether these are unidirectional feed-forward processes, or involve bidirectional interaction (e.g., Dell, 1986; Levelt, Roelofs, & Meyer, 1999).

One view is that this retrieval process involves a selection mechanism by which the most appropriate word representation (lemma or lexeme, depending on the models) is singled out from among competing entries (e.g., Duyck, van Assche, Drieghe & Hartsuiker, 2007; Schwartz & Kroll, 2006; Van Hell & De Groot, 2008). The competing candidates may be similar in meaning (semantic competition) and/or word form (phonological competition). Alternately, other models of lexical selection propose that competition may not be critical to the process if lexical selection is achieved by differential activation – i.e., the highest activated lexical node is selected for production (e.g., Finkbeiner & Caramazza, 2006; Janssen, Schirm, Mahon, & Caramazza, 2008; Mahon et al., 2007; Miozzo & Caramazza, 2003). Review of this debate is beyond the scope of this project. The key point here is that one proposed mechanism underlying the ability to discriminate among co-activated linguistic representations and limit interference from non-target items by suppressing them is grounded within executive functioning, more specifically inhibitory control (e.g., Bialystok et al., 2008; Roelofs, 2003). Many studies have suggested the involvement of inhibition during lexical access in monolingual word production (e.g., de Zubicaray, McMahon, Eastburn, & Pringle, 2006; de Zubicaray, McMahon, Eastburn, & Wilson, 2002; Jackson, Swainson, Cunnington, & Jackson, 2001; Roelofs, Piai, & Rodriguez, 2011). Though monolingual models of lexical retrieval have detailed the linguistic processing components extensively over the past four decades, inhibitory control mechanisms involved in lexical retrieval are largely underspecified (Shao, Meyer & Roelofs, 2012).

One of the most commonly used experimental paradigms to study IC in lexical retrieval is the *interference paradigm.* It includes experiments that attempt to exacerbate competition at different levels of lexical access to examine how lexical retrieval is achieved under such constraints. These paradigms typically include naming pictures in the presence of a semantically or phonologically related visual or auditory distractors (*picture-word interference task*; e.g., Schriefers et al., 1990; Roelofs, 1992; Damian & Martin, 1999; Levelt et al., 1999; Damian and Bowers, 2003), or naming blocked sets of pictures sampled from the same semantic category (*semantically blocked naming task*; Belke, Meyer, & Damian, 2005; Damien & Martin, 1999; Howard, Howard, Nickels, Colthart & Cole-Virtue, 2006; Schnur, Schwartz, Brecher, & Hodgson, 2006; Starreveld & Le Heij, 1995; Schriefers et al., 1990). Participants have been found to take longer to name the target pictures in the presence of semantically related distractors (e.g. target: table; distractor: chair) than unrelated distractors [e.g., target: table; distractor: shoe; e.g., Roelofs, 1992, 2003; Schriefers et al., 1990; Shao et al., 2012). On the other hand, the presence of phonologically related distractors has been found to facilitate speed of naming (e.g., Meyer & Schriefers, 1991; Starreveld, 2000; Starreveld & La Heij, 1995, 1996). The reported naming cost in semantically related conditions has been found to increase when individuals sequentially name pictures from within the same superordinate semantic category such as animals or fruits (cumulative semantic cost; Biegler et al., 2008; Howard et al., 2006; Schnur et al., 2006, 2009).

Cumulative semantic cost has been frequently studied using the semantically blocked naming task. This is a speeded picture-naming task where the targets are grouped by semantic similarity (*homogenous condition*), or are in mixed category sets (*mixed condition*). It has been proposed that in the homogenous blocks, previously named items continue to be in a state of activation during naming of subsequent items given the strength of their association as well as from spreading activation from related items. The need to inhibit this persistent activation of competitors is said to induce a delay in lexical retrieval (Biegler et al., 2008; Brown, 1981; Howard et al., 2006; Schnur et al., 2006, 2009). It has been proposed that the mean differences between homogenous and mixed blocks (semantic interference effect; SIE) in naming accuracy and latency could provide a measure of inhibitory control (Kroll & Curley, 1988; Kroll & Stewart, 1994; Damian & Bowers, 2003; Damian, Vigliocco, & Levelt, 2001; Maess, Friederici, Damian, Meyer, & Levelt, 2002). Hence, larger values of SIE are considered to indicate less efficient inhibition of competitors. Alternately, Oppenheim and colleagues (Oppenheim, Dell & Schwartz, 2010; Dell, Oppenheim, & Kittredge, 2008; Oppenheim et al., 2007) suggest that increasing the activation strength of the target item while weakening the connections between semantic and competing lexical representations is sufficient to explain the cumulative semantic cost (without the need to also assume lexical selection by competition). So according to this account, when a target word is named, its semantically related lexical entries all have weaker activations. By this token, the increased response latency of consecutively named targets within the same category is a direct result of the longer time it takes to overcome the previously weakened entry.

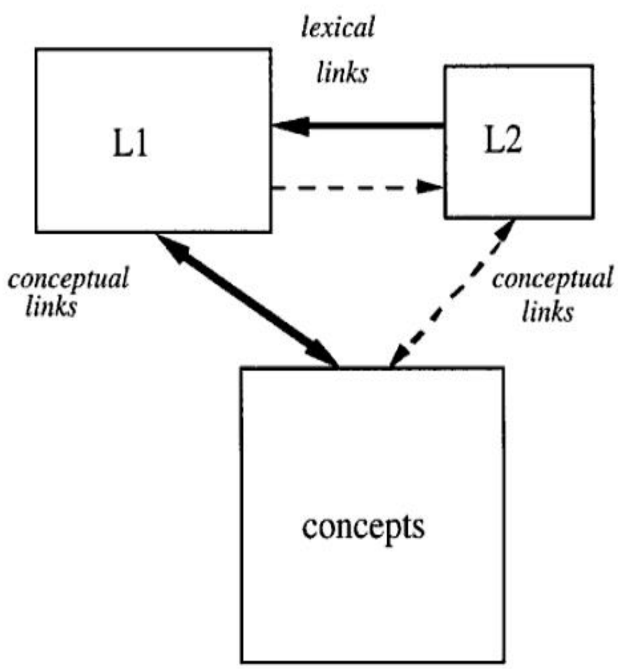
The SIE has been described as the lexical analog of the interference effect observed during the Stroop task (e.g., Piai, Roelofs & van der Meij, 2012, Roelofs, 2003; van Maanen, van Rijn & Borst, 2009); that is, the naming costs in both tasks have been suggested to result from the resolution of competition from a distractor. However, while the naming task involves semantically based competition, the Stroop task does not. It has been found that SIEs in the blocked naming task increase with repetition on successive presentations (e.g., Hodgson, Schwartz, Brecher, & Rossi, 2003). Hence a variation of the semantically blocked naming task, where the blocks were cyclically repeated, was introduced (cyclic naming task; e.g., Rahman & Melinger, 2007; Belke et al., 2005; Pickard, Brandon, Hodgson, Schwartz, & Thompson-Schill, 2003). This *semantically blocked cyclic picture naming* experimental paradigm is used in this study to examine the intactness of inhibitory control in monolingual and bilingual speakers with and without aphasia.

SIE in the semantically blocked naming task has been consistently replicated in monolingual neurologically healthy adults (Belke et al., 2005; Crowther & Martin 2014; Kroll & Stewart, 1994; Damian et al., 2001; Abdel-Rahman & Melinger, 2007; Aristei, Melinger & Rahman, 2011). However, there are no available data from the blocked naming paradigm in bilingual speakers. However, Runnqvist, Strijkers, Alario and Costa (2012) examined semantic interference in a series of five experiments completed by more than 250 Spanish-Catalan college age bilingual speakers. These participants named pictures of the semantically related words in blocks where the response language was either alternated or blocked by L1 or L2. Since the purpose of this study was to examine global inhibition of one of the languages of highly proficient bilingual speakers, the experimental set-up involved blocked by response language demands and not semantic relatedness. Results indicated that the semantic interference effects were seen in both L1 and L2 (experiment 1) and were of similar magnitude across (experiment 2) and within languages (experiment 3). Similar to Howard et al. (2006), naming latencies of bilingual NH speakers in these experiments increased when items from the same semantic category were named in succession. However, while the monolingual participants in Howard et al.'s (2006) study demonstrated a mean increase of 30 ms in English naming of each successive semantically blocked item, the bilingual speakers in Runnqvist et al.'s (2012) study showed only an increase of 18 ms with each ordinal position within homogenous semantic blocks. The magnitude of the effect was similar in L1 and L2. Furthermore, Runnqvist et al. (2012) found that alternating the response language within a testing condition (experiments 2, 4, 5) did not reduce the effect. So, despite the assumed greater lexical competition in bilingual speakers, they demonstrated smaller interference effects (Runnqvist et al., 2012) than monolingual speakers (reported by Howard et al., 2006). This could be taken as preliminary evidence for a bilingual advantage in lexical IC (at least in highly proficient bilingual NH speakers) and directly follows the prediction of BAH. However, it is important to note a few caveats while interpreting these results in the context of the present study. First, Runnqvist et al. (2012) did not have naming blocks sorted by semantic relatedness (homogenous versus mixed condition) but rather had the blocks sorted by response language demands. Hence, there was no measure of a semantic interference effect relative to the mixed low-competition condition to enable comparison to the current study or other studies using the blocked naming paradigms. Secondly, the cumulative interference effect cannot be interpreted since the experiments did not include a cyclic paradigm. Finally, there was no control group of monolingual speakers. Hence, interpretation of the results relative to IC employed in monolingual lexical retrieval should be conducted with caution. In conclusion, though this study provides some preliminary evidence for the predictions of BAH, methodological limitations preclude strong support of the hypothesis.

Competition and inhibition in bilingual lexical retrieval. Following from monolingual lexical retrieval models, it has been suggested that in bilingual speakers the competition during word production could arise from within the language being used (target language) and well as the language that is not in use (non-target language; e.g., Abutalebi, 2008; Colomé & Miozzo, 2010; Costa, Miozzo & Caramazza, 1999; Kroll et al., 2008; Kroll & Stewart, 1994; van Hell & Tanner, 2012). The activation of the target and related items in both languages is said to occur because of a common semantic system across languages within a bilingual speaker's lexicon. The revised hierarchical model (Kroll & Stewart, 1994) highlights this interconnectivity that exists between both lexicons in a bilingual individual (Figure 1). Numerous studies have examined whether the non-target language is activated during lexical selection in bilingual speakers and have found evidence of dual-language activation (e.g., Colomé, 2001; Colomé & Miozzo, 2010; Costa & Caramazza, 1999; Costa et al., 1999, 2000; Costa, Colomé, Gómez, & Sebastián-Gallés, 2003; Hermans et al., 1998; Jared & Kroll, 2001; Poulisse, 1999; Poulisse & Bongaerts, 1994; van Hell & Dijkstra, 2002). For example, Blumenfeld and Marian (2007) used the eye-tracking paradigm with German-English and English-German bilingual speakers to examine the influence of language proficiency on parallel lexicon activation. The results showed that only highly fluent German-English bilingual speakers activated German while processing English-specific targets. Other studies have also shown that higher language proficiency produces stronger parallel activation of lexicons in bilingual speakers (Jared & Kroll, 2001; van Hell & Dijkstra, 2002).

Figure 1

Revised hierarchical model of bilingual memory. Taken from Kroll and Stewart (1994). The solid lines indicate a strong connection while the dotted lines indicate a weaker connection. In the model, Kroll and Stewart explain that the link between L2 and concepts strengthens as proficiency in L2 increases



Though all theories agree on dual activation of lemmas from both languages, the extent to which these activated representations actually compete for selection (and are therefore inhibited) continues to be debated. This debate has given rise to two schools of thought - *language selective* theories (suggesting that when a bilingual speaker attempts to retrieve a word in one language, only the related lexical entries of the target language compete for selection; e.g., Costa & Caramazza, 1999; Costa et al., 1999) and *language non-selective* theories (suggesting that when bilingual speakers attempt to retrieve a specific word in one of their languages, the lexical representations corresponding to that item in both the languages simultaneously compete for selection; e.g., Green, 1986, 1998; Hermans et al., 1998).

But irrespective of which model is considered, the co-activation of representations in both languages suggests that bilingual speakers are equipped with some mechanism that examines available options and selectively controls production, not just within the target language but across languages as well. Currently available empirical evidence suggests that the intention to speak one language alone may not be sufficient to restrict activation to that language even in tasks completed in a strong monolingual context (such as sentence reading that provide strong language cues; Duyck et al., 2007; Libben & Titone, 2009; Schwartz & Kroll, 2006). While some evidence suggests that external cues such as script differences between languages may sometimes limit the extent of cross-language competition (e.g., Kim & Davis, 2003), these findings have not been consistently replicated (e.g. Hoshino & Kroll, 2006). Together, these findings suggest that external cues to language membership may aid, but are not sufficient to limit cross-language competition. Therefore, a vital control mechanism that efficiently restrains within-language and cross-language competition is imperative to facilitate successful lexical retrieval in bilingual speakers. The control mechanism engaged during lexical retrieval in bilingual speakers has been suggested to involve several executive functions such as working memory (e.g., Hernandez, Costa, & Humphreys, 2012), conflict monitoring and resolution (e.g., Costa et al., 2009; Green, 1998, Hoshino & Kroll, 2006; Teubner-Rhodes et al., 2012) and shifting attention (e.g., Bialystok, 1986, 1988, 1992,

1998) and has been hypothesized to proceed via inhibition of non-target items (e.g., Green, 1986, 1998).

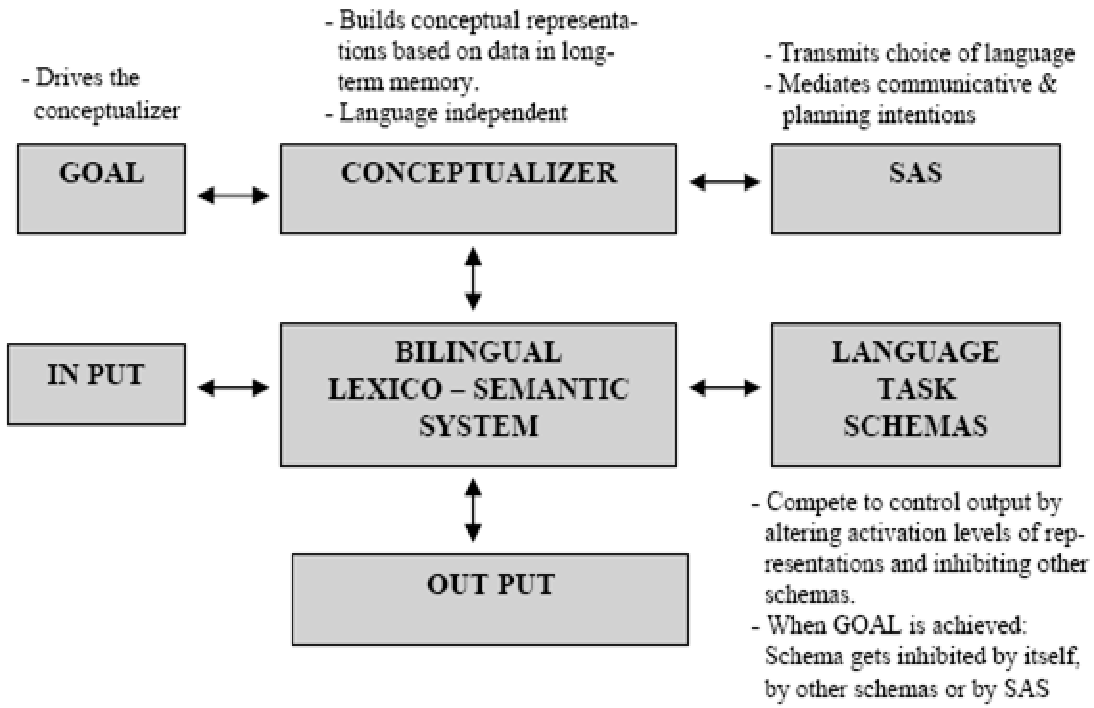
The bilingual model of lexical retrieval that explicitly proposes an inhibitory control mechanism is the Inhibitory Control Model (ICM) proposed by Green (1986, 1993, 1998). The core assumption of this model is that language production is an action that is analogous to non-linguistic physical actions (Green, 1998; Abutalebi & Green, 2007). Similar to any physical action, bilingual lexical retrieval is said to engage *task schemas* for different communicative goals. Task schemas are action sequences that are determined by a conceptualizer to achieve specific communication goals (such as naming, translation, etc.). For any given goal, it is suggested that multiple task schemas are activated and compete. The *supervisory attentional system* (SAS; Baddeley, 1986; Norman & Shallice, 1986; Shallice & Burgess, 1996) is suggested to regulate these task schemas. The SAS is an attentional control construct that has been hypothesized to regulate interference within non-routine activities (e.g., communicating in a non-dominant language). The SAS is assumed to suppress the non-target schemas via IC, and monitors the successful implementation of target goals based on input from the bilingual lexico-semantic system. Within the bilingual lexico-semantic system, *language tags* specify the language identity of each lemma. Therefore, according to the ICM, when a bilingual speaker attempts to retrieve a word in a target language, competition suppression is achieved via three mechanisms that work in tandem: (i) *language task schemas* that regulate the outputs from the lexico-semantic system by altering the activation levels of representation and by inhibiting other schemas to achieve the communication goal, (ii) *language tags* that specify the language identity of each lemma within the bilingual lexicon, and (iii) *supervisory attentional system (SAS)* which provides the attentional control that suppresses the activation of the non-target schemas and lemmas (Figure 2).

Green (1998) suggests that IC is reactive and the amount of inhibition of the non-target language is proportional to the strength of activation of these unintended lemmas, i.e., the higher the activation levels of the competing entries from the non-target language, the greater the amount of inhibition needed to suppress them in order to communicate in a single language mode (Green, 1986, 1993, 1998; Linck et al., 2008). Hence, routine inhibition of highly activated competitors (such as during lexical retrieval in highly proficient bilingual speakers) is suggested to provide repeated practice in use of IC, which could strengthen IC skills in unique ways (Bialystok et al., 2004).

Green (1998) proposed that the IC exercised within bilingual lexical retrieval is

Figure 2

Explanatory sketch of Green's Inhibitory Control Model (Based on Green, 1998). This model proposes that IC is achieved via three mechanisms: the language task schemas, the language tags within the bilingual lexico-semantic system and the supervisory attentional system (SAS)



domain-general and part of the larger executive function system. This means that the IC component of the executive function system that is used for inhibiting lexical competition is the same (or at least part of the same) IC that is used for non-linguistic IC tasks. As mentioned earlier, some neuroimaging work suggests that bilingual speakers use neural regions similar to those responsible for non-verbal domain general cognitive control including the dorsal anterior cingulate cortex, the prefrontal cortex, and the caudate nuclei (e.g., Abutalebi & Green, 2007, 2008; Crinion et al. 2006; Garbin et al., 2010, 2011; Guo, Liu, Misra & Kroll, 2011; Wang, Kuhl et al., 2009; Wang, Xue, et al., 2007). Bialystok expands on this proposed domain generality by suggesting that the mechanism by which lexical selection is achieved in bilingual speakers is “the general-purpose executive control system [that] is recruited into linguistic processing, a configuration not found for monolinguals…. If the executive control system is recruited for ordinary language processing, then that system will be fortified through practice [in bilingual speakers], possibly because it integrates with the linguistic systems generally required in these situations to create a more distributed and more robust network.” (Bialystok, 2011, p. 229); reviewed in Bialystok, Craik, Green, & Gollan, 2009).

Much of the support for cross-language inhibitory control during lexical retrieval comes from examining language switching costs in neurologically healthy bilingual speakers. The logic here is that if one language must be inhibited to produce the other in a speeded cued naming task, then these differential inhibitory demands would be revealed in the pattern of linguistic processing costs observed following a language switch. When switching into the L1, the active suppression of the dominant task on the preceding non-dominant trial was suggested to persist and hence disrupt processing on the subsequent trial. This switch-cost asymmetry has been robustly replicated during single word retrieval in speakers of different languages of varying levels of proficiency (Abutalebi & Green, 2007; Costa & Santesteban, 2004; Costa et al., 2006; Finkbeiner, Almeida, Janssen, & Caramazza, 2006; Hernandez & Kohnert, 1999; Hernandez et al., 2000; Jackson et al., 2001; Linck et al., 2008; Schweitzer & Sunderman, 2008). Similar switch costs have also been reported in natural speech situations (e.g., Grosjean, 1988, 1997; Li,

1996) and neurolinguistic studies of brain activity (e.g., Abutalebi & Green, 2008; Hernandez, Dapretto, Mazziotta & Bookheimer, 2001; Price, Green, & von Studnitz, 1999).

While cross-language inhibition has been extensively studied in bilingual speakers, we currently have no systematic investigations that examine bilingual speakers' efficiency of handling within language competition during lexical retrieval relative to their monolingual counterparts. If IC is intricately related to and honed by language experience and is as pervasive as suggested by Green's IC model, then it would be expected that bilingual speakers would more efficiently handle within-language competition during lexical retrieval, compared to monolingual speakers. On the other hand, it is also possible that dividing the available cognitive control resources between within and between-language inhibition during lexical retrieval may actually result in greater demands and consequently less efficient IC in bilingual than monolingual speakers in within-language competition. This notion of relative bilingual advantage in both lexical and non-lexical contexts as suggested by the ICM is further examined in this dissertation.

Though bilingualism has been proposed to provide advantages in executive functions, it has been reported to result in disadvantages in lexical retrieval. Studies comparing monolingual and bilingual NH speakers have shown smaller vocabulary size (Bialystok & Luk, 2012; Bialystok, Luk, Peets, & Yang, 2010; Portocarrero, Burright, & Donovick, 2007), slower picture naming times (Gollan, Montoya, Fennema- Notestine, & Morris, 2005; Poarch & Van Hell, 2012), more tip-of-the-tongue states (Gollan, Montoya, & Werner, 2002), and more interference in lexical decision tasks (Michael & Gollan, 2005) in bilingual speakers of all ages. The combination of reduced lexical resources and the need to recruit greater inhibition to resolve competition has been suggested to make linguistic processing more effortful for bilingual speakers. Thus, they tend to perform more poorly than monolingual individuals in tasks that rely on vocabulary knowledge or lexical access.

Factors influencing inhibitory control in bilingual lexical retrieval. Several factors have been suggested to influence inhibitory control in lexical retrieval in bilingual speakers with and without aphasia. These factors can be broadly classified as participant related, language related, task related and stimulus related. While the influence of each of these factors can constitute intriguing experimental investigations by themselves, in this study, their influences are not individually examined but rather controlled for to the maximum extent possible. Hence, a brief discussion of these factors is essential to validate the methodology employed in this study.

Participant related factors. Several participant related factors such as age/manner of acquisition of and relative proficiency in the two languages impact bilingual lexical retrieval in neurologically healthy speakers (Green, 2008; Lorenzen & Murray, 2008; Ijalba, Obler & Chengappa, 2004). Those bilingual speakers who acquired both languages early in life have been found to have more overlapping neural representations of L1 and L2 (e.g., Hernandez et al., 2000). Marked differences in accuracy, latency and switching costs have been noted in bilingual speakers with varying proficiency in their constituent languages (e.g., Costa & Santestaban, 2004; Green, 2005; Kroll & Curley, 1988; Chen & Leung, 1989). Better IC has been reported in bilingual speakers who acquired both languages early, presumably because of increased practice in using IC. Additionally, in speakers with bilingual aphasia, other participant variables such as site and size of lesion, time since onset and duration, language and focus of speech therapy may also influence lexical retrieval (Grosjean, 1998). In the present study, we attempted to minimize the influence of these participant related variables using stringent criteria for participant selection. All participants in the study were highly proficient in both languages prior to onset of stroke. They were all at least one year post-onset of aphasia to eliminate any confounds relating to spontaneous recovery. More specific participant selection criteria will be described under general methods.

Language related factors. Another factor that has been found to underlie conflicting findings in several psycholinguistic studies of language processing is the constituent languages of the bilingual speakers. It has often been found that speakers of languages that are more orthographically and phonologically distinct often perform differently in lexical processing/retrieval tasks (e.g., Goral, Levy, Obler & Cohen, 2006; Goral, Levy & Kastl, 2010). Specific to IC, it is likely that languages that are more similar to each other could be activated together more often and would hence require greater inhibition to suppress competitors from the non-target language (van Heuven, Conklin, Coderre & Dijkstra, 2011). The influence of cross-language similarity on lexical retrieval is controlled for in this study by the use of participants who speak dissimilar languages – Tamil and English.

Tamil is a diglossic Dravidian language spoken by more than 65 million people, primarily in India and Sri Lanka. Large Tamil-speaking communities also reside in Malaysia, Singapore, South Africa, and Mauritius. Tamil is a syllable-timed language made of ten vowels, two diphthongs and 18 consonants (Thangarajan & Natarajan, 2008). Tamil shares all its vowels and diphthongs with English (Table 2), whereas, only ten consonants are shared between the two languages (Table 3). Tamil has alpha-syllabic orthography represented by 247 compound syllabic graphemes (made of consonant-vowel combinations). Though Tamil script does not have distinct letters for voiced and unvoiced plosives, both are present in spoken form as allophones.

Table 2

Vowel inventory of Tamil and English (based on Wiltshire and Harnsberger, 2006)

	Short Vowels			**Long Vowels**		
Front	**Front**	**Central**	**Back**	**Front**	**Central**	**Back**
Close	**i**		**u**	**i:**		**u: ʊ**
Mid	**e ɛ**	**ɘ ə ɜ**	**o**	**e:**		**o:**
Open	**a æ**		**ɔ ɑ ɒ ʌ**	**a:**		

Note: Phonemes common to both languages are in black and those unique to English are highlighted in red

Table 3

Consonant inventory of Tamil and English (based on Wiltshire and Harnsberger, 2006)

	Bilabial	Labio-dental	Inter-dental	Alveolar	Retroflex	Palatal	Velar	Glottal
Plosive	**p b***		**t̪ d̪***	**t d***	**ʈ**		**k g***	
Nasal	**m**			**n**	**ɳ**	**ɲ**		
Tap				**ɾ**				
Fricative		**f v**	**θ ð**	**s z**		**ʃ* ʒ**		**h***
Affricate						**tʃ dʒ**		
Approximant					**ɻ**			
Glide	**w ʍ**	**ʋ**				**j**		
Liquid				**l r**	**ɭ**			

Note: Phonemes common to both languages are in black; phonemes unique to English are highlighted in red and those unique to Tamil are in green. * These phonemes are allophonic variations that exist in spoken but not written Tamil, primarily in words borrowed from other languages

Task related factors. The tasks used to assess inhibitory control play a vital role in the interpretation of the results. As Grosjean (1998) stresses, different tasks require participants to be in different *language modes*. Language mode refers to the state of activation of the bilingual speakers' linguistic representations during language production and processing (Grosjean, 1998). At one end of the continuum, bilingual speakers could theoretically be in a totally monolingual language mode in which one language is active and the other relatively deactivated (e.g., word reading in a single language). At the other end, they are in a bilingual language mode in which both languages are active (e.g., translation and language switching). It has been suggested that inhibitory control is differently employed at different points along this continuum. Assuming increased cross-language competition in language switching and translation tasks, a greater amount of inhibitory control is likely to be employed here when compared to word reading in a single language. For example, Abutalebi, Annoni, et al. (2007) found that the specific activity of the left caudate in bilingual speakers was dependent on the language and task context. While naming in L1 in a bilingual context increased activation in the left caudate and ACC, this activation was found to be absent when participants were completed the task in a monolingual L1 naming context. A recent review by Hervais-Adelman, Moser-Mercer and Golestani (2011) also indicates that there is more brain activation within the frontal and sub-cortical control circuits for tasks that require more inhibition such as translation and interpretation versus naming.

Stimuli related factors. Several factors related to stimuli used in the experimental tasks have been found to influence lexical retrieval. Variables such as word frequency (lower frequency), word familiarity (less familiar), word length (longer word length), and word imageability (less imageable words) have all been found to negatively impact accuracy and speed of lexical retrieval in monolingual and bilingual speakers (e.g., Costa et al., 2000; Costa, Colome, & Caramazza, 2000; de Groot, Dannenburg, & van Hell, 1994; de Groot, Borgwaldt, Bos, & van den Eijnden, 2002; van Hell & De Groot, 1998). Also, words that share greater cross-linguistic similarity are expected to be activated together and hence involve different inhibitory mechanisms compared to words that share fewer attributed across languages. For example, cognates (words that share meaning and orthographic/phonological form across languages) are retrieved faster than non-cognate words (Lalor & Kirsner, 2001; Roberts & Deslauriers, 1999). In order to control for these stimuli-related confounds, all stimuli used in the present study were concrete picturable nouns that are non-cognates in Tamil and English. In lieu of lexical frequency norms, comparable word familiarity norms were obtained by norming the stimuli on neurologically healthy bilingual Tamil-English speakers.

Lexical-semantic inhibition in monolingual versus bilingual neurologically healthy speakers. As reviewed in the previous sections on competition and inhibition in monolingual and bilingual lexical retrieval, there are several sources of evidence for use of IC during lexical retrieval by both groups of speakers. However, bilingual speakers have been suggested to rely more on and have more practice with inhibitory control in lexical retrieval given that they have to manage two sources of inhibition (within language and across languages) as opposed to monolingual speakers who manage within language interference only. Based on Green's ICM (1998), if bilingualism influences lexical inhibitory control, then bilingual speakers will be expected to perform differently than monolingual speakers when they encounter within language lexical-semantic interference. However, a review of existing literature indicates that there are no studies at the present time that have directly compared lexical-semantic inhibition within a single language in bilingual and monolingual neurologically healthy speakers. The present study is the first to systematically examine this in groups of highly proficient bilingual speakers and matched monolingual controls.

Non-Lexical Inhibitory Control in Monolingual and Bilingual Neurologically Healthy Speakers

As indicated earlier, inhibitory control involves suppression of non-target competitors while performing any goal-directed activity (Dempster, 1992), and is not limited to lexical retrieval. In fact, many researchers consider that the IC used in lexical retrieval may not be unique to language processing but is rather domain-general (common to any goal directed activity that involves conflict resolution; Green, 1998). Non-lexical inhibition has been studied by using a variety of tasks, two of which are: tasks that involve linguistic stimuli such as words (linguistic IC) and tasks that involve non-linguistic stimuli such as shapes and symbols (non-linguistic IC).

Linguistic inhibitory control. Several tasks have been used to measure linguistic IC, the most common of which is the Stroop task (Stroop, 1935). In the classic Stroop task (also known as the color-word Stroop task), participants are presented with names of colors (red, green, etc.) printed in different ink colors (RED in red or green ink), and are asked to respond to the ink color. The classic color-word Stroop task is considered to be a "linguistic" task because it utilizes words, and presumably automatically activates the meaning of the printed word. In this task, it is suggested that IC is recruited to overcome the interference from the automaticity of reading the words, in order to respond accurately to the color of the ink in this task (Hilchey & Klein, 2011). The interference from the automaticity of word reading has been found to result in lower accuracy and slower reaction times when responding to incongruent items (items where the color and word mismatch; e.g., RED) than congruent items (items where the color and word match;

e.g., RED), relative to a neutral condition (Stroop interference effect). The Stroop task has been manipulated by changing response modality (verbal versus manual) or by altering the cognitive complexity of the tasks, for example, by increasing demands of working memory or changing the complexity of the stimuli themselves (e.g., bilingual Stroop task, where stimuli are presented in one language, and responses were made in the other language) to assess inhibition as a function of other task dependent variables. Though the exact underlying cognitive and neural process underlying the Stroop interference effect has often been disputed, as McLeod (1991, 2005) reviewed, the Stroop interference effect has been in general, robustly noted irrespective of the response modality, language and task based variation.

The Stroop interference effect has, however, been found to vary as a function of individual (Kane & Engle, 2003) and developmental differences (Homack & Riccio, 2004; Zelazo, Craik & Booth, 2004). Larger values of the interference effect are taken to reflect less efficient inhibitory control (McLeod, 1991). The Stroop interference effect has also been found to vary across the life span with smaller effect sizes noted with the development of inhibitory control in children (Dempster, 1992; Harnishfeger, 1995) and larger Stroop interference effect sizes noted in late adulthood (Bruyer & Scailquin, 1999; Davis, Fujawa & Shikano, 2002; Hartman & Hasher, 1991; May, Hasher & Stoltzfus, 1993; McDowd, Oseas-Kreger, & Filion, 1995; Rush, Barch & Braver, 2006; Weir, Bruun & Barber, 1997; West & Baylis, 1998). Larger Stroop interference effects in older adults have been attributed to an overall slowing in processing (also resulting in corresponding longer latencies in congruent trials; e.g., Salthouse & Meinz, 1995;

Verhaeghen & De Meersman, 1998) and age-related decrease in the efficiency of inhibitory processes (Hartley, 1993; West & Alain, 2000; Hasher et al., 2007). It has also been found to be sensitive to a wide range of conditions including frontal lobe damage (e.g., Alvarez & Emory, 2006; Stuss, Gallup and Alexander, 2001; Thompson-Schill et al., 2002). An important caveat that makes the direct comparison of results from different studies difficult is the method of calculation of the Stroop interference effect. The most commonly used measurements of the Stroop interference effect are (i) response latency on incongruent trials (e.g., Liotti, Woldorff, Perez & Mayberg, 2000), (ii) incongruent minus neutral (e.g., Coderre, van Heuven & Conklin, 2014), (iii) incongruent minus congruent (e.g., Blumenfield & Marian, 2011), and (iv) difference between performance on incongruent and congruent trials divided by performance on the congruent trials (conflict ratio; Green et al., 2010). Because the different measures may emphasize the influence of different processes underlying the Stroop, different findings may be expected across studies that used different indices (Khng & Lee, 2014).

Though the color-word Stroop task has been extensively used to investigate IC in monolingual speakers, very few studies have utilized it to examine the relative differences in performance between bilingual and monolingual speakers. The inhibitory control model of Green (1998) predicts superior conflict resolution via IC between competing language nodes in bilingual speakers. The bilingual advantage hypothesis suggests that this extends to non-lexical conflict tasks like the Stroop task. Consistent with the bilingual advantage hypothesis, some studies have found that bilingual speakers demonstrate lesser interference in the incongruent trials relative to monolingual speakers in the Stroop task. Bialystok et al. (2008) found that, irrespective of age, highly proficient bilingual speakers demonstrated smaller interference effects (difference in accuracy and latency between incongruent and neutral conditions) and larger facilitation effects (difference in accuracy and latency between congruent and neutral conditions) when compared to matched monolingual speakers. Hernández, Costa, Fuentes, Vivas and Sebastian-Galles (2010) also report similar findings in groups of neurologically healthy highly proficient bilingual speakers in a numerical version of the Stroop task. But it is important to note that a closer inspection of the bilingual performance on different trials in different conflict tasks shows that bilingual speakers are not only faster on incongruent trials but also on congruent and neutral trials, where there is no conflict (Bialystok et al., 2006; Costa, Hernandez, Sebastian-Galles, 2008; Martin-Rhee & Bialystok, 2008). This has led several authors to suspect that it may be overall processing efficiency that is better in bilingual speakers – not specifically IC. However, several studies have not been able to replicate the bilingual advantage consistently in the Stroop task. Kousaie & Phillips (2012) examined monolingual and bilingual young and older adults using a Stroop task and found no evidence for bilingual inhibitory advantage. Another study comparing Spanish-English highly proficient bilingual speakers and two groups of monolingual speakers (Spanish, English) also did not find any statistically significant difference between the three groups on the Stroop task (Roselli et al., 2002). Ryskin (2012) utilized the Stroop task as part of a larger battery of executive function tests and found that bilingual young adults from diverse language backgrounds did not differ from matched monolingual speakers in terms of Stroop interference effects. It can therefore be seen that the evidence for bilingual advantage in the linguistically based IC using the color-word Stroop task is limited and inconclusive.

The relative proficiency of bilingual speakers has also been reported to influence IC in the Stroop task. Zied et al. (2004) investigated the impact of bilingualism on inhibitory control using versions of the Stroop task in each of the bilingual participants' languages, as well as a between-language condition where stimuli were presented in one language, and responses were made in the other language. Participants who were equally proficient in both languages demonstrated faster response times for all Stroop conditions than did the bilinguals who were unbalanced. Singh and Mishra (2012, 2013) compared two groups of Hindi-English bilinguals who differed in their L2 proficiency on an occulomotor version of the Stroop task. Their results also indicated that proficiency modulated the Stroop interference effect (smaller Stroop interference effects were noted with higher proficiency).

Non-linguistic inhibitory control. One of the tasks commonly used to study non-linguistic inhibitory control is the flanker task. Here, a participant must indicate the direction a target arrow is pointing (right or left), while ignoring interfering or distracting stimuli that flank it (Eriksen & Eriksen, 1974). The flanking arrows can either point to the same direction as the target (congruent condition) or the opposite direction of the target (incongruent condition). In this task, the interference is suggested to be due to the dimensional overlap between the task-relevant and the task-irrelevant stimuli (Chen, Tang & Chen, 2013). This interference has been found to result in lower accuracy and slower reaction times when responding to incongruent items (items where the directions of the target and flankers mismatch; e.g., > > < > >) than congruent items (items where the directions of the target and flankers match; e.g., > > > > >) relative to a neutral condition. Other non-linguistic tasks used to study IC include the *Simon task* [Simon & Rudell, 1967; where a stimulus associated with either the left or the right visual field requires a motor response consistent with its location (e.g. a letter requiring a right key press appearing on the right side of the screen) or inconsistent with it (e.g. a letter requiring a right key press appearing on the left side of the screen)], the *anti-saccade task* (e.g., Munoz & Everling, 2004; where participants are required to focus on the center of the screen while suppressing the reflexive urge to look at a visual target that suddenly appears in the peripheral visual field), *Wisconsin card sorting task* (Berg, 1948; examines IC in response flexibility when participants sort cards that differ in color, number or form of the shapes depicted on them), the *stop signal task* (Logan, 1994; Verbruggen & Logan, 2009; examines the cancellation component of IC by studying response in an ongoing manner until cued by a separate signal not to do so) and the *go/no-go tasks* (examines the restraint component of IC by studying response to one or more stimuli while withholding response to another; Drewe, 1975; Picton et al., 2007). For purposes of this study, domain-general IC was examined using the Stroop (linguistic) and flanker (non-linguistic) tasks since they have well documented robust interference effects and have been extensively studied in neurologically healthy and brain-injured individuals.

Developmentally, interference control on flanker tasks appears around four years of age with adult levels of control reached between the ages of seven and ten (Ridderinkhof, van der Molen, Band & Bashore, 1997; Rueda et al., 2004). While some studies have demonstrated that older adults are less able to inhibit flanker interference, (Colcombe, Kramer, Erickson & Scalf, 2005; Machado, Devine & Wyatt, 2009; Shaw, 1991), others have failed to find significant differences between younger and older adults (Falkenstein, Hoormann, & Hohnsbein, 2001; Fernandez-Duque and Black, 2006; Jennings, Dagenbach, Engle, & Funke, 2007; Madden & Gottlob, 1997; Nieuwenhuis et al., 2002; Wild-Wall, Falkenstein, & Hohnsbein, 2008). A few others have also found the opposite pattern in which older adults exhibit less interference than younger adults (Kamijo et al., 2009; Madden & Gottlob, 1997; Mathewson et al., 2005; for a more comprehensive review, see Guerreiro, Murphy, van Gerven, 2010).

Difference in non-linguistic IC between monolingual and bilingual speakers investigated using the flanker task indicated that bilingual children and adults demonstrated smaller interference compared to matched monolingual participants on the incongruent trials, but comparable effects in the congruent trials (Costa et al., 2008; Costa et al., 2009; Yang, Yang & Lust, 2011). Again, similar to the Stroop task this reported bilingual advantage on the flanker task is equivocal. Paap and Greenberg (2013) used the same flanker task used by Costa et al. (2008) to examine executive functioning advantages in groups of highly proficient bilingual and monolingual speakers. They found no trends for a bilingual advantage, but rather small (non-significant) bilingual disadvantage. Emmorey et al. (2009) examined the flanker effect in three groups of participants: a bilingual group (from varied second language backgrounds), a monolingual group, and a bimodal bilingual (American sign language and English) group. Results did not reveal any processing advantages for the bilingual speakers relative to monolingual participants. Luk et al. (2010) also found similar behavioral results on a modified flanker task that was used to study brain activation differences between bilingual and monolingual speakers. Hilchey and Klein (2011) in their review of non-linguistic inhibitory control in bilingual speakers also report the absence of any bilingual advantage on the flanker task. Therefore, it can be seen that the bilingual advantage in flanker task has been reported only in a limited number of studies and has not been reliably replicated.

Comparison of lexical and non-lexical IC: Bilingual advantage hypothesis. It has been suggested that the IC used to resolve competing alternatives in lexical retrieval is the same executive functioning component in tasks such as the Stroop and flanker (irrespective of the linguistic/non-linguistic nature of the stimuli). This notion of domain-generality of IC forms the basis of the bilingual advantage hypothesis (BAH; Bialystok, 1999; Bialystok, 2001; Bialystok & Craik, 2010; Bialystok & Depape, 2009; Bialystok & Senman, 2004; Bialystok, Martin, & Viswanathan, 2005; Martin-Rhee & Bialystok, 2008). Based on Green's (1998) inhibitory control theory, BAH suggests that since the domain-general inhibitory control system holds additional responsibilities in bilingual speakers (by constraining both within and cross-language interference) in order to effectively communicate the need for and reliance on IC for successful lexical retrieval is likely to be greater in bilingual speakers compared to monolingual speakers. This practice of dependence on IC has been suggested to make them more efficient in managing interference in lexical retrieval when compared to monolingual speakers.

Neuroimaging findings that reveal recruitment of the same brain areas for completion of lexical and non-lexical IC tasks in bilingual speakers have been provided as evidence for domain-general IC (Botvinick et al., 2004; Hedden & Gabrieli, 2010; Robbins, 2007; Xue, Aron & Poldrack, 2008). For example, using functional magnetic resonance imaging (fMRI) it was found that all IC tasks activated largely overlapping brain regions, namely, the anterior cingulate cortex (ACC) and the left prefrontal cortex (Fan et al., 2003). Similar overlap between cortical/sub-cortical brain regions involved in linguistic and non-linguistic IC has also been reported both in monolingual and bilingual neurologically healthy speakers.

The important question here is if similar activation in brain areas for lexical and non-lexical processing indicates engagement of identical cognitive resources. In support of proposed domain-generality, behavioral evidence from some studies report that bilingual individuals generalize their advantage in lexically based IC to perform better than monolingual speakers in non-linguistic tasks such as, dimensional change switching tasks (Garbin et al., 2010; Prior & MacWhinney, 2010), attentional network task (Costa et al., 2008), spatial Stroop task (Bialystok, 2006), flanker task (e.g., Costa et al., 2008) and Simon task (e.g., Bialystok, 2001). Bilingual speakers are reported to have smaller interference effects in these non-lexical tasks (less slowed by interference from non-target stimuli) relative to monolingual speakers.

However, several recent studies cast serious doubt on the validity of the BAH in non-lexical experimental tasks. Bialystok and colleagues conducted a series of studies with young, middle-aged, and older adults to examine the developmental persistence of the bilingual advantage of IC (Bialystok, et al., 2004; Bialystok, Craik, et al., 2005; Bialystok, 2006; Bialystok et al., 2008). These studies revealed inconsistent advantage that was found to be task dependent (for a critical review, see Hilchey & Klein, 2011). Other studies investigating young adults found that bilinguals had faster global reaction times on the flanker task (Costa et al., 2009), the Simon task (Bialystok, Craik, et al., 2005), and the spatial Stroop task (Bialystok & DePape, 2009; see Hilchey & Klein, 2011), that did not specifically reflect an IC advantage. Most notably, Paap and Greenberg (2013) examined a variety of non-linguistic tasks that tap into inhibition (Simon, antisaccade, flanker, color-shape switching) in monolingual and bilingual adults. They found that not only was their performance on these tasks similar, but also that the individual tasks themselves did not test the same aspects of cognitive function. For example, the interference effects in flanker effects and Simon effects (reported as equally dependent on IC) were not correlated ($r = -0.01$). The authors caution that task-specific differences between tasks may affect interpretation of results. Emmorey et al. (2008) also found no difference in the performance of bilingual speakers, bimodal (speech-sign bilingual) speakers and monolingual speakers on a flanker task. Kousaie and Phillips (2012) also point out that because results from a variety of studies are so contradictory and rely on very specific task criteria, this does not support a robust advantage for bilingual speakers. A critical analysis of available data by Hilchey and Klein (2011) also provided no evidence for a bilingual IC advantage. Furthermore, recent evidence has also indicated that the reported benefits of bilingualism in delaying onset of dementia

(Bialystok, Craik & Freedman, 2007; Perquin et al., 2013) may not be as ubiquitous as once believed (Chertkow et al., 2010).

Furthermore, if a domain-general IC were engaged in all tasks then it would be expected that there would be strong correlations between behavioral performances on these tasks. Unsworth and Spillers (2010) found support for this notion when they compared interference effects between flanker and Stroop tasks in a group of monolingual young adults. However, this prediction has not been confirmed by several other investigations. Fan et al. (2003) found that despite the overlapping regions of brain activation in the Stroop and flanker tasks, interference effects across these tasks was uncorrelated. In a similar study by Stins et al. (2005), it was found that the interference effects between Stroop and flanker tasks were uncorrelated in monolingual children. Sommer et al. (2004) also reported comparable findings using slightly different versions of the two tasks in a similar group of monolingual adults. Likewise, Kousaie and Phillips (2012) report no significant correlations between the Stroop, Simon and flanker tasks in a group of 51 monolingual young adults. Most recently, Paap and Greenberg (2013) also reported poor correlations between interference effects in bilingual and monolingual young adults using the Simon, flanker and the antisaccade tasks.

To summarize, available behavioral evidence questions the reliability of the "bilingual advantage" in non-lexical tasks (critically reviewed in Hilchey & Klein, 2011). Some studies suggest an enhanced inhibitory mechanism for bilingual speakers, while others maintain that any advantage is more global in nature. Yet others have failed to find any advantage at all. Furthermore, in studies in which a bilingual advantage is demonstrated, bilingual speakers tend to outperform monolingual speakers on both congruent and incongruent trials (Hilchey & Klein, 2011; Martin-Rhee & Bialystok, 2008). This finding seems to suggest that, if there is indeed an advantage, bilingual speakers may possess not just superior inhibitory processing skills, but rather superior general executive functioning skills compared to monolingual speakers (Hilchey & Klein, 2011). Additionally, current neurolinguistic and behavioral evidence provides conflicting findings of association between linguistic and non-linguistic tasks. This dissociation is difficult to reconcile with the notion of domain generality of IC. A domain-general IC system has been proposed to share core components such as working memory and attention between all processing domains (e.g., Bialystok et al., 2012). Despite the proposed shared sub-systems, there is insufficient evidence of correlation between IC measures in lexical-semantic, linguistic and non-linguistic tasks.

The association between the three types of IC is particularly important to understand in order to examine (i) if the same inhibitory control mechanism is used for all tasks involving conflict resolution, irrespective of the nature of stimulus as some studies suggest, and (ii) whether practice in lexical-semantic inhibition may confer linguistic inhibitory advantages or more general non-linguistic cognitive advantages or both. To examine this, the current project used an individual differences approach to examine the correlation between interference effects in semantically blocked naming, Stroop and flanker tasks separately in bilingual and monolingual speakers with and without aphasia. If domain-general inhibitory control processes were differently involved in monolingual and bilingual speakers, then the relationship between lexical-semantic, linguistic and non-linguistic inhibitory tasks would differ across the two groups. More specifically, if bilingual experience resulted in recruitment and modulation of domain-general cognitive control processes, then bilingual speakers would show stronger relationships between IC in the three tasks, as compared to monolingual speakers (in addition to smaller interference effects in blocked naming, Stroop and flanker tasks).

Inhibitory Control and Aphasia

Lexical retrieval in persons with aphasia is often characterized by interference from co-activated semantic and phonological items, resulting in semantic paraphasias (e.g., *chair* for table) and phonological paraphasias (e.g., *bable* for *table*). A few case reports of individuals with aphasia also indicate that inhibitory control deficits and linguistic deficits may sometimes co-occur in monolingual (e.g., Biegler et al., 2008; Green et al., 2010, 2011; Scott & Wilshire, 2010; Wilshire & McCarthy, 2002) and bilingual individuals (e.g., Green et al., 2010, 2011) with aphasia. It is therefore possible that individuals with aphasia may have an impairment in IC in addition to linguistic processing deficits that result in slower and less accurate lexical retrieval relative to unimpaired speakers. However, if bilingual speakers develop domain-general advantages in IC as proposed by BAH, then this non-lexically based advantage could be expected to provide BPWA better ability to resolve interference in both lexically and non-lexically based tasks, compared to monolingual PWA. Hence individuals with aphasia provide a unique opportunity to examine the proposed bilingual lexical IC advantage and the nature of its cross-domain generality. In the following sections, lexical and non-lexical inhibitory control in monolingual and bilingual PWA is reviewed.

Lexical Inhibitory Control in Individuals with Aphasia

As detailed earlier, IC is proposed to be essential for successful lexical retrieval because of the need to suppress activated lexical competitors (e.g., Roelofs, 2003; Green 1998). However, inhibitory control engaged in lexical retrieval in aphasia has not been extensively studied. This study is an attempt to provide much needed empirical evidence in this area. It has been suggested that, if inhibitory mechanisms are absent (Mari-Beffa, Hayes, Machado, & Hindle, 2005), reduced (Hasher, Stoltzfus, Zacks, & Rypma, 1991), slowed (Prather, Zurif, Stern, & Rosen, 1992), or overactive, production errors may occur in the lexical retrieval of persons with aphasia. For example, when attempting to name a picture of a table, a semantic error could be produced if the target representation of "table" and its associates have been activated initially, but the inhibitory mechanism failed to reduce the activation of its associates (e.g., instead of the target "table", semantically related "desk" may be produced). If inhibition is not absent but simply reduced or intermittent, the subsequent trial to produce "table" may be successful. Slowed inhibitory processing may result in initial word-retrieval difficulty, with the correct target word produced after an extended period of time. Inhibition in this instance may be intact, but may require extra time to operate. An overactive inhibitory mechanism may result in no response to the picture since interference cannot be resolved. While IC deficits are not suggested to be the sole cause of word retrieval deficits in individuals with aphasia (since other loci of linguistic processing such as phonological encoding may also result in word retrieval errors), the role of IC in word retrieval in individuals with aphasia remains under-explored.

IC in monolingual speakers with aphasia. Studies of semantic interference using the semantically blocked naming paradigm have found that monolingual non-fluent PWA have an exaggerated interference effect relative to neurologically healthy (Biegler et al., 2008; McCarthy & Kartsounis, 2000; Schnur, Lee, Coslett, Schwartz, & Thompson-Schill, 2005; Schnur, Schwartz, Brecher, & Hodgson, 2006; Wilshire & McCarthy, 2002) or fluent individuals with aphasia (Biegler et al., 2008). For example, Schnur et al. (2006) tested two groups of patients with aphasia (non-fluent and fluent; total n = 18) and matched controls using the semantic blocking paradigm repeated over four cycles. They replicated the findings of previous studies (Belke et al., 2005; Damian et al., 2001; Kroll & Stewart,1994) in a group of older neurotypical participants and found increasing semantic interference effect in later naming cycles. Since they did not have enough accurate responses to meaningfully extract statistical significance from latency measures in their group of participants with aphasia, Schnur et al. (2006) primarily studied the semantic interference effect in these participants with accuracy scores. They found that while all participants with aphasia demonstrated SIE that increased over successive naming cycles, non-fluent participants demonstrated greater interference effects than fluent and neurotypical participants. In a follow-up to this study, Schnur et al. (2009) investigated the neural correlates of IC further in a subset of the same participants with aphasia (n = 12) and matched neurotypical controls (n = 16) using fMRI. They found that the degree of activation of the Broca's area in neurologically healthy speakers and damage to the Broca's area in individuals with aphasia was associated with IC on the production task. That is, the less lesioned the Broca's area was, the better participants were at linguistic IC. Hamilton and Martin (2005) also report that a non-fluent PWA showed exaggerated interference effects in the semantically blocked naming task (in addition to other non-lexical tasks such as the recent negatives task). Scott and Wilshire (2010) also reported a participant with Broca's aphasia with identical performance.

One way of modulating the strength of the competitors for individuals with aphasia in this task is by varying the response-stimulus intervals (RSI) between test items. Presumably, longer RSI would provide an opportunity for the persistent activation to decay and therefore interfere subsequent lexical retrieval to a lesser degree. Biegler et al. (2008) found some support for this when they manipulated the RSI in two versions of the blocked cyclic naming task. They tested three monolingual participants with aphasia (2 non-fluent, 1 fluent) in the blocked naming task at response-stimulus intervals of 1s and 4s. They found that while the non-fluent participants with aphasia demonstrated larger interference effects (less efficient IC) in the short RSI, the participant with fluent aphasia and neurologically healthy speakers showed the opposite pattern (larger interference with longer RSI). Additionally, they reported that the non-fluent participants demonstrated exaggerated blocking interference relative to the fluent speaker with aphasia in naming latencies only, and not accuracy. They accounted for the differences between fluent and non-fluent individuals with aphasia in terms of their sites of lesion. Anterior lesions involving the frontal lobe IC circuits (non-fluent PWA) were proposed to impact IC to a greater extent than posterior lesions (in fluent PWA). In conclusion, review of current evidence indicates that inhibitory control deficits can co-occur with linguistic deficits in at least some monolingual speakers with aphasia. Results from these studies suggest that in addition to linguistic processing deficits, monolingual individuals with aphasia may have impairment to a control mechanism that would have normally acted to diminish the activation of the relevant competing items during lexical retrieval.

However, the exaggerated interference effects have not been reliably replicated in tasks that have used only one naming cycle (Gotts, della Rocchetta, & Cipolotti, 2002; Hodgson et al., 2003; Lambon Ralph, Sage & Roberts, 2000; Schwartz & Hodgson, 2002). These results suggest that impaired IC may not be the sole reason for reports of interference effects; they could also be a result of task difference between studies. It appears that the interference effects build up over time and, repetition over multiple cycles helps capture what may otherwise be a short-lived interference effect. These findings suggest the role of inhibitory control in lexical retrieval deficits in individuals with aphasia needs to be further studied.

Inhibitory control in bilingual speakers with aphasia. Three sources of evidence have been documented so far to implicate inhibitory control breakdown in bilingual aphasia. These include language recovery patterns, pathological language switching or language switching errors, and translation disorders.

- Language recovery patterns**:** The failure of IC in bilingual aphasia has been commonly implied in the context of recovery of the different languages post-brain injury (Abutalebi & Green, 2007; Green, 1986, 1998; Green & Price, 2001; Paradis, 1998). Paradis (2001) reviewed published reports of BPWA and reported five types of recovery: *parallel recovery* (equal recovery of both languages, analogous to their proficiency prior to brain injury), *differential recovery* (better recovery in one language than other), *blended recovery* (inappropriate mixing of the two languages during recovery), *selective recovery* (recovery of one language only), and *successive recovery* (recovery of one language after another). Several case studies report BPWA presenting with a variety of recovery patterns as evidence for IC deficits (e.g., Green, 2008; Lorenzen & Murray, 2008).Though these are explanations to account for the different patterns of language recovery, none of these studies have explicitly tested within or cross-language inhibition or loss of it. However, IC deficits cannot solely be taken to account for different recovery patterns. Contextual factors such as language use patterns post-stroke, pre-morbid proficiency, and language of post-stroke rehabilitation can also impact the observed patterns (Lorenzen & Murray, 2008). For example, if a person is interacting primarily with family members after stroke in an L1 dominant environment, then the L1 is more likely to be practiced and improve better. Therefore, recovery patterns themselves do not provide evidence for IC deficits because it is influenced by multiple variables. Consequently, IC needs to be directly examined in lexical tasks.

- Pathological language switching or language switching errors: Based on bilingual models of lexical retrieval, it has been suggested that if there is a breakdown of the control mechanism that enables effective communication in one language only, then the non-target language is more likely to interfere during verbal productions in the target language (Ansaldo, Saidi & Ruiz, 2010; Green, 2008). This is called pathological language switching or language switching errors (e.g., production of *mesa* (Spanish) for *table* when target response language is English). Several studies have reported language-switching errors during naming in BPWA exhibiting different recovery patterns (e.g., Abutalebi, Miozzo and Cappa, 2000; Ansaldo & Marcotte, 2007; Ansaldo et al., 2010; Goral et al., 2006; Kohnert, 2004). However, IC was not directly tested in any of these case reports. And in studies of empirically tested IC deficits, BPWA do not show any language switching errors (Green et al., 2010). The presence of language switching deficits alone cannot be taken to indicate IC deficits since BPWA may voluntarily switch to use another language when experiencing a word finding breakdown in the target language, in order to produce some response (Goral et al., 2006). Therefore, IC deficits in BPWA cannot to be understood without direct empirical evidence that documents it. This study is an effort in that direction.

- Translation disorders: Translating from one language to another may rely extensively on inhibitory control because when a word is provided in one language, the speaker has to use that word to conduct a lexical search in the other language. Therefore, this activates lexical competitors in both languages that have to be suppressed. Deficits in IC mechanisms are suggested to manifest as involuntary translation of their own or others' utterances, or inability to translate at all or to only one language (e.g., Ansaldo & Marcotte, 2007; Fabbro, 2001; Fabbro & Paradis, 1995; Goral et al., 2006; Lorenzen & Murray, 2008). As with language switching errors, translation disorders have been accounted for by proposals of IC deficits. But these proposals have not been empirically evaluated at this point. Given that IC has been insufficiently investigated at this point in BPWA, it is unreliable to make definite generalizations about their role in lexical retrieval deficits in bilingual aphasia.

To summarize, IC deficits in bilingual aphasia have been proposed on the basis of observed post-stroke language recovery patterns, language switching errors and translation deficits. However, none of these observed signs language processing breakdown in BPWA have been empirically evaluated using tasks that explicitly evaluate IC in lexical retrieval. This study is the first to systematically examine IC in BPWA using a lexical retrieval task (semantically blocked cyclic naming).

Lexical inhibitory control in monolingual versus bilingual speakers.

In the face of limited research examining IC in MPWA and BPWA, it is not surprising that the bilingual advantage hypothesis has not been examined so far in individuals with aphasia. Given that any bilingual advantage in IC is proposed to be a direct consequence of language experience, it is unclear how it may be impacted by acquired language disorders such as aphasia. It could be that BPWA retain a developmental IC advantage and consequently perform better than MPWA on tasks that place demands on IC. Given that bilingual speakers rely on IC to a greater extent for communicative success, it is also possible that they actually demonstrate greater deficits in IC post brain injury. Both of these proposals are tested in this study.

Non-lexical (linguistic and non-linguistic) inhibitory control in individuals with aphasia

Monolingual aphasia. A review of current literature indicated that there are very few studies that have directly examined inhibitory control in domain-general linguistic and non-linguistic tasks in monolingual individuals with aphasia. Hamilton and Martin (2005) report of a non-fluent monolingual PWA who (relative to monolingual healthy controls) demonstrated exaggerated effects of interference (but not facilitation) on the verbal color-word Stroop and recent-negatives tasks, while demonstrating normal performance on a non-verbal spatial Stroop and the antisaccade tasks. Though this study does report dissociation between linguistic (Stroop) and non-linguistic (spatial Stroop, antisaccade), it must be noted that the participant demonstrated similar interference effects on the Stroop task and the recent negatives task. So the poor correlation between Stroop and spatial Stroop may be a result of the response modality (verbal/non-verbal) rather than the input characteristics. In a recent study, Pompon (2013) tested inhibitory control in 19 MPWA using a Stroop task. Results indicated that participants with aphasia demonstrated larger interference effects and facilitation effects on the Stroop task (compared to neurologically healthy controls). But these results were not compared to non-linguistic IC tasks. Purdy (2002) found that PWA experienced impairments in accuracy and speed in tests of executive function. Purdy (2002) examined executive function ability in monolingual individuals with aphasia compared to a normal control group and found that the PWA were slower and less accurate on half of the tests administered that tapped into IC (Porteus Maze Test, Wisconsin Card Sorting Test, Tower of London, Tower of Hanoi). However, the authors did not correlate lexical retrieval with IC and hence the question of how they are inter-related is still unclear. Together these studies suggest that aphasia and executive dysfunction (including IC deficits) may be concomitant conditions, though the nature of their relationship (if any) is unclear.

Bilingual aphasia. At this time, there are only two studies that have explicitly tested domain-general IC in BPWA. Green et al. (2010) examined the IC ability of two L2 English speakers. Linguistically based conflict resolution was tested using lexical decision and Stroop tasks and non-verbal conflict resolution was examined using flanker task. Responses to the linguistically based tasks were verbal, and non-verbal responses were used in the non-linguistic task. Green at al. (2010) found that the results were inconclusive. While one participant (P1) demonstrated poorer performance in linguistic IC tasks (lexical decision and Stroop) relative to the non-linguistic IC flanker, the other participant (P2) demonstrated the opposite pattern. Yet, both these patients presented with similar recovery patterns and linguistic profiles. Using the same experimental tasks, Green et al. (2011) replicated the findings of P1 (greater impairment in language based conflict tasks with relatively intact non-linguistic control) in another highly proficient German-English-Spanish trilingual with parallel recovery. Several factors could have contributed to this observed dissociation in Green et al.'s (2010) study. P1 and P2 had different ages of L2 acquisition and different durations of L2 usage, despite self-reports of high pre-stroke proficiency. Previous investigations have indicated that neural inhibitory control networks in early and late bilingual speakers are markedly different and hence this could have contributed to the observed results. Also, P1 was a quadri-lingual whereas P2 was late bilingual and hence, it is likely that P1 had higher baseline verbal conflict resolution abilities given that she had to juggle four languages constantly. Additionally, the tasks employed may not have been equal in terms of cognitive demands since response modalities varied between verbal and non-verbal responses amongst the three tasks. Hence it would be important to replicate this study with better experimental control in participants and more consistent response modality between tasks to assess the nature of linguistic and non-linguistic IC in BPWA.

Monolingual versus bilingual aphasia. Although no study has directly compared IC in BPWA and MPWA, one study compared five executive function measures in 10 MPWA and 2 BPWA (Penn, Frankel, Watermeyer & Russell, 2010). These measures tested inhibition (Stroop color-word, trail making), working memory (self-ordered pointing, complex figures, Wisconsin card sorting), planning, problem solving (tower of London, Raven's progressive matrices) and reconstitution (five point test, design fluency). They found that BPWA were not significantly different from MPWA on the Stroop and complex figures tests but demonstrated a bilingual advantage on other measures. They also report better use of executive functions such as topic maintenance and revisions for greater success in conversational speech. So, Penn et al. (2010) suggested that enhanced executive function skills in neurologically healthy bilingual speakers may translate to better preserved executive function skills in bilingual PWA. Interestingly, though some monolingual individuals with aphasia in this study demonstrated a similar executive function profile as the BPWA, they still showed poor use of those functions in conversational speech. Since the authors provided limited participant language profiles, it is unclear to what extent other variables such as language recovery patterns and specific lexical retrieval deficits impacted these findings. The participants also appear to be quite varied in type of aphasia. In addition, no clear statistical analysis was performed to account for the heterogeneity of the aphasia symptoms between groups, as the authors only report comparison of WAB aphasia quotient scores and not individual subtest scores. Although results are preliminary, it suggests that there may be a bilingual advantage for overall executive functions. However, given the small bilingual sample size (n=2), unequal group sizes and methodological flaws, these results are not reliable.

Association Between Lexical and Non-Lexical Inhibitory Control in Individuals with aphasia

Support for association between for IC and lexical retrieval comes from clinical reports of brain-injured individuals who present with both lexical retrieval deficits (aphasia) and inhibitory control deficits. Both monolingual (Biegler et al., 2008; Hamilton & Martin, 2005, 2007; January, Trueswell, & Thompson-Schill, 2009; Novick, Kan, Trueswell, & Thompson-Schill, 2009; Novick, Trueswell, & Thompson-Schill, 2010; Purdy, 2002; Schnur et al., 2006, 2009; Scott & Wishire, 2010; Thompson-Schill et al., 1997, 1998; Thothathiri, Schwartz, & Thompson-Schill, 2010; Wiener, Conner & Obler, 2004; Wilshire & McCarthy, 2002) and bilingual speakers with aphasia (e.g., Abutalebi & Green, 2007; Green, 1986; Green & Price, 2001; Green, Ruffle, Grogan, Ali, Ramsden, et al., 2011; Kohnert, 2004; Paradis, 1998; 2004) have been found to have impaired inhibitory control in variants of the picture naming task. Robinson and colleagues indicate that lesions in the inferior frontal gyrus also found impairments in verbal IC and response selection in individuals with aphasia (Robinson, Shallice & Cipolotti, 2005). It is important to note that while several neurological conditions can result in IC deficits (e.g., Parkinson's disease, Alzheimer's disease), the study of IC deficits in aphasia is particularly germane since it provides a platform to help us understand the interface between IC and linguistic processing.

Summary and Statement of the Problem

The review of extant literature on IC neurologically healthy speakers and individuals with aphasia highlights some key points related to bilingualism. Bilingual speakers experience dual activation of the target word and its related entries in both languages during lexical retrieval (de Groot, 2011; Green, 1998; Kroll & Stewart, 1994). Hence, some researchers hypothesize that managing conflict from this dual activation routinely leads bilingual speakers to acquire enhanced lexical-specific *and* domain-general (linguistic and non-linguistic) inhibitory capacities relative to monolingual speakers who do not rely on IC to the same extent (Bialystok, 2006; Bialystok, Craik, et. al., 2005). However, studies examining this bilingual advantage have yielded highly variable results. Among studies that have revealed a bilingual advantage, bilingual participants often performed better on both the conflict trials and the non-conflict trials, leading to the suggestion that bilingualism may impact executive functioning as a whole and not necessarily just inhibition (Hilchey & Klein, 2011; Prior & MacWhinney, 2010)

At the present time, there are few studies that have investigated IC control in MPWA, and these indicate that in addition to the expected linguistic deficits, monolingual PWA have deficits in general executive function (e.g., Penn et al., 2010; Purdy, 2002; Wiener et al., 2004) including inhibition (Hamilton & Martin, 2005; Pompon, 2013). Very few studies have examined IC in bilingual aphasia. One study (Green et al., 2010) showed that BPWA have a breakdown in IC that can differentially impact linguistic and non-linguistic domains. The other study (Penn et al., 2010) found that BPWA might have preserved executive functioning skills compared to MPWA, though differences between them were significant in measures of linguistic IC (Stroop) but not in non-linguistic IC (trail making).

Therefore, based on current evidence, (i) it is unclear if bilingual speakers demonstrate IC advantages in within-language lexical retrieval contexts when compared to monolingual speakers. If daily practice with lexical interference is at the core of the bilingual advantage, then the IC advantage should be more apparent in the lexical domain (e.g., selecting relevant words in the face of competition from other words) than any other; (ii) the domain generality of the proposed bilingual advantage is questionable. Given the inconsistency in replication of IC advantages in non-lexical tasks, it is possible that the lexical/non-lexical tasks utilized in previous findings may share processing components such as attention and working memory without essentially engaging the same IC mechanism; (iii) it is unclear if lexical retrieval in bilingual and monolingual speakers with aphasia is differently impacted by their varying degrees of reliance on IC proposed by BAH.

Statement of Purpose

The main aims of this study are to 1) test the bilingual advantage hypothesis and its generality across domains, 2) test the bilingual advantage hypothesis in the context of damage to left hemisphere language networks. While bilingualism has been proposed to render IC advantages, acquired brain injury has been reported to be associated with less efficient IC that may influence lexical retrieval in individuals with aphasia (Biegler et al., 2008; Green et al., 2010, 2011; Scott & Wilshire, 2010; Wilshire & McCarthy, 2002). So, given that (i) IC has been proposed to be central to bilingual lexical retrieval, and (ii) bilingualism has been proposed to provide IC advantages, and (iii) overlapping neural regions have been identified for both language and IC processing, a systematic investigation of IC in bilingual and monolingual PWA provides an ideal platform to test the bilingual advantage hypothesis.

The current study examined inhibitory control in bilingual and monolingual persons with and without aphasia using the semantically-blocked cyclic picture naming (lexical), Stroop (linguistic), and flanker (non-linguistic) tasks. Each of these tasks had a conflict condition (where IC was engaged) and non-conflict conditions. Dissociating the specific context (lexical-semantic, linguistic, non-linguistic processing) that impacts IC in bilingual and monolingual speakers is important because it will aid in systematically testing the basis and nature of the proposed bilingual advantage (Green, 1998; Mahon et al., 2007). For example, though parallel language activation during lexical retrieval has been cited as a potential source of bilingual IC advantages (e.g., Kroll et al., 2008), a direct link between demands in lexical retrieval and IC in bilingual versus monolingual speakers has not yet been established. Additionally, studying individuals with language impairment (aphasia) provides a particularly relevant opportunity to examine the linguistic basis of the IC advantages proposed by BAH. That is, if BAH is grounded in increased IC practice during lexical retrieval in bilingual speakers then lexical retrieval deficits should differently impact lexical IC in BPWA, relative to MPWA. Bilingual speakers' increased reliance on IC may result in BPWA having more IC deficits than MPWA. Alternatively, they could have a stronger and more widespread IC system, which may result in greater resilience. Consequently, they may present with lesser IC deficits than MPWA. Also, individuals with aphasia afford the opportunity to examine possible dissociation between lexical and non-lexical IC advantages proposed by BAH. For instance, if individuals with aphasia demonstrate IC advantages over MPWA in lexical but not in non-lexical tasks (or vice versa), it directly informs the domain generality of IC proposed by BAH. These proposals are examined using the research questions detailed in the next chapter.

CHAPTER 3: RESEARCH QUESTIONS

The following research questions and specific hypotheses were proposed in order to study the nature of bilingual IC within the context of left-hemisphere damage in individuals with aphasia.

(i) The BAH proposes that bilingual advantages in IC arise from bilingual speakers' practice in inhibiting double the lexical-semantic competition (within and across languages) during lexical retrieval, when compared to monolingual speakers. Based on the ICM (Green, 1998), if speakers' lexical retrieval success (whether monolingual or bilingual) reflects their ability to control competition during lexical retrieval, then any advantage in lexical IC should be most evident in tasks that explicitly demand such control. In order to test this, the following research question was examined:

(i) Do bilingual and monolingual speakers with aphasia differ in lexical-semantic inhibition, as measured by a semantically blocked picture naming task? Do bilingual and monolingual PWA exhibit similar patterns in lexical-semantic inhibition as matched neurologically healthy speakers?

If IC supports successful lexical retrieval as suggested by Green's (1998) ICM, then a more efficient IC system should lead to greater success in retrieval of target words in the presence of lexical-semantic competition. Hence, if bilingual lexical retrieval is supported by a more efficient inhibitory control mechanism compared to the monolingual system as predicted by BAH (Bialystok, 2007, 2009), then bilingual neurologically healthy speakers are expected to demonstrate smaller semantic interference effect (SIE) compared to matched monolingual speakers (advantage in lexical-semantic inhibition) in the semantically homogenous blocking conditions of the cyclic picture naming task. Alternately, bilingual speakers' need to limit interference from both within and across languages and their overall lower proficiency in each language could result in larger SIEs compared to monolingual speakers. If there are no differences in semantic interference effects between bilingual and monolingual speakers in this task, then it would provide evidence against the BAH. Though findings of greater SIE in bilingual speakers and the absence of differences in SIE between the two groups question the validity of BAH, it is important to note that current theories of bilingual advantage do not claim superiority in lexical retrieval in bilingual speakers. Therefore, these findings need to be interpreted with caution.

Similarly individuals with aphasia who have a more efficient IC system post-brain injury are expected to better limit interference during lexical retrieval. This leads us to hypothesize that if the bilingual advantage proposed by BAH is evidenced by PWA, then BPWA would be able to better limit competition from semantically related activations during word retrieval. This would lead them to demonstrate smaller SIEs in the conflict conditions of the naming task compared to MPWA. Alternately, it is possible that brain injury resulting in linguistic deficits may actually impact IC to a greater degree in bilingual than monolingual speakers (given that bilingual speakers have been proposed to rely on IC to a greater extent for successful lexical retrieval). In this case, BPWA will demonstrate a disadvantage relative to MPWA while dealing with interference on the conflict trials.

It is also possible that IC engaged during lexical retrieval may be more domain-general in nature, or may not be directly influenced by bilingual experience as proposed by the ICM and BAH. In this case, it is hypothesized that IC may not differently impact lexical retrieval deficits in BPWA and MPWA. This is would be evidenced by absence of differences in SIEs in the picture naming task. However, these null effects need to be interpreted with caution, since factors extraneous to IC mechanism (such as lexical retrieval breakdown, lesion location, etc.) may also influence these findings.

(ii) Do bilingual and monolingual speakers with aphasia differ in linguistically-based inhibitory control as measured by the Stroop task? Do bilingual and monolingual PWA exhibit similar patterns in Stroop interference as matched neurologically healthy speakers?

Previous research has revealed conflicting findings with regard to bilingual IC advantages in linguistically-based IC tasks. If the IC engaged in non-lexical processing is enhanced by bilingual language experience, then bilingual individuals are expected to demonstrate smaller interference effects (greater accuracy and shorter response latency) on the conflict trials of the Stroop task relative to monolingual speakers. This finding would provide support for non-lexical bilingual advantages, which at least extend to processing linguistic stimuli.

BAH states that proposed IC advantages are rooted in linguistic experience. Consistent with this, if language networks are impaired due to left hemisphere damage, then all individuals with aphasia are expected to demonstrate impaired IC on the Stroop task, as indexed by a decrease in accuracy and an increase in the time required while responding to conflict trials (exaggerated interference effects). By extension, it is hypothesized that BPWA will demonstrate smaller interference effects than MPWA when engaging IC in conflict trials of the Stroop task. This would provide support for a bilingual advantage hypothesis that extends at least to non-lexical processing involving linguistic stimuli. Alternately, MPWA could resolve interference on the conflict trials better than BPWA. This would indicate that BPWA rely to a greater extent on an IC mechanism that has been impacted by language processing deficits. It is also possible that both BPWA and MPWA perform similarly on conflict trials (similar interference effects) of the non-lexical task. The influences of neurolinguistic factors unrelated to IC on performance of PWA (such as lesion location) are to be critically considered while interpreting these null results.

(iii) Do bilingual and monolingual speakers with aphasia differ in non-linguistically based inhibitory control, as measured by the flanker task? Do bilingual and monolingual PWA exhibit similar patterns in flanker interference as matched neurologically healthy speakers?

If bilingualism has a generalized effect on inhibitory control that extends beyond lexical and linguistic processing to non-linguistic processing as well (as proposed by BAH), then it is hypothesized that bilingual speakers will demonstrate smaller interference effects on conflict trials of the flanker task (greater accuracy and shorter response latencies) compared to matched monolingual speakers.

When language networks are impaired due to left hemisphere damage in speakers with aphasia, then domain-general BAH would be supported if BPWA demonstrate lesser interference than MPWA on the conflict conditions. The absence of domain-general bilingual advantage can be marked by one of two results: it is possible that BPWA could demonstrate a disadvantage relative to MPWA while dealing with interference on the conflict trials. Or there may be no significant difference in interference effects between the monolingual and bilingual individuals with aphasia.

(iv) Are domain-general linguistic and non-linguistic inhibitory abilities associated with each other in bilingual and monolingual speakers with and without aphasia?

If domain-general cognitive control processes were differentially involved in monolingual and bilingual speakers, then the strength of the relationship between linguistic and non-linguistic IC would differ across the two groups. Specifically, if bilingual experience resulted in modulation of domain-general IC processes differently than monolingualism as proposed by Abutalebi and Green (2007), then bilingual speakers would show stronger relationships between inhibition in language based and non-language based tasks as compared to monolingual speakers. Similarly, findings of stronger correlations between linguistic and non-linguistic tasks in individuals with aphasia will provide additional support for a domain-general BAH. If there is non-significant correlation between IC in these tasks, then it would suggest that linguistic and non-linguistic IC might be processed in unique ways.

The following chapters describe the methods and results of the experimental tasks that were used to study these questions.

Relevance of the study

Through the three experiments, the overarching objectives of this study are twofold: 1) to examine the link between linguistic experience and inhibitory control in bilingual versus monolingual speakers, and, 2) to examine the nature of this relationship in the face of linguistic deficits in individuals with aphasia of different language backgrounds. Findings of this study are particularly relevant because of the following theoretical implications that are discussed below:

1. Studying the interface between IC and language helps inform and refine our understanding of the cognitive underpinnings of language production.
2. Examining IC involved in lexical-semantic, linguistic and non-linguistic processing informs our understanding of the domain-generality of IC
3. Contrasting IC between bilingual and monolingual speakers informs our knowledge of the role of linguistic experience in modulating executive function, specifically inhibition.

First, studying the interface between IC and language helps inform and refine our understanding of the role of executive function skills such as IC in language production. As reviewed earlier, while largely underspecified in monolingual models, some models of bilingual language processing speak to the role of inhibitory control in lexical retrieval (Inhibitory control model; Green, 1998). While there is evidence of an association between cognitive control and lexical retrieval in neurologically healthy adults (e.g., Shao et al., 2013), this relationship has not been well investigated in PWA, specifically bilingual speakers. It is possible that inhibitory control has a greater impact on word retrieval in PWA due to weakening of lexical representations and altered inhibitory mechanisms following brain damage (McCarthy & Kartsounis, 2000; Wilshire & McCarthy, 2002). Additionally, bilingual speakers have also been found to have weaker links between lexical-semantic representations (Gollan & Acenas, 2004; Gollan & Silverberg, 2001; Gollan, Montoya, & Bonanni, 2005; Gollan, Montoya, et al., 2005). This may also impact the role of IC in managing co-activated representations (of possibly different activation strengths) during lexical retrieval. If results of the study indicate that bilingual and monolingual speech production mechanisms do not differently engage IC in lexical retrieval as measured by the semantically blocked naming task, they may suggest that the cognitive processes engaged during lexical retrieval may be similar in the two groups. These results can also lend support to the argument that minimizing interference from co-activated lexical representations may not be mediated via IC but rather through differential activation strengths of the target and competitors as has been suggested by some proposals (e.g., Oppenheim et al., 2010).

Secondly, Green's inhibitory control model also indicated that IC proposed within the ICM is domain-general and not limited to linguistic/lexical processing. Empirical support for a domain-general bilingual IC advantage is inconclusive at the present time.

Proponents of BAH suggest that bilingual advantages occur because the same IC mechanism is used for all tasks involving conflict resolution, irrespective of the processing domain. Findings that identify a link between lexical retrieval and domain-general IC processes would provide empirical support for the hypothesis that linguistic competition is central to general bilingual cognitive advantages previously reported in the literature (e.g., Bialystok, 2006; Costa et al., 2008). However, it is possible that lexical retrieval engages a language-specific inhibitory mechanism allowing for any refinement of IC skills in linguistic domain only. Evidence that verifies domain-general IC advantages in bilingual speakers, especially in those with aphasia, would provide support for domain-general transference of long-term cognitive benefits induced by domain-specific language processing.

Finally, this study can provide valuable data to inform the recent debate concerning the proposed bilingual advantage in IC. Bilingual speakers' experience with inhibition of simultaneously activated within and cross-language competitors has been proposed as source of bilingual cognitive advantages (e.g., Kroll et al., 2008). If the assumption that the SAS constitutes a general inhibitory control exerted on language selection in bilingual speakers is valid, then bilingualism may function as training to this control mechanism. Bilingual speakers may therefore have an advantage over monolingual speakers in top–down inhibitory control.

CHAPTER 4: GENERAL METHODS

Three experiments were used to compare inhibitory control in monolingual and bilingual speakers with and without aphasia. Experiment 1 used a cyclic picture naming task to examine inhibitory control within the *lexical* system. Experiment 2 examined the inhibitory control with *linguistic* stimuli using a color-word computerized Stroop task. Experiment 3 studied inhibitory control with *non-linguistic* stimuli in a computerized flanker task. A general description of the participants and the procedure is provided in this chapter and the specific methodology of each experiment is outlined in subsequent chapters.

Participants

Participants with aphasia. Ten monolingual native English-speaking adults and ten bilingual native Tamil-speaking adults (L2: English) participated in the study. The participants were recruited via flyers and mailings posted at acute care hospitals, skilled nursing facilities and university clinics in the local area in Maryland as well as in Tamil Nadu, India as approved by the Institutional Research Board (IRB) at University of Maryland, College Park. IRB-approved Internet mailings were also distributed via listservs (e.g., msha@yahoogroups.com) and emails, to professional colleagues, aphasia support groups and cultural/community centers.

All participants sustained a single left hemisphere lesion resulting in aphasia, at least one year prior to participation. Participants' medical and neurological reports were reviewed to establish medical/treatment history and site of lesion data. All participants with aphasia were right-handed pre-stroke and had at least high school level of education. None of the participants had any history of other neurological conditions, alcohol/drug abuse, neuropsychiatric conditions or dementia. Current medications of the participants were also reviewed to rule out intake of any drugs that alter levels of alertness during participation in the study. All participants passed an audiometric screening at 40dBHL at 500 Hz, 1000 Hz, and 2000 Hz (American National Standards Institute, ANSI, 1969). Corrected visual acuity was at least 20/40 as measured on the Snellan's chart. Spatial neglect and visual field deficits were ruled out per participants' self-reports.

Additionally, all bilingual speakers with aphasia completed the LEAP-Q (Marian, Blumenfield & Kaushanskaya, 2007; Appendix A) twice to separately report pre-stroke and post-stroke abilities. As needed, the tester or caregiver assisted participants in completing these forms. All participants had acquired both Tamil and English before the age of five. On a scale of zero to ten (0 = no proficiency and 10 = excellent), all bilingual individuals with aphasia reported pre-stroke proficiency scores of greater than or equal to 9 in L1 and greater than or equal to 7 in L2. All bilingual individuals with aphasia demonstrated exposure to both languages every day both pre- and post-stroke, with a minimum of 30% current use of each language in daily communicative contexts (per self-report). The pre-morbid language proficiency/use of bilingual individuals with aphasia was utilized to determine eligibility. The demographic, linguistic and neurological details of all participants with aphasia are summarized in Table 4. The LEAP-Q (Marian et al., 2007) scores of all bilingual participants with aphasia are summarized in Table 5. Unfortunately, since the information regarding sites of lesion was accessible only via participants' hospital discharge records, very limited neurological information was available.

All monolingual and bilingual participants with aphasia were matched with neurologically healthy participants (described in the next section) on the following factors: age, education level, number of languages known, age of acquisition of L1 and L2 and language proficiency (bilingual speakers). There were no statistically significant differences between PWA and NH participants from monolingual and bilingual backgrounds in any of these factors (t-test; all $t(9) < 1.6$, $p > 0.53$).

All participants with aphasia completed a set of background tests to determine eligibility to participate in the study. These tests are described below and their findings are summarized in Table 6.

Table 4

Demographic profiles of monolingual and bilingual participants with aphasia

	Age/ Gender	Years of education	Pre-Stroke Occupation	Handedness	Etiology/ Site of lesion	Time post-onset (years)	Languages Known Pre-Stroke
MA1	64/F	16	Nurse	Right	L Frontal CVA	6	English
MA2	63/M	12	Mechanic	Right	Basal ganglia CVA	6	English
MA3	54/F	16	Budget Analyst	Right	L Frontal CVA	7	English
MA4	61/M	18	Accountant	Right	L Frontal CVA	6	English
MA5	75/M	23	Professor	Right	L Frontal CVA	4	English
MA6	64/F	12	Entrepreneur	Right	L Frontal CVA	14	English
MA7	68/M	12	Plant Technician	Right	L Frontal CVA	3	English
MA8	57/F	18	Technician	Right	L Frontal CVA	8	English
MA9	73/M	18	Attorney	Right	L fronto-parietal CVA	4	English
MA10	78/F	20	Physician	Right	L Frontal CVA	22	English
BA1	64/M	17	Engineer	Right	L Frontal CVA	2	Tamil/English
BA2	58/F	15	Banker	Right	L Frontal CVA	5	Tamil/English

BA3	63/F	18	Homemaker	Right	L Sub-cortical CVA	8	Tamil/English/Hindi
BA4	73/M	20	Linguist	Right	L Fronto-parietal CVA	4	Tamil/English/Hindi
BA5	68/M	15	Pastor	Right	L Basal Ganglia CVA	11	Tamil/English
BA6	75/M	17	Banker	Right	L Frontal CVA	7	Tamil/English
BA7	78/M	15	Banker	Right	L Parietal/ L Basal Ganglia CVA	16	Tamil/English
BA8	77/M	15	Teacher	Right	L Basal Ganglia CVA	6	Tamil/English/Telugu
BA9	69/M	20	Accountant	Right	L Frontal CVA	7	Tamil/English
BA10	72/M	15	Teacher	Right	L Frontal CVA	13	Tamil/English

[a] Based on classification by scores on Western Aphasia Battery - Revised (Kertesz, 2006); L CVA = Left hemisphere lesion resulting from cerebrovascular accident

Table 5

Self-reported pre- and post-stroke Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfield & Kaushanskaya, 2007) scores of bilingual participants with aphasia

		BA1		BA2		BA3		BA4		BA5		BA6		BA7		BA8		BA9		BA10	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
L1	Language/AOA†	Tamil/ birth		Tamil/ birth		Tamil/ birth		Tamil/ birth		Tamil/ birth		Tamil/ birth		Tamil/ birth		Tamil/ birth		Tamil/ birth		Tamil/ birth	
	Proficiency: speaking *	10	5	10	5	10	3	10	5	10	5	10	2	10	4	10	2	10	5	10	5
	Proficiency: understanding *	10	8	10	8	10	5	10	5	10	7	10	5	10	8	10	5	10	5	10	8
	Proficiency: reading *	10	5	10	2	10	1	10	5	10	5	10	5	10	3	10	5	10	5	10	3
	Exposure (% of time)	50%	80%	50%	75%	50%	70%	50%	50%	50%	70%	50%	80%	50%	80%	50%	100%	50%	90%	50%	75%

		BA1		BA2		BA3		BA4		BA5		BA6		BA7		BA8		BA9		BA10	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
L2	Language/ AOA†	English/ 4		English/ 4		English/ 4		English/ 4		English/birth		English/ 4		English/ 4		English/birth		English/birth		English/ 4	
	Proficiency: speaking *	10	2	10	5	10	5	10	3	10	5	10	3	10	2	10	2	10	5	10	5
	Proficiency: understanding *	10	7	10	8	10	6	10	3	10	4	10	6	10	8	10	5	10	7	10	8
	Proficiency: reading *	10	3	10	2	10	3	10	3	10	4	10	4	10	3	10	5	10	5	10	2
	Current exposure (% of time)	50%	20%	50%	25%	50%	30%	50%	50%	50%	30%	50%	20%	50%	20%	50%	0%	50%	10%	50%	25%

† Age of acquisition; * proficiency rated on a 10-point scale ranging from 0 (none) to 10 (perfect)

Table 6

Background test scores of participants with aphasia

Participant	Language Background Measures									Cognitive Background Measures				
	Aphasia Quotient* (max = 100)/ Aphasia Type		Mean Single Word Reading Comprehension [c] (max = 10)		Single Word Translation Production [c] (max = 10)		Color Screen [d] (max = 6)		Semantic Judgment [e] [max=52 (MA), 46 for (BA)]	Short-term Memory [f] (max = 10.5 per subtest)			Switching [g] (max = 10)	Problem Solving [h] (max = 8)
	L1 [a]	*L2* [b]	*L1*	*L2*	*L1*	*L2*	*L1*	*L2*		*Digit pointing*	*Picture pointing*	*Spatial pointing*		
MA1	65.8/ Broca's	n/a	7	n/a	n/a	n/a	6	n/a	52	4	4	7.5	10	8
MA2	65.4/ Broca's	n/a	8	n/a	n/a	n/a	5	n/a	50	5.5	4	7	10	8
MA3	67.8/ Broca's	n/a	7	n/a	n/a	n/a	6	n/a	51	7	5.5	8.5	10	7
MA4	52.2/ Broca's	n/a	7	n/a	n/a	n/a	6	n/a	50	5.5	4	7	10	8
MA5	84.9/ Broca's	n/a	8	n/a	n/a	n/a	5	n/a	52	4	2.5	5.5	10	8
MA6	45.6/ Broca's	n/a	7	n/a	n/a	n/a	6	n/a	49	3	3	5.5	9	8
MA7	72.9/ Broca's	n/a	7	n/a	n/a	n/a	5	n/a	50	5.5	4	6	10	8
MA8	80.5/ Broca's	n/a	9	n/a	n/a	n/a	6	n/a	52	5.5	5	7.5	10	8
MA9	77.6/ Broca's	n/a	8	n/a	n/a	n/a	6	n/a	50	4	4	5.5	10	7
MA10	87.2/ Broca's	n/a	8	n/a	n/a	n/a	5	n/a	52	4	3	5	10	8
BA1	72.2/ Broca's	63.5	7	8	6	5	6	6	46	5.5	4	7	10	8

BA2	72.6/ Broca’s	74.6	9	8	5	5	6	5	43	5.5	3.5	4	10	8
BA3	88.6/ Broca’s	57.4	9	8	4	6	6	6	42	7.5	5	6	10	7
BA4	63.4/ Broca’s	67.3	8	8	6	5	6	6	45	5.5	4	7.5	9	8
BA5	73.8/ Broca’s	72.8	8	8	7	6	6	6	46	4	4	7	10	8
BA6	69.4/ Broca’s	65.6	7	7	5	5	6	6	46	5.5	4	7	10	7
BA7	82.2/ Broca’s	70.2	8	8	6	7	6	5	46	5.5	5	4	10	8
BA8	56.9/ Trans-cortical Motor	55.4	8	8	4	5	6	6	44	4	3.5	5.5	9	8
BA9	79.4/ Broca’s	62.9	9	9	5	4	6	6	46	5.5	4	6	10	8
BA10	89.8/ Broca’s	73.5	9	9	7	6	6	5	46	5.5	4	5.5	10	8

[*] Scores from sub-tests provided in Appendix B [a] Based on scores on Western Aphasia Battery - Revised (WAB-R; Kertesz, 2006); AQ = Aphasia Quotient, [b] Based on scores on Tamil translation of the WAB-R (Kumar, 2007), [c] Bilingual Aphasia Test (Paradis, 1987; English and Tamil versions of single word reading and translation production subtests), [d] Written-word-to-color matching tasks of the six colors in the WAB-R color palette, [e] Pyramids and Palm Trees Test (Howard and Patterson, 1992), [f] Non-verbal Short-term Memory Test (DeRenzi and Nichelli, 1975; norms provided in Table 7) [g] Trail making subtest from the Cognitive-Linguistic Quick Test (CLQT, Helm-Estabrooks, 2001); [h] Maze subtest from the Cognitive-Linguistic Quick Test (CLQT, Helm-Estabrooks, 2001)

General language profile. Scores from the language assessments of participants with aphasia are summarized in Table 6.

Western Aphasia Battery – Revised (WAB-R; Kertesz, 2006). The WAB-R assesses four language areas: narrative language production, auditory comprehension, repetition and single word naming. Performance on these language sub-tests is used to calculate overall severity of language deficits (aphasia quotient; AQ, maximum = 100) and an aphasia profile. Tamil-English bilingual participants also completed the standardized non-norm referenced Tamil translation of the WAB-R (Kumar, 2007) to obtain language profiles in Tamil. Details of participants' performance on the individual sub-tests are provided in Appendix B. Eligibility criteria included (i) WAB-R auditory comprehension score of greater than four, (ii) WAB-R verbal expression marked by information content scores of greater than four and fluency content score of greater than three. Participants' other sub-tests scores were not used as exclusionary criteria. There were no significant differences between the L1 AQ scores of MPWA and BPWA ($Z = -.71$, $p = .47$) and L1 AQ of MPWA and L2 AQ of BPWA ($Z = .94$, $p = .35$). BPWA did not differ in their AQ scores in L1 and L2 ($Z = 1.70$, $p = .09$).

Bilingual Aphasia Test (BAT; Paradis, 1987). All bilingual participants with aphasia completed word level reading comprehension subtests and word-level translation production subtests of the BAT in Tamil and English (Table 6). The tester (native speaker of Tamil), administered the subtests of the BAT in each of the participants' languages according to the instructions in the test manual. All bilingual participants with aphasia demonstrated relatively spared reading abilities at word level with scores of at least 70% in single word reading on the BAT. BPWA did not differ between L1 and L2 in their single word reading comprehension ($Z = .34$, $p = .73$) and single word translation production ($Z = .19$, $p = .85$) scores.

Pyramids and Palm Trees Test (PPT; Howard and Patterson, 1992). All participants with aphasia also completed the picture version of the Pyramids and Palm Trees Test (PPT; Howard and Patterson, 1992) to assess semantic judgment (Table 6). The PPT is a forced-choice non-verbal test developed in English that assesses participants' semantic knowledge by examining their ability to access meaning from pictures. The target picture (e.g., pyramid) is presented above two other drawings and the participant is asked to decide which of the two drawings (e.g., palm tree or pine tree) has the closest association to the target picture. Since it has been proposed that conceptual representations are shared between the lexicons of the two languages (e.g., revised hierarchical model; Kroll & Stewart, 1994), results from PPT in English could be taken as reflecting the integrity of the bilingual conceptual-semantic system. But because this test has been developed for urban European populations and is subject to cultural and geographic biases, stimuli that are culturally unfamiliar for Tamil-English bilingual participants (as determined by tester; n = 5) were not presented to bilingual individuals with aphasia. All monolingual and bilingual participants scored greater than 85% on this test. There were no significant differences between the semantic judgment scores of MPWA and BPWA ($Z = -.26$, $p = .79$).

Cognitive assessments. The non-verbal short-term memory span of all participants was assessed using the digit pointing, picture pointing and spatial pointing subtests of DeRenzi and Nichelli's (1975) memory test in English. Short-term memory has been found to be an important predictor of performance in tasks of inhibitory control such as the Stroop task (e.g., Bélanger, Belleville, & Gauthier, 2010; Engle & Kane, 2004; Kane & Engle, 2003; Sung, Kim, Jeong & Kang, 2012). Each subtest has a maximum score of 10.5. For the purpose of this study, PWA scores were compared against the published normative data from neurologically unimpaired (n = 30) and left hemisphere damage with no visuospatial deficits (LH; n = 39) groups. Normed mean scores for neurologically healthy and left-hemisphere damaged individuals for each subtest are provided in Table 7. In general, both MPWA and BPWA performed better than the left hemisphere norms provided by the authors. There were no significant differences between MPWA and BPWA in any of the three subtests (all $Z < .73$, all $p > .27$).

Table 7

Normed mean scores (reference values) of working memory subtests (de Renzi & Nichelli, 1975)

Participant	NH[1]	LH-[2]
Digit Pointing	5.9	3.07
Picture Pointing	4.81	2.62

Spatial Pointing	5.92	5.28

[1] NH = Neurologically healthy unimpaired group; [2] LH = Left hemisphere damaged group (without visual deficits)

Additionally, participants also completed the symbol trails and maze subtests of the cognitive linguistic quick test (CLQT; Helm-Estabrooks, 2001), which assessed switching and problem solving respectively to examine participants' general executive function abilities. MPWA and BPWA did not significantly differ in their ability to complete either of these subtests (both $Z < .35$, all $p > .73$).

Assessing ability to perform experimental tasks. The color palette card of the auditory comprehension subtest of the WAB-R was used to screen for color identification and naming. All participants matched written word to the color (e.g. match written stimuli "green" with the green color patch). This ensured that participants could access semantic representations from the orthographic word form for performance on the Stroop task. There were no significant differences between MPWA and BPWA in L1 ($Z = -1.47$, $p = .14$) and MPWA in L1 and BPWA in L2 ($Z = -.34$, $p = .73$). BPWA did not differ in their color identification ability in L1 and L2 ($Z = 1.09$, $p = .27$).

Presence of significant oral-motor weakness and speech motor planning difficulties (apraxia) are likely to impact latency of verbal productions. Additionally, the presence of limb apraxia may impact participants' response to non-verbal experimental tasks. Hence all participants also completed an oral-motor examination and apraxia screens [non-verbal and verbal agility subtests from the Apraxia Battery for Adults – second edition (ABA-2; Dabul, 2000) and apraxia subtest of the WAB-R; Kertesz, 2006)] to identify verbal, oral and limb apraxia (Table 8). All participants demonstrated no greater than mild oral/verbal/limb apraxia. There were no significant differences between MPWA and BPWA on any of these subtests (all $Z < .47$, all $p > .39$).

Table 8

Apraxia test scores of participants with aphasia

Participant	BDAE non-verbal agility (max = 12)	BDAE verbal agility (max = 14)	WAB-R upper limb apraxia subtest (max = 15)
MA1	10	6	10
MA2	9	5	9
MA3	7	5	10
MA4	5	5	11
MA5	10	7	12
MA6	6	5	10
MA7	8	4	9
MA8	9	7	11
MA9	7	5	12
MA10	10	7	12
BA1	7	6	10
BA2	10	7	13
BA3	6	5	13
BA4	8	7	11
BA5	7	5	10
BA6	9	7	10

BA7	10	6	10
BA8	10	7	9
BA9	9	4	9
BA10	5	4	11

Neurologically healthy Speakers. Ten monolingual and ten bilingual neurologically healthy speakers participated in the study. All monolingual participants were native speakers of standard American English and all bilingual speakers were highly proficient in Tamil (native language - L1) and English (non-native language - L2). All bilingual neurologically healthy participants resided in India (in order to match with BPWA for language experience and cultural context). Bilingual proficiency was established via scores greater than eight in both languages on the language experience and proficiency questionnaire – LEAP-Q (Marian et al., 2007). The participants were recruited via flyers and mailings posted at in the local area in Maryland as well as in Tamil Nadu, India as approved by the Institutional Research Board (IRB) at University of Maryland, College Park. IRB-approved Internet mailings were also disbursed via listservs (e.g., msha@yahoogroups.com) to professional colleagues and cultural/community centers. All neurologically healthy participants were screened for any reported history of prior speech and/or language deficits, vision and hearing deficits, substance abuse or neuropsychiatric disturbances. There was no significant difference between monolingual and bilingual groups based on age ($t(9) = 0.59$, $p = 0.98$). But bilingual NH speakers had significantly more years of formal education than monolingual NH speakers ($t(9) = 0.23$, $p < 0.05$). This difference is not unexpected since high proficiency in English (L2) is typically acquired only through formal training (usually at least through college-level) within the English-dominant education system in India.

All bilingual neurologically healthy speakers were recruited from Tamil Nadu (India) in order to match the language background of bilingual individuals with aphasia. The bilingual participants' language acquisition, dominance and use of L1 (Tamil) and L2 (English) were measured using the LEAP-Q (Marian et al., 2007). According to self-reports, all bilingual speakers acquired both L1and L2 prior to 5 years of age and used both languages almost equally currently in daily life (mean L1 use: 54%; mean L2 use: 47%). On a scale of zero to ten (0 = no proficiency and 10 = excellent), all bilingual speakers reported proficiency scores of greater than or equal to 9 in L1 and greater than or equal to 7 in L2. The demographic details and additional information relating to the linguistic background of both monolingual and bilingual neurologically healthy participants are summarized in Table 9.

Design and Analyses

This study consisted of a mixed design, where the between-group factor was the language background (bilingual and monolingual) and the within-group factor was the experimental condition (interference-eliciting and non-interference eliciting conditions). All ten participants in each of the four groups (monolingual and bilingual neurologically healthy speakers and individuals with aphasia) completed all three experimental tasks. All the bilingual participants completed the naming and Stroop tasks in both L1 (Tamil) and L2 (English). Performance was scored and analyzed separately for each experiment and group analyses were completed. Performance of participants with aphasia was also compared to matched neurologically healthy controls. Throughout the study, raw scores for accuracy are reported in percentages and raw scores for latency are in milliseconds (ms). All statistical analyses were carried out using either arcsine (accuracy) or log transformations [latency: $\log_{10}$ (latency)] to control for violations in normality of distributions. To test the hypotheses, linear mixed effects analyses (Baayen, Davidson, & Bates, 2008) using the testing condition and language background as the fixed factors and participants as the random factors were conducted on the transformed scores using SPSS. Mixed effects model analysis was preferred over repeated measures ANOVA because it allows for examination of random effects from participants and items simultaneously. Additionally, mixed effects models do not assume independence amongst observations (which is often the case in the testing paradigms utilized in this study). Due to the large number of statistical comparisons across the multiple experiments in the study, unless otherwise specified, an alpha-level of $p < 0.01$ was set as the criterion for statistical significance to reduce the probability of type I errors.

Table 9

Demographic and language profiles of monolingual and bilingual neurologically healthy participants

Participant	Age/ Sex	Years of Education	Occupation	Languages Known		Age of L2 Acquisition (years)	% Daily Exposure		Self-reported Proficiency [a] (Scale of 0-10)					
									Speaking		Understanding		Reading	
				L1	*L2*		*L1*	*L2*	*L1*	*L2*	*L1*	*L2*	*L1*	*L2*
MN1	62/F	12	Store manager	English	n/a	n/a	100%	n/a	10	n/a	10	n/a	10	n/a
MN2	50/F	18	Designer	English	n/a	n/a	100%	n/a	10	n/a	10	n/a	10	n/a
MN3	65/M	16	Landscaper	English	n/a	n/a	100%	n/a	10	n/a	10	n/a	10	n/a
MN4	64/M	20	Programmer	English	n/a	n/a	100%	n/a	10	n/a	10	n/a	10	n/a
MN5	56/F	15	Administrative Assistant	English	n/a	n/a	100%	n/a	10	n/a	10	n/a	10	n/a
MN6	68/M	19	Retd Public Health Officer	English	n/a	n/a	100%	n/a	10	n/a	10	n/a	10	n/a
MN7	61/M	23	IT Manager	English	n/a	n/a	100%	n/a	10	n/a	10	n/a	10	n/a
MN8	59/F	15	Technician	English	n/a	n/a	100%	n/a	10	n/a	10	n/a	10	n/a
MN9	63/F	13	Retd Manager	English	n/a	n/a	100%	n/a	10	n/a	10	n/a	10	n/a
MN10	66/F	16	Retd Teacher	English	n/a	n/a	100%	n/a	10	n/a	10	n/a	10	n/a
BN1	63/M	17	Retd Banker	Tamil	English	5	50%	50%	10	10	10	10	10	10
BN2	60/F	21	Retd Teacher	Tamil	English	7	60%	40%	10	10	10	10	10	10
BN3	64/M	15	Pastor	Tamil	English	7	60%	40%	10	10	10	10	10	10
BN4	59/F	15	Nurse	Tamil	English	5	50%	50%	10	10	10	10	10	10
BN5	61/M	21	Retd Teacher	Tamil	English	6	50%	50%	10	10	10	10	10	10
BN6	65/F	17	Retd Teacher	Tamil	English	7	50%	50%	10	10	10	10	10	10
BN7	59/M	17	Manager	Tamil	English	5	60%	40%	10	10	10	10	10	10
BN8	55/F	17	Home maker	Tamil	English	7	75%	25%	10	10	10	10	10	10
BN9	51/M	17	Businessman	Tamil	English	7	30%	70%	10	10	10	10	10	10
BN10	57F	17	Home maker	Tamil	English	6	50%	50%	10	10	10	10	10	10

[a] As reported on the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfield & Kaushanskaya, 2007)

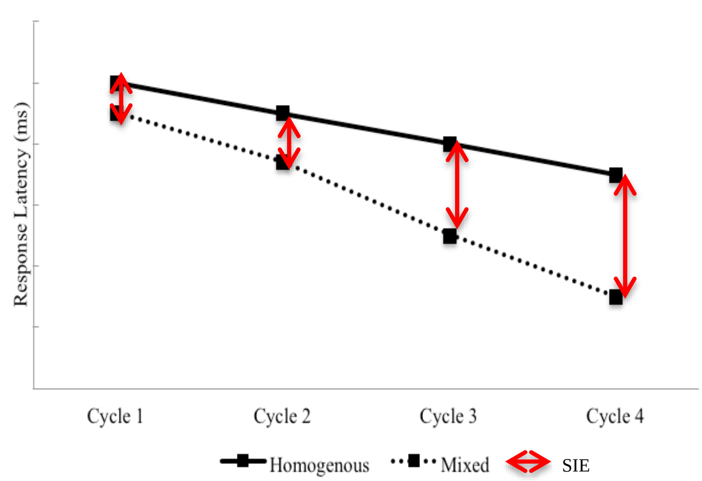
CHAPTER 5: AN INVESTIGATION OF LEXICAL-SEMANTIC INHIBITION

According to many models of word production, successful lexical retrieval is predicted to depend on the ability to limit interference from co-activated lexical-semantic representations (e.g., Caramazza, 1997; La Heij, Kuipers, & Starreveld, 2006; Levelt et al., 1999; Roelofs, 1992). In bilingual speakers, these co-activations could potentially arise within and across languages (e.g., Green, 1986, 1998; Hermans et al., 1998). Because of potentially twice the competition during lexical retrieval (which could arguably lead to more interference from competitors), bilingual speakers are proposed to have greater practice in effectively limiting interference from the competitors. The BAH proposes that bilingual speakers' greater practice with use of IC provides them an IC advantage relative to monolingual speakers. If bilingual lexical retrieval is supported by a more efficient inhibitory control mechanism compared to the monolingual system, then bilingual neurologically healthy speakers are expected to demonstrate smaller interference effects compared to matched monolingual speakers (advantage in lexical-semantic inhibition) in highly competitive scenarios such as the semantically homogenous blocking conditions of the cyclic picture naming task.

Since repeated practice of successful lexical retrieval is hypothesized to be at the root of the proposed IC advantage, it is possible that deficits in lexical retrieval may impact this proposed bilingual IC advantage. As reviewed in chapter 2, reports of some individuals with aphasia indicate the presence of IC deficits in addition to linguistic deficits (e.g., Abutalebi & Green, 2007; Biegler et al., 2008; Green et al., 2010; Hamilton & Martin, 2005, 2007). If bilingual speakers develop IC advantages from practice with limiting lexical interference (as per BAH), then despite more competition, BPWA can be expected to demonstrate smaller interference effects than MPWA in high conflict naming conditions. On the other hand, given BPWA's greater reliance on IC for successful lexical retrieval, it is possible that BPWA may actually demonstrate larger interference effects relative to MPWA. This study tested these predictions of the BAH using a semantically blocked cyclic picture naming task.

The semantically blocked cyclic naming task is particularly relevant for the study of lexical-semantic inhibition because picture naming is a semantically driven task. So there is natural competition among words that share semantic features (with greater competition in bilingual speakers). When multiple exemplars from the same superordinate category are presented for naming on consecutive trials (homogenous blocks), presence of several primed competitors may prolong the time required for the target to win the competition, relative to blocks of semantically unrelated items (mixed blocks; e.g., Schnur et al., 2006, 2009). Within each block, a set number of unique target items are typically repeated in successive cycles. The

Figure 3
SIE across cycles within each blocking condition in a semantically blocked picture naming task. (adapted from Crowther and Martin, 2014)



mean difference in accuracy/response latency between the homogenous condition and mixed condition in each cycle is called the *semantic interference effect* (SIE = homogenous – mixed). SIEs have been reported to increase over successive naming cycles (Figure 3). Larger SIEs are therefore indicative of less effective inhibition of non-target competitors. Specific predictions of participants' performance in this task within the context of the BAH are elaborated below.

Research Question and Hypotheses

Do bilingual and monolingual speakers with aphasia differ in lexical-semantic inhibition, as measured by a semantically blocked picture naming task? Do bilingual and monolingual PWA exhibit similar patterns in lexical-semantic inhibition as matched neurologically healthy speakers?

Overall, based on a robust body of prior literature, bilingual participants with and without aphasia were expected to be slower and less accurate in naming than their monolingual counterparts (e.g., Gollan et al., 2005, 2007). However, according to BAH, the magnitude of SIE is expected to be smaller in neurologically healthy bilingual speakers relative to monolingual participants (Bialystok, 2007, 2009). Similarly, if the bilingual advantage continues in individuals with aphasia, then BPWA would demonstrate smaller SIEs in the naming task compared to MPWA. Therefore, the BAH would be supported if results of the experiment indicated a significant interaction effect between language background (bilingual, monolingual) and cycle (1-4) in analyses of mean differences in SIEs.

Method

Participants. Ten monolingual and bilingual speakers with aphasia as well ten monolingual and bilingual matched neurologically healthy participants described earlier (in the *General Methods* chapter) completed this experiment.

Norming of Stimuli. The purpose of this norming procedure was (1) to establish naming agreement of target pictures, (2) to obtain word familiarity ratings from bilingual neurologically healthy Tamil-English speakers (in lieu of frequency norms), and (3) to establish membership in superordinate semantic category. All items used for norming were taken from the International Picture Naming Project (IPNP) database (Szekely, Jacobsen, D'Amico, Devescovi, Andonova, Herron, et al., 2004). The IPNP database contains 520 pictures of concrete nouns in English. Of these, all items that are compound nouns in English (e.g. ice cream cone), those that do not have a single word translation in Tamil (e.g. spider is translated as /etu kal putʃi/, which is a noun phrase that means eight-legged bug), and those that are not culturally relevant (e.g. spaghetti) were excluded. Additionally, all words that are cognates (words that share semantic and phonological forms in the two languages; e.g., balloon) and homophones (words that share only phonological form in the two languages; e.g., pie – refers to the dessert in English but refers to bag in Tamil) were also excluded. All remaining stimuli (n=224) were identified as potential stimuli for norming. Tamil translations of these words were verified using an English-Tamil dictionary (Percival, 2000). Black and white line drawings of these potential stimuli were obtained from the IPNP database (Szekely et al., 2004).

Twenty-five bilingual neurologically healthy Tamil-English speakers (residing in the United States) named these 224 pictures, rated their familiarity in both Tamil and English, and provided the semantic category for each item. Naming agreement was calculated as the percentage of participants who produced the dominant name for each item. In each language, items that did not have at least 80% name agreement were excluded. Familiarity ratings were obtained because there are no available lexical frequency norms for Tamil. Participants rated familiarity of the pictured nouns on a seven-point Likert rating scale (1=very unfamiliar and 7=very familiar) in each language. Items that received an overall mean rating of 4-7 in both languages were included in the study. Participants in the norming procedures also named the semantic category to which each exemplar belongs. The most commonly listed categories and their most salient exemplars (identified by greater than 80% consensus in categorization of that item across all participants) were included in the study.

At the end of this norming process, sixty nouns were identified. These pictures included five unique targets in twelve semantic categories. The categories include accessories, animals, birds, body parts, nature, people, shapes, toys, utensils, vegetables, vehicles and weapons. The list of the targets and their categories and the mean values of naming agreement, familiarity and categorical identity is given in Appendix B.

Procedure. The experimental paradigm was based on the one reported by Schnur et al. (2006). The experiment was programmed in SuperLab experimental software and run on a Windows operating system. There were 24 blocks (twelve homogenous and twelve mixed category blocks). In each block, five unique pictures were named once (cycle 1), then again in a different random order (cycle 2), and so on for a total of 4 cycles (20 trials per block; Table 10). On each trial, one target was presented for naming. In homogeneous blocks, targets were five exemplars from the same semantic category (e.g., five animals) and in a mixed block the targets were five exemplars from different categories in random order (one animal, one toy, one vehicle, etc.). Phonological overlap within blocks was kept to a minimum. In each experimental run, all 24 blocks were named, with the homogeneous-mixed presentation order randomly varied. Each participant received one-half the targets first in the homogeneous blocks and the other half first in the mixed blocks. Participants were provided with as many rest breaks as needed between blocks. Over the entire experiment, each participant named all 12 categories in two blocking conditions (homogenous and mixed) for a total of 24 blocks resulting in 480 trials per subject. Monolingual participants named the targets in English and bilingual participants named them in Tamil and English. Tamil and English testing for bilingual participants were completed in different testing sessions, at least 10 days apart.

Table 10

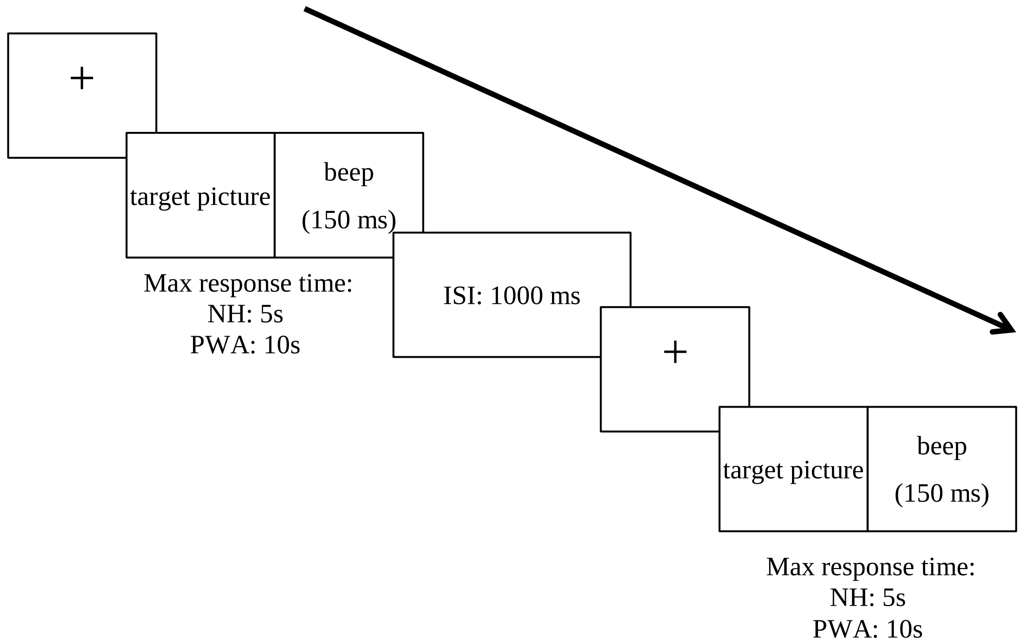
Sample order of stimulus presentation in the homogenous and mixed blocks of the semantically blocked picture naming task

Trial #	**Cycle #**	**Homogenous block**	**Mixed block**
1	Cycle 1	Monkey	Knife
2		Lion	Eye
3		Cow	Ring
4		Cat	Ax
5		Dog	Cat
6	Cycle 2	Cat	Hat
7		Cow	Arrow
8		Monkey	Duck
9		Dog	Roof

10		Lion	Boat
11	Cycle 3	Monkey	Cannon
12		Cat	Monkey
13		Lion	Earring
14		Cow	Mountain
15		Dog	Rainbow
16	Cycle 4	Cow	Top
17		Dog	Necklace
18		Monkey	Star
19		Cat	Lion
20		Lion	Onion

Each participant was tested individually in a well-lit room, free of distractions. Participants were asked to name the picture on the computer as quickly and accurately as they could. The task instructions were presented to the participants in written mode on the computer and verbally, in English, and were repeated if necessary. Every trial started with a central fixation cross for 500ms, followed by the target picture. The onset of each target was accompanied by a beep (150ms in duration) to mark the stimulus presentation (Figure 4). This was to assist in response latency measures (described below). This target picture stayed on the screen until the participant responded or until the response duration was over (whichever is earlier). Response duration of 10 seconds was provided for individuals with aphasia and 5 seconds for neurologically healthy controls. Participants were instructed to move on to the next trial by pressing the space bar. A response-stimulus interval of 1000 ms was maintained between all trials. Participants completed at least 10 practice items before performing the task to ensure that they understood the task requirements. All participants' responses were recorded on digital voice recorder.

Figure 4
Schematic representation of stimulus presentation in the semantically blocked picture naming task



Scoring. All participants' responses were transcribed (including self-corrections and other comments) during the testing session and later verified with the audio recording of the testing sessions. In cases of non-word errors, responses were transcribed phonetically. Only the first complete response produced by the participant was scored for accuracy. Only if the response provided was the target word or a dictionary synonym (e.g. *round* for *circle*), it was scored as accurate (even if preceded by filled pauses/dysfluencies). Any other variant of the target (including non-words, filled pauses followed by no responses) and incorrect responses eventually self-corrected to the target word (e.g., square ….no circle) were coded as errors.

The latency of participants' responses was manually timed for all accurately produced responses using Praat software (Boersma & Weenink, 2009; version 5.3.12). The time from the onset of the word (marked by the beep) to the onset of the verbal response was calculated as the response latency in milliseconds. Each participant's production latencies that were 2.0 standard deviations above or below their overall mean were excluded from the analyses as outliers. This resulted in exclusion of a total of 2.21% and 7.92% of the data points of neurologically healthy speakers and individuals with aphasia respectively. The mean naming accuracy and latency were calculated in each naming cycle for each blocking condition in both language groups. The mean difference in accuracy/latency between the homogenous and mixed conditions at each cycle was calculated as the semantic interference effect (Figure 3).

Another trained rater completed reliability of accuracy and latency scoring for 30% of all trials. Inter-rater reliability was examined using kappa statistics (K). Inter-rater agreement was "almost perfect" (Vierra & Garret, 2005) with K values of 0.89 and 0.81 on accuracy and latency measures respectively.

Analyses. Mean SIEs in accuracy and latency were transformed using arcsine and logarithmic transformations respectively. These transformed SIEs were compared using a mixed effects measures ANOVA with two factors – language background (bilingual, monolingual) as the between-group factor and naming cycle (1,2, 3, 4) as the within-group factors. The covariate for analyses of individuals with aphasia was the aphasia quotient score from the Western Aphasia Battery - revised (WAB AQ). In both neurologically healthy adults and PWA, separate analyses were completed to (i) compare SIE in L1 naming between bilingual and monolingual (L1= Tamil in bilingual and English in monolingual speakers) and, (ii) compare interference effects in English naming. Where indicated, post-hoc two-tailed t-tests (statistical significance determined at $p < 0.05$) were performed with a Bonferroni correction.

Results

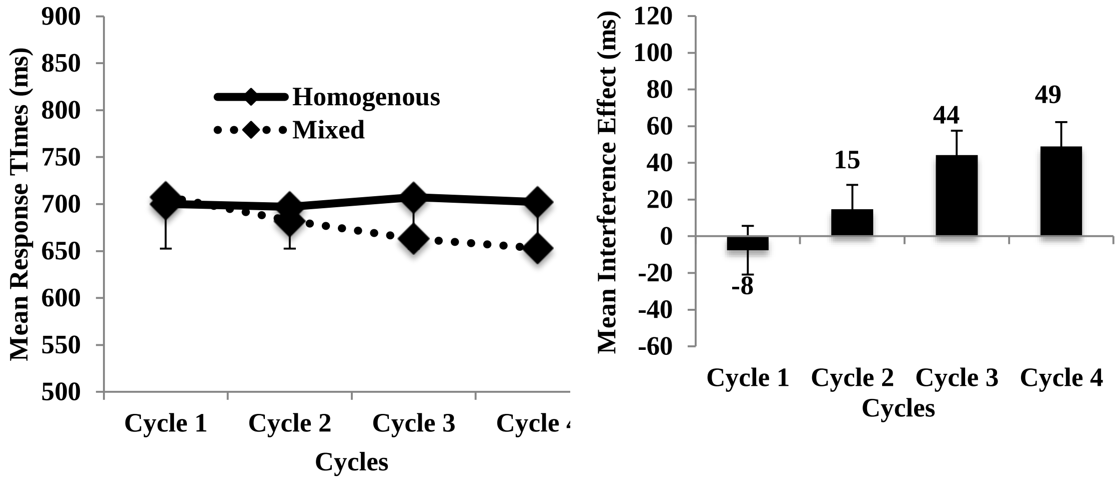
Neurologically Healthy Speakers

Accuracy. Overall, bilingual and monolingual neurotypical speakers demonstrated mean naming accuracy of greater than 98% across languages tested exhibiting a ceiling effect. There were no significant main effects of language background or cycle, and no significant interaction between them (all F (1, 72) > .02, all p = ns).

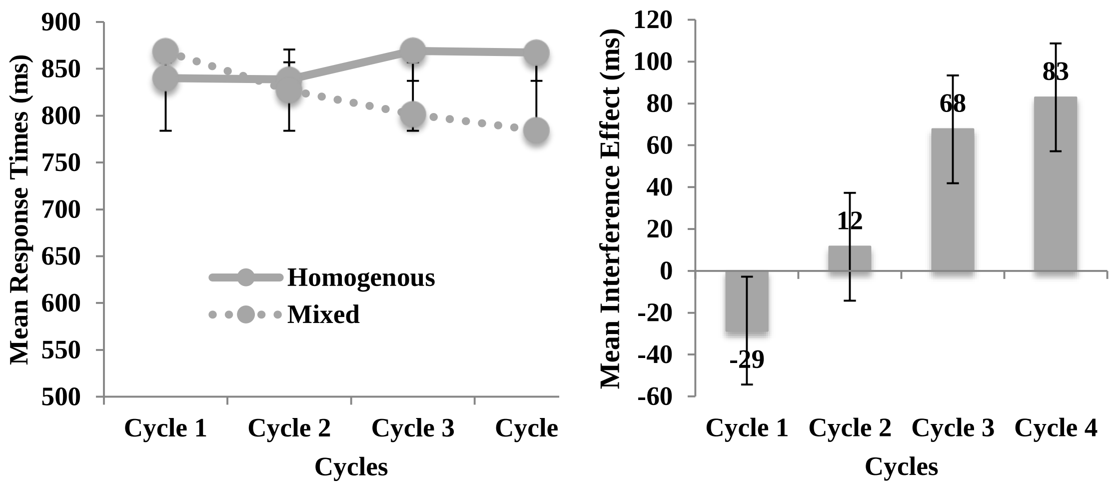
Latency. Mean naming latencies in homogenous and mixed blocks and corresponding interference effects in monolingual speakers (Figure 5a), bilingual speakers in L1 (Figure 5b) and bilingual speakers in L2 (Figure 5c) are summarized in the Figure 5. Summary of the results of the mixed model ANOVAs are provided in Table 12 and interpreted in the following text.

Figure 5
Mean naming latency (ms) and interference effect (ms; mean difference between homogenous and mixed conditions) on the semantically blocked cyclic picture naming task by repetition cycle in monolingual neurologically healthy speakers (Figure a), bilingual speakers in L1 (Figure b), and bilingual speakers in L2 (Figure c); error bars are standard deviations

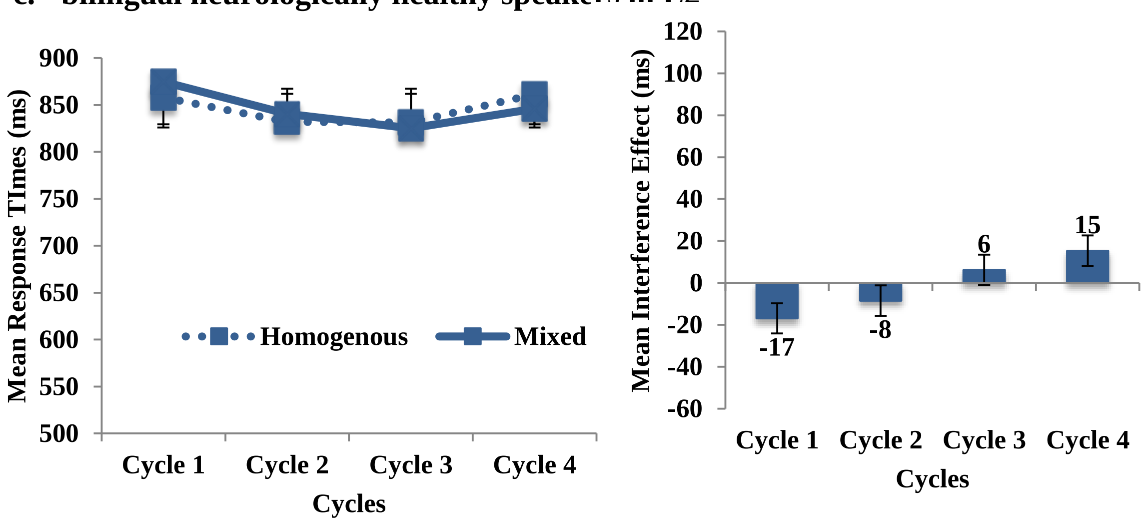
a. monolingual neurologically healthy speakers



b. bilingual neurologically healthy speakers in L1



c. bilingual neurologically healthy speakers in L2



Consistent with prior research, comparisons of cycle 1 naming latency between monolingual and bilingual speakers (Table 11) indicated that bilingual speakers were overall slower than monolingual speakers irrespective of response language (all $t(9) > 42.33$; $p < 0.01$).

Table 11

Mean accuracy (%) and latency (ms) values and SIE (homogenous – mixed) in cycle 1 of the semantically blocked cyclic picture naming task for each participant group

Language Background	Accuracy				Latency (ms)			
	L1		L2		L1		L2	
Homogenous	%	*SIE*	%	*SIE*	Duration (ms)	*SIE*	Duration (ms)	*SIE*
Bilingual Neurologically Healthy	99.83	*0.33*	99.83	*-.17*	840.03	*-29*	857.77	*-17*
Bilingual Aphasia	75.00	*2.33*	69.67	*0.50*	2560.25	*102*	1815.08	*-128*
Monolingual Neurologically Healthy	98.67	*0.00*	n/a	*n/a*	700.33	*-8*	n/a	*n/a*
Monolingual Aphasia	72.00	*-.83*	n/a	*n/a*	1702.51	*2*	n/a	*n/a*
Mixed								
Bilingual Neurologically Healthy	99.50	--	100.00	--	868.60	--	874.70	--
Bilingual Aphasia	72.67	--	70.17	--	2458.19	--	1943.41	--
Monolingual Neurologically Healthy	98.67	--	n/a	--	707.86	--	n/a	--
Monolingual Aphasia	72.83	--	n/a	--	1700.14	--	n/a	--

Separate analyses were conducted to compare (log-transformed) SIEs between monolingual L1 (English)/bilingual L1 (Tamil) naming and monolingual L1 (English)/bilingual L2 (Tamil) naming. Both analyses revealed significant main effects of cycle verifying the presence of SIE. Post-hoc pair-wise analysis of main effect of cycle in monolingual and bilingual L1naming using Bonferroni correction indicated that irrespective of their language backgrounds, all neurologically healthy speakers demonstrated significantly larger SIEs in successive L1 naming cycles, except between cycles 3 and 4 (which were not significantly different). Similar post-hoc analysis of monolingual L1/bilingual L2 naming, indicated that though cycle 4 SIE was significantly larger than other cycles, none of the other pairwise comparisons revealed significant differences. The main effects of language background were not significant in both monolingual L1 versus bilingual L1 and monolingual L1 versus bilingual L2 comparisons. However, in both these analyses there was a significant interaction between language background and cycle. Specifically, contrary to the hypothesis, bilingual participants demonstrated significantly larger SIEs relative to monolingual participants in cycles 3 and 4 only while naming in L1. When naming in L2, they demonstrated the hypothesized pattern of results – bilingual speakers demonstrated smaller SIEs than monolingual speakers in cycles 3 and 4. There was no difference between the SIEs in bilingual and monolingual NH speakers in cycle 2 irrespective of the language used by bilingual speakers. To summarize, with increasing competition in lexical retrieval, bilingual speakers had larger SIEs in L1, but smaller SIEs in L2when compared to monolingual speakers.

Table 12

Results of mixed model repeated measures ANOVA using (transformed) mean semantic interference effects (SIE) in accuracy and latency as dependent variables

Group	Comparison	Variables	Degrees of Freedom		F	*p*
			Numerator	Denominator		
	Dependent variable: Accuracy SIE					
Neurologically Healthy Participants	Bilingual L1 versus monolingual L1	Lang	1	18	.00	.99
		Cycle	3	72	1.02	.39
		Lang x Cycle	3	72	.49	.69
	Bilingual L2 versus monolingual L1	Lang	1	18	.17	.69
		Cycle	3	72	.51	.67
		Lang x Cycle	3	72	.34	.79
	Dependent variable: Latency SIE					
	Bilingual L1 versus monolingual L1	Lang	1	18	.68	.42
		Cycle*	3	54	53.90	.00
		Lang x Cycle*	3	54	5.54	.00
	Bilingual L2 versus monolingual L1	Lang	1	18	1.19	.29
		Cycle*	3	54	8.55	.00
		Lang x Cycle*	3	54	6.35	.00
	Dependent variable: Accuracy SIE					
Participants with aphasia	Bilingual L1 versus monolingual L1	Lang	1	18	3.29	.09
		Cycle	3	54	1.90	.14
		Lang x Cycle	3	54	1.44	.24

Bilingual L2 versus monolingual L1	Lang	1	18	4.85	.09
	Cycle	3	54	1.80	.15
	Lang x Cycle	3	54	1.88	.14
Dependent variable: Latency SIE					
Bilingual L1 versus monolingual L1	Lang	1	18	1.34	.26
	Cycle	3	54	1.96	.13
	Lang x Cycle	3	54	1.89	.14
Bilingual L2 versus monolingual L1	Lang	1	18	.10	.75
	Cycle	3	54	2.49	.07
	Lang x Cycle	3	54	1.76	.17

* = Statistical significance at p = .01; SIE = semantic interference effect (Homogenous – Mixed); Bilingual L1 = Tamil; Bilingual L2, Monolingual L1 = English

Persons with aphasia

Accuracy. To compare overall accuracy differences between PWA and NH participants (Table 11), two-way ANOVAs were conducted using neurological status (aphasia, healthy) and language background (monolingual, bilingual) as the independent variables separately for bilingual L1 and bilingual L2. There were significant main effects of neurological status in comparisons between monolingual participants and bilingual speakers in L1 ($F(1, 36) = 19.82$, $p < .01$) and bilingual speakers in L2 ($F(1, 36) = 20.60$, $p < .01$). NH speakers were more accurate than PWA, irrespective of the response language. However, there was no main effect of language background (bilingual L1 versus monolingual: $F(1, 36) = .01$, $p = .91$; bilingual L2 versus monolingual: $F(1, 36) = .08$, $p = .78$) and no interaction effects between neurological status and language background (both L1 and L2 comparisons: $F(1, 36) > .07$, $p > .70$).

Monolingual and bilingual PWA's mean naming accuracies and interference effects by blocking condition and repetition cycle are summarized in Figure 6. Summary of the results of the mixed model ANOVAs of SIEs are provided in Table 12. There were no-significant main effects of language background and cycle in both bilingual L1 and L2 comparisons against monolingual speakers (Table 12). The analyses also showed non-significant interaction effects. Taken together, these results suggest that the SIE in accuracy did not differ significantly between BPWA and MPWA in both L1 and L2.

Figure 6
Mean naming accuracy (%) and interference effect (%; mean difference between homogenous and mixed conditions) on the semantically blocked cyclic picture naming task by repetition cycle in monolingual individuals with aphasia (Figure a), bilingual individuals with aphasia in L1 (Figure b), and bilingual individuals with aphasia in L2 (Figure c); error bars are standard deviations

Figure a (monolingual individuals with aphasia)

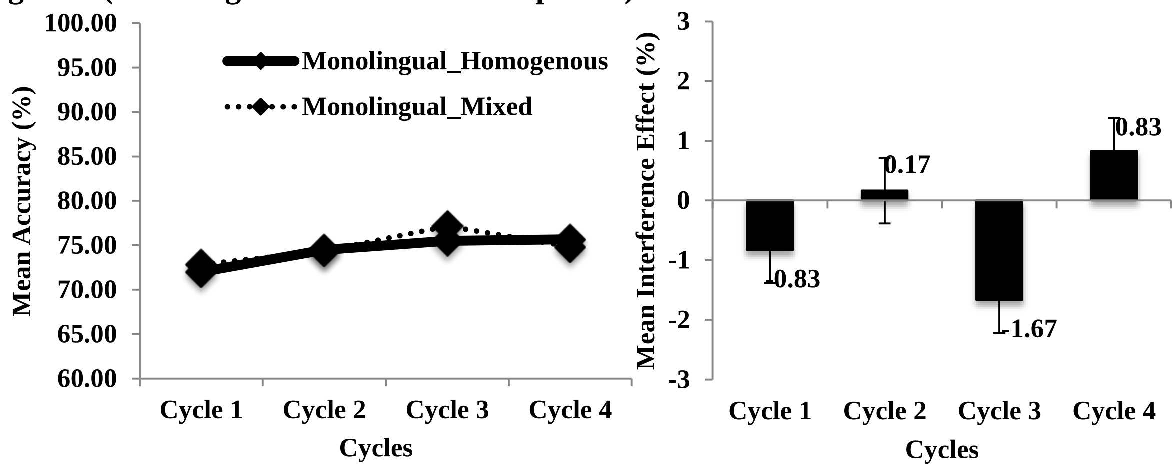


Figure b (bilingual individuals with aphasia in L1)

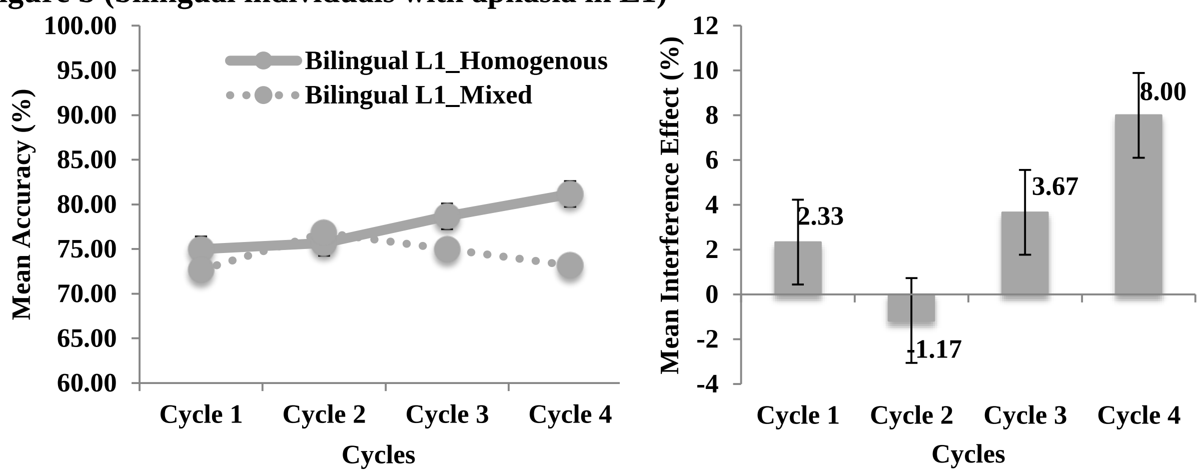
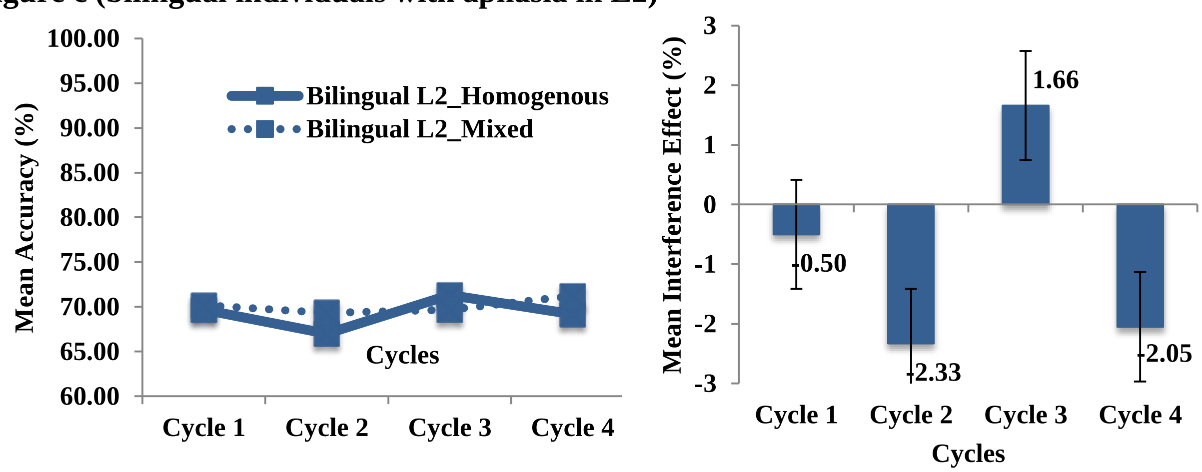


Figure c (bilingual individuals with aphasia in L2)



Latency. Latency differences between PWA and neurotypical participants (Table 12) were compared using two-way ANOVAs with neurological status and language background as the independent variables and (log-transformed) naming latency as dependent variable at $p < .05$. PWA and neurotypical speakers' latencies were separately compared when bilingual participants responded in both L1 and L2. Results of the analyses in both languages indicated significant main effects of neurological status (L1: $F(1, 36) = 9.93$, $p = .02$; L2: $F(1, 36) = 7.55$, $p = .01$) and language background (L1: $F(1, 36) = 9.96$, $p < .01$; L2: $F(1, 36) = 9.29$, $p < .01$). These results reveal that, as expected, PWA were overall significantly slower than neurologically healthy controls. Also, consistent with existing research, bilingual speakers were slower than monolingual speakers in naming responses. Results also indicated significant interaction effects (in both L1 and L2 bilingual responses: $F (1, 36) > 9.79$, $p < .05$) suggesting that the effect of language background on response latency was greater in PWA than neurotypical speakers.

Monolingual and bilingual individuals with aphasia' mean naming latencies and interference effects by blocking condition and repetition cycle are summarized in Figure 7. Comparisons of cycle 1 naming latency between monolingual and bilingual L1 naming as well as monolingual and bilingual English naming in individuals with aphasia (Table 11) indicated that, similar to neurologically healthy speakers, BPWA were slower than MPWA in picture naming (all $t(9) > 47.79$; $p < 0.01$) . Summary of the results of the mixed model ANOVAs of SIEs are provided in Table 12. Statistical analyses of SIEs in latency revealed non-significant main effects of language background and cycle in both bilingual L1 and L2 comparisons against monolingual PWA (Table 12). The analyses also showed non-significant interaction effects. Taken together these results suggest that 1) PWA did not show an effect of blocks or cycles, and 2) BPWA are slower than MPWA, but did not significantly differ from MPWA in the semantic interference effects.

To summarize, (i) relative to neurologically healthy speakers, individuals with aphasia were overall less accurate and slower in naming in the blocked naming paradigm, (ii) bilingual and monolingual speakers with and without aphasia did not differ in SIE for accuracy, (iii) compared to neurologically healthy monolingual speakers, neurotypical bilingual participants demonstrated larger latency-based SIEs in later cycles than monolingual participants when responding in L1 but had smaller SIEs compared to monolingual speakers in L2, (iv) there was no main effect of language or cycle or interaction between these factors in both accuracy and latency based SIEs in PWA. Together, results of this experiment indicate that relative to matched monolingual NH speakers, NH bilingual speakers have an IC disadvantage in lexical-semantic processing in L1, but an advantage in L2. However, these differences do not persist in individuals with aphasia.

Figure 7
Mean naming latency (ms) and interference effect (ms; mean difference between homogenous and mixed conditions) on the semantically blocked cyclic picture naming task by repetition cycle in monolingual individuals with aphasia (Figure a), bilingual individuals with aphasia in L1 (Figure b), and bilingual individuals with aphasia in L2 (Figure c); error bars are standard deviations

Figure a (monolingual individuals with aphasia)

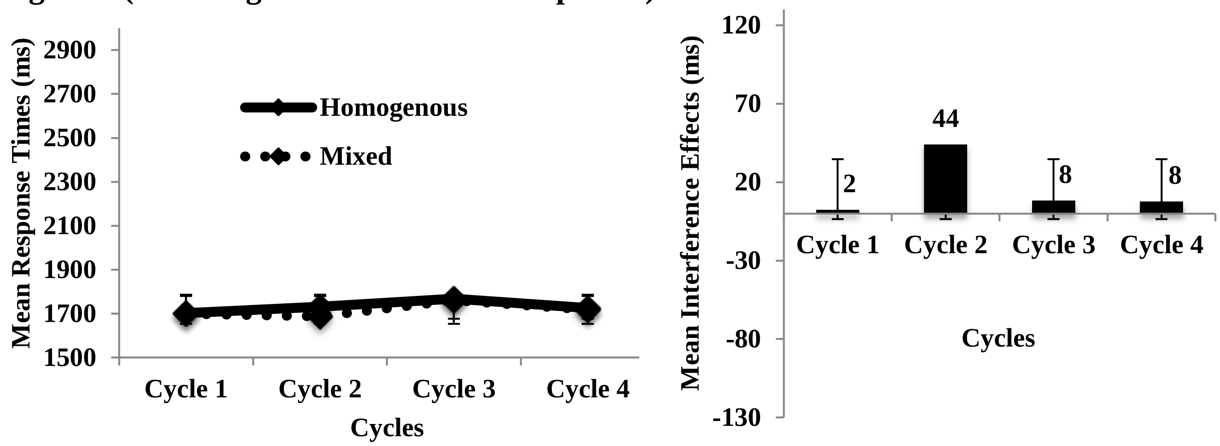


Figure b (bilingual individuals with aphasia in L1)

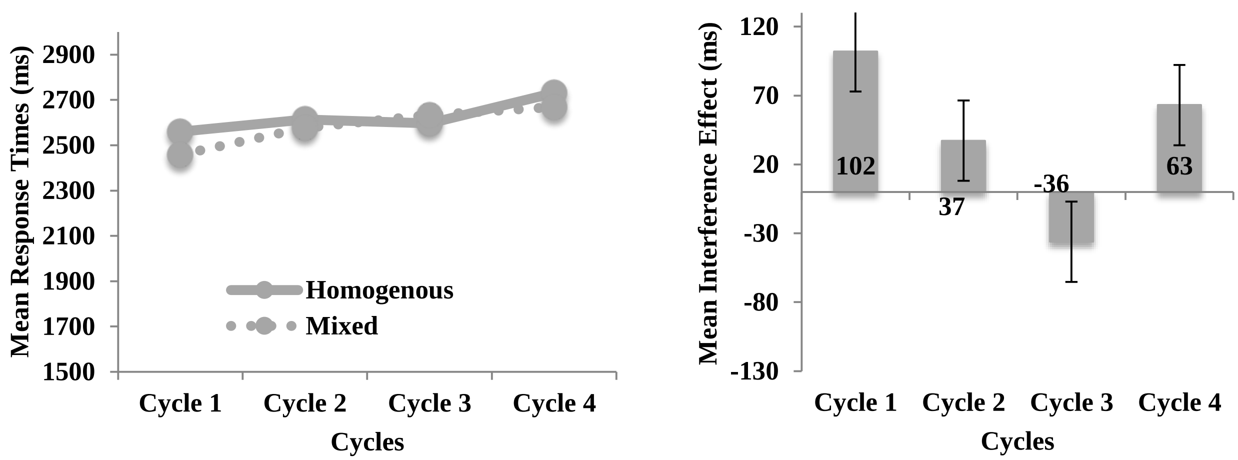
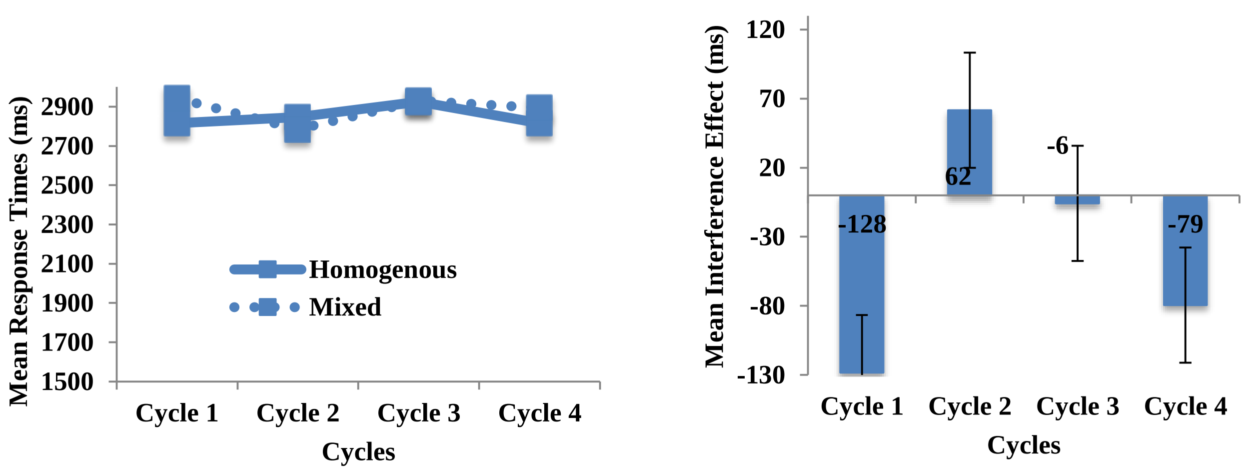


Figure c (bilingual individuals with aphasia in L2)



Discussion

The aim of this experiment was to examine if IC, as measured by semantic inference effect, is different between bilingual and monolingual speakers. Results of this study indicate that MNH and BNH speakers differ from each other in the lexical IC engaged during the semantically blocked cyclic picture naming task. Specifically, when compared to monolingual speakers, bilingual NH speakers had larger SIEs in L1 (bilingual disadvantage), but smaller SIEs in L2 (bilingual advantage) in high competition conditions (later naming cycles). Contrarily, MPWA and BPWA did not differ from each other in lexical IC. In fact, neither one of the groups of PWA demonstrated the SIE previously reported in the monolingual aphasia literature (Schnur et al., 2006, 2009). The implications of these results on our understanding of lexical retrieval in aphasia, and bilingual lexical retrieval are described in the following sections.

Lexical retrieval in aphasia

Relative to their respective matched NH control groups, both bilingual and monolingual PWA demonstrated IC deficits as evidenced by larger (normalized) SIEs in cycle 1 of the naming task. This is not unexpected given that all PWA (monolingual and bilingual) experienced lesions in the neural areas typically implicated in language control (LIFG or basal ganglia). PWA were also less accurate and slower than matched healthy controls across all naming conditions. Therefore, results from this study support lexically based IC deficits in PWA, irrespective of language background. These results are not surprising given that all PWA in this study presented with lesions in neural regions typically implicated in inhibitory control (LIFG or basal ganglia).

However, neither bilingual nor monolingual PWA in this study demonstrated cyclic build-up of interference effects with increasing lexical competition. The absence of the cyclic SIE on PWA in this study is contrary to the results from neurologically healthy bilingual and monolingual speakers who demonstrated significant cyclic increase in SIE (in response latency), irrespective of response language. The results are also different from the SIE previously reported in monolingual literature (Schnur et al., 2006, 2009). These null effects may have been influenced by both participant related and methodological variables, which are discussed in the following sections. The implications of these results on our understanding of language processing in aphasia are also discussed.

The participant variable that is most relevant to the current findings is their sites of lesion. The general pattern of results from the aphasia literature indicates that the exaggerated build-up of semantic interference induced by cyclic manipulations are a defining feature of the performance of individuals with aphasia resulting from lesions in the left frontal cortical sites, including the left inferior frontal gyrus (LIFG; Broca's area). Schnur et al. (2009) compared PWA with lesions in either the LIFG or the left temporal cortex, and found that although all participants had difficulties with word production, the ability to resolve competition during language production depended selectively on the integrity of the LIFG (see also Schnur et al., 2006). Other studies examining PWA also support the relationship between SIE and LIFG lesions (e.g., McCarthy and Kartsounis, 2000; Wilshire and McCarthy, 2002; Biegler et al., 2008). It is however important to note that this association between non-fluent speakers with Broca's aphasia and exaggerated interference effects may have less to do with a causal relationship but may rather highlight the role of the LIFG in conflict resolution (Novick, Trueswell, & Thompson-Schill, 2005; Pisoni, Papagno & Cattaneo, 2012). Some studies report that some individuals with aphasia who were non-fluent and diagnosed with Broca's aphasia demonstrated greater interference effects in later cycles (except one MPWA reported by Schnur et al., 2006 and one reported by Wilshire and McCarthy, 2002) than those with other aphasia subtypes (e.g., Schnur et al., 2006, 2009) and some neurologically healthy adults (Biegler et al., 2008; Scott & Wilshire, 2010; Wilshire & McCarthy, 2002). PWA who exhibit poor inhibitory control on non-lexical experimental tasks or whose lesions include inhibitory circuits typically demonstrate exaggerated interference effects (e.g., Scott & Wilshire, 2010). Based on these findings in previous literature, the absence of SIE in speakers with aphasia in this study was particularly surprising. Irrespective of language background, participants generally had left frontal lesions involving the perisylvian region and/or the sub-cortical control circuits (Table 4). However, since there are no additional details regarding the lesions, it is difficult to make specific conclusions about the impact of lesion size and location on IC in these participants.

The unified theory of inhibitory control proposed by Munakata et al. (2011) provides a preliminary framework to interpret these non-significant results in the face of the sites of lesion of PWA in this study. They argue inhibition possibly comprises of (i) targeted global inhibition and, (ii) indirect competitive inhibition. Though not mutually exclusive, they propose that different regions of the neural control circuits sub-serve different types of inhibition depending on “their connectivity with other brain regions and the content of the abstract information represented” (Munakata et al., 2011, p. 452). This can be reconciled with the ideas of inhibition proposed by Green in the ICM. Within the cognitive architecture, the “targeted global inhibition” could be supported by SAS and the “indirect competitive inhibition” by the reactive inhibition within the lexical retrieval system. It is possible that a task such as the semantically blocked picture naming relies to a lesser degree on global inhibitory control in the context of naming blocks and to a greater extent on the competitive inhibition. The sites of lesions in these patients may uniquely impact neural connections involved in this competitive inhibition to a greater degree than global inhibition resulting in the observed null results.

It is also important to recognize that the current study differed from those reporting significant cyclic SIE build-up in some important methodological ways that may have impacted the differences in results. First, in all three of the previously reported studies where PWA demonstrated the cyclic build-up of SIE (Schnur et al.,2006; Schnur et al., 2009 Wilshire & McCarthy, 2002), the experimental paradigms had smaller response durations (either 1s, 3s or 5s) compared to the current study (10s). Also, given that the speeded naming task in this study was self-paced, the response duration and inter-stimulus interval were not consistent across all PWA. A combination of both of these factors may have resulted in decay of semantic activation from the previous trial, thereby limiting interference elicited in the subsequent trial. Additionally, it is also possible that reduced activation of the target limited the strength of competitors within related semantic networks. Another important methodological factor that may have impacted the present study is the inability to control for lexical frequency to the extent reported in the previous studies. This is primarily because the available English lexical frequency data and the word familiarity pilot data for Tamil had to be accommodated within stimulus properties.

No study until this point has examined semantic interference effects using the semantic blocking paradigm in bilingual speakers with aphasia. Results from this novel study indicated that neither monolingual nor bilingual participants with aphasia demonstrated any interference effects in the task. Therefore, these results cannot provide evidence to inform if BPWA qualitatively differ from matched MPWA in their ability to limit interference from lexical competitors during picture naming (bilingual advantage hypothesis). But the findings of the current study need to be interpreted with caution. The bilingual participants in this study were quite homogenous in language background, both pre- and post-stroke. All BPWA were early, balanced highly proficient bilingual speakers pre-stroke (per self-report). Post-stroke, all BPWA used each of their languages appropriately, with no evidence of pathological language switching. A majority of them demonstrated parallel recovery of both languages post-stroke. These factors may impact the generalizability of the findings. It is possible that BPWA exhibiting other patterns of language recovery that are less balanced may present with different patterns of performance.

Bilingual lexical retrieval

This study is the first of its kind to examine lexical inhibitory control in bilingual speakers using this paradigm. As expected, the results of the study demonstrated an overall disadvantage in bilingual naming in individuals with and without aphasia (Table 11). This disadvantage is consistent with previously reported findings that indicate that bilingual adults name pictures more slowly than monolinguals (Gollan et al. 2005; Ivanova & Costa, 2008), produce fewer words on verbal fluency tasks (Gollan, Montoya, and Werner 2002; Rosselli et al. 2000), and experience more tip-of-the tongue episodes (Gollan and Acenas 2004). Gollan et al. (2005) observed that bilingual adults named object pictures more slowly than monolinguals, but both groups classified the object pictures equally rapidly into categories. Hence, though monolingual and bilingual speakers accessed the objects' semantic information similarly, bilingual disadvantages in naming emerged in post-semantic processing - possibly between the semantic and phonological levels of encoding (Runnqvist et al., 2012). Bilingual speakers have been found to have smaller vocabulary sizes (Bialystok et al., 2010; Bialystok & Luk, 2011) and lower lexical frequency of each lexical entry (Gollan & Silverberg, 2001; Gollan & Acenas, 2004; Gollan, Bonanni, et al., 2005; Gollan et al., 2005, 2008), which negatively impact their lexical retrieval. There is also broad agreement that lexical access is more challenging for bilingual speakers since both languages of the bilingual are active and interact during speech production in either language, creating the need for some type of attention or selection. Despite little consensus on how bilingual lexical activation and cross-language interaction influences bilingual lexical retrieval (reviewed in chapter 2), there is general agreement that there is a beneficial role for some form of cognitive control in bilingual lexical retrieval.

The possibly differential role of this control mechanism in monolingual and bilingual lexical retrieval was examined in the current study by comparing interference effects of bilingual and monolingual speakers in the semantically blocked picture naming task. The blocked naming paradigm worked as expected, showing worse naming on homogenous compared to mixed trials (larger SIE) over naming cycles in all neurotypical adults. Semantic interference effects in categorically blocked semantic contexts have been identified in some previous investigations of monolingual neurologically healthy speakers (Rahman & Melinger, 2007, 2011; Belke, 2008[a,b]; Belke, 2013; Belke, Brysbaert, Meyer, & Ghyselinck, 2005; Belke et al., 2005; Damian & Als, 2005; Damian, Vigliocco, & Levelt, 2001; Howard et al., 2006; Kroll & Stewart, 1994; Schnur et al., 2006) and some individuals with aphasia (e.g., Belke, 2008; Belke & Stielow, 2013; Belke, Meyer, et al., 2005; Oppenheim et al., 2010; Schnur et al., 2006, 2009; Scott & Wilshire, 2010; Wilshire, 2008). Two possible sources of the semantic interference have been discussed in literature. One set of hypotheses suggest that this effect occurs during the selection of a target lexical item from among co-activated semantically related lexical entries (lexical competition), which is assumed to be more difficult when many semantically related lexical entries are named in close succession than when unrelated lexical entries are being named. Therefore, the greater the semantic competition (as in later naming cycles), the greater the inhibition required to overcome the competition. However, since it has also been found that the interference is generally resistant to small time intervals and small numbers of intervening unrelated trials, others have proposed that the resilience of the semantic interference cannot be accounted for by just a temporary change in activation level of the target over the competitors. So alternately, the interference has been suggested to be the result of longer lasting changes in connection weights between semantic features and the target in the homogenous blocking conditions (Damian & Als, 2005; Howard et al., 2006; Oppenheim et al., 2010; Schnur et al., 2006; Schnur, 2014). Though resolution of this debate is beyond the scope of this project, both these schools of thought provide interesting bases for discussion of the results of this experiment.

Another notable finding was the dissociation between bilingual NH speakers' performance in L1 (bilingual disadvantage) and L2 (bilingual advantage) relative to monolingual NH speakers. Current bilingual models of lexical retrieval can explain these opposing effects in L1 and L2. Several recent studies suggest that there may be inhibition of the stronger L1 to enable production of the weaker L2 (e.g., Levy, McVeigh, Marful, & Anderson, 2007; Linck, Kroll, & Sunderman, 2009; Philipp, Gade, & Koch, 2007; Philipp & Koch, 2009). Because few bilingual speakers are truly balanced, the asymmetry observed in these studies (i.e., where L1 may be inhibited more than L2) is likely to characterize the situation for even highly proficient bilinguals who are more dominant in one of the two languages, typically the native language. Another factor that plays an important role in understanding this L1-L2 difference in inhibition is the extent to which the items in the stimuli actually inhibit one another in Tamil versus English. For example, naming words such as "cat" and "dog" in English (that are highly associated words and commonly used together in English contexts) in succession is likely to create greater competition and hence require more inhibition than when naming “lion” following the word “dog”. Additionally, the strength of the association between “cat” and “dog” is likely to be stronger in English where they frequently co-occur in similar contexts than in Tamil, where their co-occurrence in contextual use is more limited. Therefore, stimulus characteristics are likely to have contributed to the varying patterns of IC measured in L1 and L2.

Prior studies have also shown that bilingual speakers differ from monolingual native speakers of a language in their vocabulary size and in the complexity of semantic representations associated with the lexical items in word-association tasks (e.g., Meara, 1982; Verhallen & Schoonen, 1998). These have been found to be influenced by language experience (Kaushanskaya, Yoo & Marian, 2011). These factors may have also influenced the differential performance of bilingual speakers in L1 and L2, given their impact on the richness of the vocabulary and semantic relatedness.

CHAPTER 6: AN INVESTIGATION OF LINGUISTICALLY BASED INHIBITORY CONTROL

Bilingual speakers need to inhibit within and cross-language interference to effectively communicate. This routine need to inhibit the non-target language has been argued to give bilingual speakers a developmental advantage over monolingual speakers in exercising IC, which extends to at least other linguistically-based tasks such as picture naming, lexical decision, and grammaticality judgment tasks (Bialystok et al., 2004). The previous experiment used the semantically blocked picture naming task to study this proposed lexically based IC advantage. However, it has been proposed that the IC mechanism used in lexical-lexical-semantic inhibition may not be specific to lexical retrieval, but rather a domain-general mechanism that regulates interference across different tasks (e.g., Green, 1998). This chapter details the study of non-lexical IC using the Stroop task.

The Stroop task involves the inhibition of a pre-potent response that is elicited by the meaning of the word (color). Similar to the lexical-semantic task where the language schema of the non-target language has to be suppressed during bilingual naming, the task schema for reading the word has to be suppressed in the Stroop task. Given their parallel demands, the two tasks may engage similar IC independent of the nature of processing stimuli. This is the underlying construct of the bilingual advantage hypothesis that was tested in this experiment. Though the Stroop task involves linguistic stimuli, it does not engage lexical-semantic IC as the blocked naming task does. Since Stroop interference effects have been replicated with linguistic (e.g., color words) and non-linguistic stimuli (e.g., shapes and symbols), the IC engaged in this task is suggested to be broader than just the language domain (e.g., Piai, Roloefs, Acheson & Takashima, 2013). However, it must be noted here that the domain-neutrality of the IC in the Stroop task continues to be debated given that at least the color-word variant of the Stroop task (that is used in this study) still heavily relies on linguistic processing given the nature of the stimuli.

Research Question

This study examined the following question: ***Do bilingual and monolingual speakers with and without aphasia differ in linguistically based domain-general inhibitory control?*** This question was studied in neurotypical speakers and PWA using a mixed model design, where the independent variables included language background (*bilingual* and *monolingual*) as the between-groups factor and the Stroop condition (interference-eliciting *incongruent* condition and non-interference eliciting *congruent* condition) as the within-groups factor. The dependent variables were Stroop interference and facilitation effects in response accuracy and latency.

Hypotheses

If bilingualism strengthens domain-general IC as proposed by BAH, it was hypothesized that bilingual individuals will demonstrate lesser interference (greater accuracy and shorter response latency) on the conflict trials of the Stroop task, relative to matched monolingual participants. Similarly in individuals with aphasia, if BAH is based on a domain-general IC mechanism, then any bilingual advantage is expected to persist even post-brain injury in PWA since aphasia is primarily a language-based deficit.

Therefore, it is hypothesized that BPWA will outperform (better accuracy and shorter latency) MPWA when engaging IC in conflict trials of the Stroop task. Bilingual IC advantage is expected to manifest as a significant language background (bilingual, monolingual) by Stroop condition (congruent, incongruent) interaction with smaller Stroop interference effects for bilingual speakers on incongruent trials of the Stroop task. This interaction would indicate that there is a specific inhibitory advantage (if the interaction effect is smaller for bilingual speakers, but the facilitation effect is not). However, if bilingual speakers (with and without aphasia) demonstrate advantages in interference and facilitation effects, then this would provide evidence against the BAH, since it would indicate a more general executive function advantage, not specifically IC advantage. It was also expected that if BPWA demonstrated parallel recovery of languages post-stroke, the above predictions will hold true irrespective of the response language of the bilingual speakers used in the analysis.

Task

The non-verbal Stroop task (Stroop, 1935) is well suited to examine linguistically based inhibitory control using non-verbal response modalities. In this experiment, the traditional non-verbal color-word Stroop task was adapted for computerized presentation. Since individuals with aphasia have expressive language deficits, use of the non-verbal response mode significantly reduces the possibility of an inflated error rate due the influence of factors such as paraphasic errors or apraxia. Though some participants with aphasia self-reported overall low reading proficiency post-stroke in functional tasks such as reading a book or newspaper (Table 5), they all had the ability to complete the Stroop task as indicated by their performance on the color naming, color identification and written word to color matching screening tests (additional details provided in *General Methods*)

Method

Participants. Ten monolingual and bilingual speakers with aphasia as well ten monolingual and bilingual matched-control participants described earlier (in the *General Methods* chapter) completed this experimental task.

Stimuli. In the English version of the task, *red*, *green* and *yellow* were the target stimuli and *plan* was the neutral stimulus. A linguistic neutral stimulus with no strong color association was preferred over a commonly used symbolic one (e.g., %%%%), since the latter does not engage reading while naming the color. The Tamil translations of the stimuli were used in the Tamil version of the task (Table 13). The English words were typed using the "Times New Roman" (size 76) in lower case and the Tamil words were typed using the 'Latha' font (size 76).

In each language, for every color word there was one congruent condition (naming the ink color when the ink color and the word name match; e.g., ***red***), one incongruent condition (naming the ink color when the ink color is different from the word name; e.g., ***red***) and one neutral condition (naming the ink color of the neutral stimulus ***plan***). The two dimensions (ink color and word) were manipulated orthogonally resulting in a total of nine conditions (three colors x three conditions). For each language, these were repeated a number of times in such a way that there were 20 trials in each condition for each color (congruent, incongruent and neutral; total n = 180). The stimuli and Stroop testing conditions in each language are summarized in Table 13. The order of the trials were pseudo-randomized for presentation, ensuring that each color and its three conditions occurred equal number of times with no repetition of the target word and condition on adjacent trials (i.e., the design avoided negative priming from a previous trial). It was also ensured that the stimulus word of the previous trial was not the same as the name of the color on the current trial (e.g., the incongruent trial ***yellow*** did not precede the congruent trial ***yellow***). That is, no color reoccurred as the color or word on the next trial and no word reoccurred as the color or word on the next trial. This was done to limit carry-over effects since some studies report that it is easier to complete a trial if the preceding trial was also the same testing condition (conflict adaptation) when there is at least partial repetition of features between the stimuli of subsequent trials (Purmann & Pollmann, 2015). The same pseudo-randomized sequence of presentation was used for all participants.

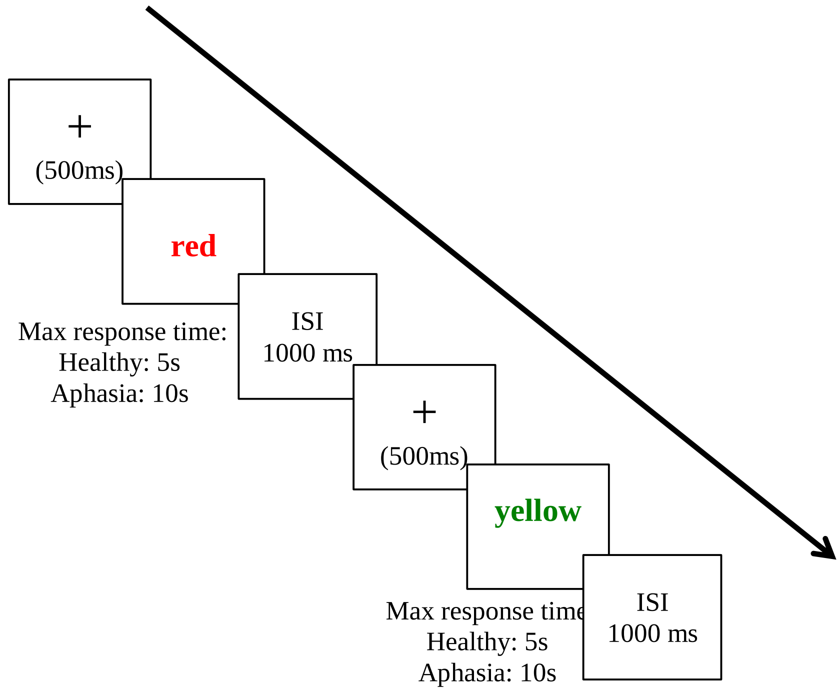
Table 13

Stimuli and testing conditions used in the computerized non-verbal Stroop task

Language	Stimuli (20 trials per color per condition)	Testing Condition		
		Congruent	Incongruent	Neutral
English (total n = 180)	red	**red**	**red** or **red**	**plan**
	green	**green**	**green** or **green**	**plan**
	yellow	**yellow**	**yellow** or **yellow**	**plan**
Tamil (total n = 180)	சிவப்பு (/sivʌpu/)	**சிவப்பு**	**சிவப்பு** or **சிவப்பு**	**திட்டம்**
	பட்சை (/pʌtʃəi/)	**பட்சை**	**பட்சை** or **பட்சை**	**திட்டம்**
	மஞ்சள் (/mʌɲdʒʌl/)	**மஞ்சள்**	**மஞ்சள்** or **மஞ்சள்**	**திட்டம்**

Procedure. Each participant in the four experimental groups (bilingual and monolingual PWA and bilingual and monolingual neurologically healthy speakers) completed the English version of the task. Only the bilingual participants completed the Tamil version on a different day from the English version. The task was administered via SuperLab experimental software running on a windows laptop. The trials were grouped into two experimental blocks of 90 trials each with a mandatory rest break (2 minutes) between the blocks and the trials were presented one at a time to the participants. All participants were instructed to use their left index finger only to indicate whether the stimulus word was presented in red, green, or yellow by pressing the keys Y, K or F respectively on the computer keyboard as quickly and accurately as possible. These letter keys were covered with colored patches that matched the associated response. They were instructed to rest their fingers on the space bar between trials. The left index finger was chosen as the response modality since many stroke survivors with aphasia also present with concomitant right hemiparesis/hemiplegia and they typically use the non-dominant hand for all activities. In order to prevent an effect of the use of the non-dominant hand on response speed only in some participants with aphasia, all participants were instructed to complete the task with their left hand. Each trial started with a fixation sign (+) presented for 500 ms at the center of the screen. After this, the stimulus was presented at the center of the screen until the participant responded by button press or until the end of the response duration (10s for PWA and 5s for neurologically healthy controls; Figure 8). A response-stimulus interval of 1 second was maintained. No feedback on accuracy of performance was provided during the experimental testing. Prior to initiation of the task, 20 practice trials were provided. Practice trials were repeated if needed until 80% accuracy was obtained on the practice. The order of presentation of the English and Tamil versions of the tasks was counterbalanced for the bilingual participants. The task instructions for all tasks were presented to the participants in written mode on the computer and verbally, in English, and were repeated if necessary.

Figure 8
Schematic representation of stimulus presentation in the Stroop task in English



Analyses

Accuracy (%) and latency (s) was retrieved from SuperLab. For each participant, latencies that were two standard deviations above or below their mean were excluded from the analyses as outliers as these are likely to indicate anticipations or loss of attention (MacLeod, 2005). This data trimming resulted in a loss of 3.79% of total data in PWA and 2.22% of total data in neurologically healthy speakers. Only the response latencies of correct responses were included in latency analysis. Prior studies have utilized absolute values of performance on incongruent trials or the difference between incongruent and congruent trials (e.g., Blumenfield & Marian, 2011) as the measure of the interference effect. However, in this study the Stroop interference effects were calculated relative to the neutral condition, i.e., the differences in accuracy and response latency between the incongruent and neutral trials (IC-N) were calculated as the interference effect, and congruent and neutral trials (C-N) were calculated as the facilitation effect. This was done so that facilitation and interference effects can be disambiguated and clearly measured.

Separate linear mixed model analyses were performed for the two dependent variables, accuracy and latency. Separate analyses were performed for neurologically healthy participants and those with aphasia. For bilingual speakers, L1 and L2 were separately analyzed. The fixed factors were language background (bilingual and monolingual) and Stroop condition (incongruent and congruent), while participants were used as the random factor. The aphasia quotient score from the Western Aphasia Battery (WAB AQ) for the language under study was used as the covariate for analyses of individuals with aphasia. Due to the multiple comparisons, a more conservative alpha value of $p = .01$ was used.

Results

Measurement reliability of the Stroop task was examined using a split-half procedure, separating the trials of a given condition by odd and even counts. Cronbach's Alpha values ranged from 0.79 to 0.92 across conditions in neurologically healthy speakers and PWA indicating high internal consistency of the task.

Neurologically Healthy Speakers

Accuracy. Overall, bilingual and monolingual neurotypical speakers demonstrated mean accuracy of greater than 97% across all conditions of the Stroop task in all languages tested (ceiling effect; Table 14; Appendix C). Hence, they demonstrated similar interference and facilitation effects in all tested languages as marked by non-significant interaction and main effects (Table 16). However, it must be noted that when comparing bilingual L2 performance with monolingual performance, the main effect of condition was significant across both groups with a less stringent *p* value of 0.05, indicating a trend towards larger Stroop interference effects in the incongruent condition than in the congruent condition in both groups.

Table 14

Mean response accuracy (%) and latency (ms) in interference and facilitation effects in neurologically healthy speakers and participants with aphasia for each condition of the Stroop task. The numbers in parentheses are standard deviations

Group	Variable	Language Background	Experimental Conditions in L1					Experimental Conditions in L2				
			Congruent	Incongruent	Neutral	IE	FE	Congruent	Incongruent	Neutral	IE	FE
Neurologically healthy participants	**Accuracy**	Bilingual	99.00	98.50	99.50	-0.60	-0.30	99.17	97.67	99.33	-1.00	-0.10
			(0.05)	*(0.10)*	*(0.03)*	*(0.70)*	*(0.82)*	*(0.04)*	*(0.08)*	*(0.02)*	*(1.83)*	*(0.74)*
		Monolingual	99.67	98.67	100.00	-1.33	-0.33	--	--	--	--	--
			(0.03)	*(0.08)*	*(0.00)*	*(1.72)*	*(0.70)*					
	Latency	Bilingual	933.24	1044.42	982.80	61.62	-49.56	977.58	1124.80	1032.77	92.03	-55.18
			(131.89)	*(163.94)*	*(135.00)*	*(39.16)*	*(74.08)*	*(173.20)*	*(188.13)*	*(202.00)*	*(28.78)*	*(42.49)*
		Monolingual	1034.59	1121.94	1060.58	61.36	-25.99	--	--	--	--	--
			(147.98)	*(176.53)*	*(157.22)*	*(50.25)*	*(39.04)*					

	Accuracy	Bilingual	92.33	81.50	91.00	-9.50	1.33	93.33	77.67	91.50	-13.83	1.83
			(0.25)	*(0.38)*	*(0.28)*	*(8.13)*	*(3.15)*	*(0.21)*	*(0.37)*	*(0.25)*	*(10.72)*	*(4.61)*
		Monolingual	95.50	76.50	88.50	-12.00	7.00	--	--	--	--	--
Participants			*(0.16)*	*(0.28)*	*(0.22)*	*(16.46)*	*(13.17)*					
with aphasia	**Latency**	Bilingual	1070.79	1253.97	1104.57	149.40	-33.78	1130.18	1345.84	1201.08	144.76	-70.90
			(274.21)	*(225.24)*	*(172.03)*	*(134.45)*	*(83.33)*	*(125.45)*	*(310.78)*	*(154.49)*	*(92.27)*	*(48.36)*
		Monolingual	1406.75	1647.80	1553.14	94.66	-146.38	--	--	--	--	--
			(326.37)	*(358.05)*	*(348.91)*	*(141.70)*	*(192.75)*					

L1 = Tamil and English in bilingual and monolingual participants respectively; L2 = English in bilingual participants; IE= Interference effect = difference in accuracy/latency between the incongruent and neutral trials (IC-N); FE=Facilitation effect = difference in latency (ms) between the congruent and neutral trials (C-N)

Latency. Participants' mean response latencies by trial type (congruent, incongruent and neutral) in each language and corresponding interference and facilitation effects are provided in Table 14 and graphically presented in Figure 9 for both monolingual and bilingual neurologically healthy speakers. The results of statistical analyses of the differences between bilingual and monolingual participants are summarized in Table 15. Effects that are significant at $p < .01$ are highlighted in bold.

Table 15

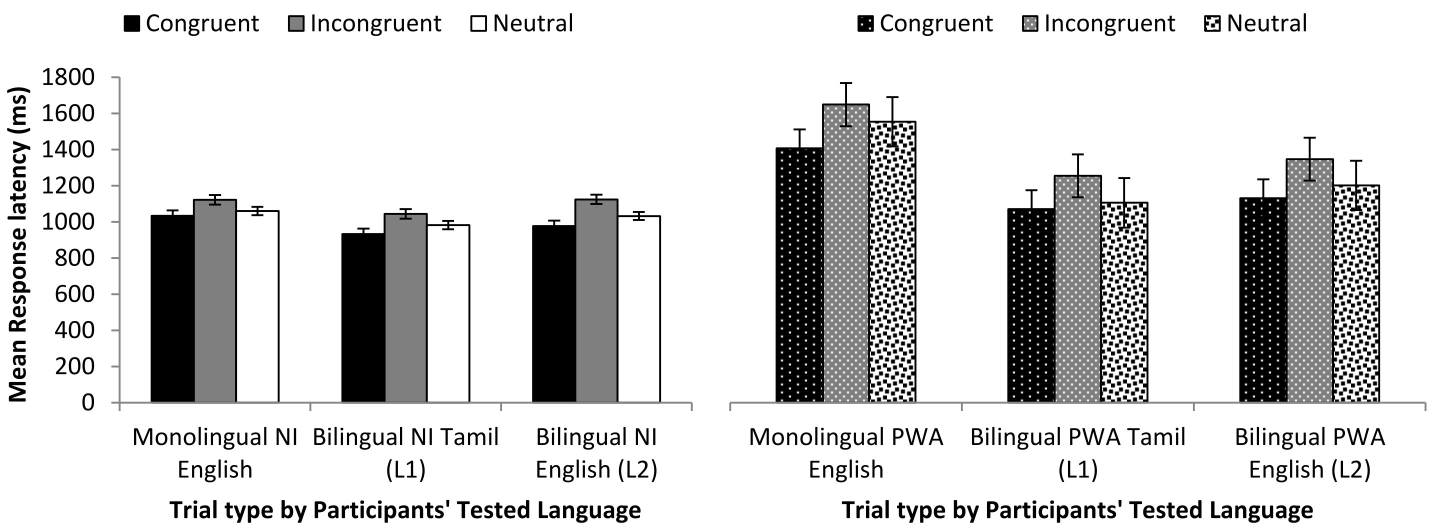
Summary of results of mixed model analyses of Stroop interference and facilitation effects in neurologically healthy participants. Significant effects are highlighted in bold

	Dependent variable†	Main effect of language background	Main effect of condition	Language background x Condition interaction effect
Accuracy				
Bilingual L1 (Tamil) versus Monolingual L1 (English)	Interference/ facilitation effects	Non-significant ($F(1, 36) = .03$, $p = .85$)	Non-significant ($F(1, 36) = 2.81$, $p = .09$)	Non-significant ($F(1, 36) = .31$, $p = .58$)
Bilingual L2 (English) versus	Interference/ facilitation effects	Non-significant ($F(1, 36) = .19$, $p = .67$)	Non-significant ($F(1, 36) = 5.18$, $p = .02$)	Non-significant ($F(1, 36) = .03$, $p = .86$)

Monolingual L1 (English)				
<u>Latency</u>				
Bilingual L1 (Tamil) versus Monolingual L1 (English)	Interference/ facilitation effects	Non-significant ($F(1, 36) = 6.14$, $p = .02$)	**Significant ($F(1, 36) = 23.89$, $p < .001$)**	**Significant ($F(1, 36) = 23.89$, $p < .001$)**
Bilingual L2 (English) versus Monolingual L1 (English)	Interference/ facilitation effects	Non-significant ($F(1, 36) = .14$, $p = .71$)	**Significant ($F(1, 36) = 145.35$, $p < .001$)**	**Significant ($F(1, 36) = 12.34$, $p < .001$)**

L1 = Tamil and English in bilingual and monolingual participants respectively; L2 = English in bilingual participants; †All dependent variables were arsine transformed or log transformed for accuracy and latency respectively.

Figure 9. Mean response latency (ms) of monolingual and bilingual neurologically healthy (NH) speakers and persons with aphasia (PWA) in each response language in a computerized adaptation of the color-word Stroop task (Stroop, 1945). Error bars represent standard errors.



Bilingual L1 (Tamil) versus Monolingual L1 (English). Analysis of interference and facilitation effects revealed a significant main effect of Stroop condition, indicating that both groups experienced a significantly larger interference effect than facilitation effect, consistent with expected trends. However, there was no main effect of language background. Most central to the purpose of this study was the significant interaction effect between language background and condition, which indicated that relative to the monolingual speakers, bilingual neurotypical speakers demonstrated a larger facilitation effect despite comparable interference effects.

Bilingual L2 (English) versus monolingual L1 (English). Similar to their performance in L1, bilingual participants demonstrated a significant main effect of condition and non-significant main effect of language background when completing the

Stroop task in L2. Hence, irrespective of their language background, both groups of participants experienced significantly larger interference versus facilitation effect. Critically, there was also a significant interaction effect; relative to monolingual speakers, bilingual speakers demonstrated a larger interference effect in the incongruent condition than facilitation effect in the congruent condition.

To summarize the performance of neurologically healthy adults on the Stroop task, accuracy measures were not significantly different across groups or conditions. In latency analyses, both bilingual and monolingual neurologically healthy adults demonstrated Stroop interference effects consistent with current literature. Additionally, neurologically healthy bilingual participants differed significantly from their monolingual counterparts in Stroop interference and facilitation effects in L1 and L2 (significant interaction effects). The pattern of these results are similar to the semantic interference effects in the previously reported blocked picture naming experiment. Relative to monolingual speakers, bilingual participants demonstrated only larger Stroop facilitation effects in L1 but larger interference and facilitation effects in L2. In order to ensure that the way the Stroop interference effects were calculated (relative to the neutral condition) did not influence the results, the statistical analyses were repeated with transformed accuracy and latency values of incongruent and congruent conditions as well as the values of the Stroop effect (IC-C) as dependent variables. Results remained unchanged across all comparisons.

Additional analyses of the bilingual participants’ Stroop interference and facilitation effects comparing their L1 and L2 were completed, using a 2-way mixed model ANOVA with language (L1, L2) and condition (congruent, incongruent) as independent variables and bilingual accuracy and latency effects as the dependent variables. Results from accuracy and latency analyses indicated significant main effects of condition (Accuracy: F (1, 2378) = 329.68, p < .001; Latency: F (1, 2378) = 4.48, p = .03) and non-significant main effects of language (Accuracy: F (1, 2378) = .08, p = .77; Latency: F (1, 2378) = 1.06, p = .32). These results indicate that though bilingual participants did not differ in their overall magnitude of Stroop effects between L1 and L2, they demonstrated larger effects in the incongruent condition rather than the congruent conditions. Though the language x condition interaction was not significant in accuracy analysis (F (1, 2378) = 1.11, p = .29), the latency analysis revealed a significant interaction (F (1, 2378) = 8.21, p = .004). This revealed that in response latency, bilingual neurologically healthy speakers had larger Stroop interference effects compared to facilitation effects in L2 but not in L1.

Participants with aphasia

Accuracy. Participants' mean response accuracies by trial type (congruent, incongruent and neutral) in each language are provided in Table 11 for monolingual and bilingual individuals with aphasia. As a first step, accuracy differences between PWA and NH speakers were examined in separate two-way mixed model ANOVAs (neurological status x language background) in L1 and L2. Both L1 and L2 analyses indicated a significant main effect of neurological status (aphasia versus neurologically healthy; all F > 19.01, all p < .001) but non-significant main effect of language background (bilingual versus monolingual; all F < 1.11, all p > .70). Not surprisingly, neurologically healthy speakers were more accurate than individuals with aphasia. Furthermore, monolingual response accuracy did not differ from bilingual L1 or L2 response accuracy for neurologically healthy speakers and PWA (non-significant interaction effects: all $F > .14$, all $p > .09$).

To answer the research question of effect of bilingualism on IC in aphasia, the results of statistical analyses of the differences between BPWA and MPWA are summarized in Table 16. Effects that are significant at $p < 0.01$ are highlighted in bold. The text provides interpretation of the results in Table 16.

Table 16

Summary of results of mixed model analyses of accuracy and latency of participants with aphasia in the Stroop tasks

	Dependent variable[†]	Main effect of language background	Main effect of condition	Language background x Condition interaction effect
Accuracy				
Bilingual L1 (Tamil) versus Monolingual L1 (English)	Interference/ facilitation effects	Non-significant ($F(1, 36) = 0.27$, $p = .61$)	**Significant ($F(1, 36) = 74.34$, $p < .001$)**	**Significant ($F(1, 36) = 5.58$, $p = 0.01$)**

Bilingual L2 (English) versus Monolingual L1 (English)	Interference/ facilitation effects	Non-significant (F (1, 36) = 1.81, p = .19)	**Significant (F (1, 36) = 104.12, p < .001)**	Non-significant (F (1, 36) = 0.95, p = .35)
Latency				
Bilingual L1 (Tamil) versus Monolingual L1 (English)	Interference/ facilitation effects	Non-significant (F (1, 36) = 1.80, p = .20)	**Significant (F (1, 36) = 219.66, p < .001)**	**Significant (F (1, 36) = 67.11, p < 0.001)**
Bilingual L2 (English) versus Monolingual L1 (English)	Interference/ facilitation effects	Non-significant (F (1, 36) = 0.44, p = 0.51)	**Significant (F (1, 36) = 221.07, p < .001)**	Non-significant (F (1, 36) = 0.09, p = 0.77)

L1 = Tamil and English in bilingual and monolingual participants respectively; L2 = English in bilingual participants; †All dependent variables were arsine transformed or log transformed for accuracy and latency respectively.

Bilingual L1 (Tamil) versus Monolingual L1 (English). Results of analysis indicated a significant main effect of Stroop condition but no main effect of language background. These results suggest that though the magnitude of the overall effects in the Stroop task did not differ based on language background of PWA, participants experienced significantly larger interference effects (lower accuracy) on the incongruent condition versus facilitation in the congruent condition. The analysis also revealed a significant interaction effect indicating that BPWA had larger interference and smaller facilitation effects than MPWA in accuracy of task completion in L1.

Bilingual L2 (English) versus monolingual L1 (English). When BPWA's performance in L2 was compared with MPWA, results revealed a significant main effect of condition but non-significant main effect of language background. This suggests that though the magnitude of the effects in Stroop accuracy of performance did not differ between bilingual and monolingual participants with aphasia, they all experienced a significantly larger interference effect on the incongruent condition versus facilitation in the congruent condition - similar to performance in L1 and consistent with expected trends. However, unlike performance in L1, results indicated a non-significant interaction effect. This suggests that the magnitude of the Stroop interference and facilitation effects did not significantly differ between MPWA and BPWA when bilingual speakers completed the task in L2.

Latency. As a preliminary step, latency differences between PWA and NH speakers were examined in separate two-way mixed model ANOVAs (neurological status x language background) in L1 and L2 at alpha levels of .05. Results indicated significant main effects of neurological status and language background in both L1 and L2 (all $F > 7.5$, all $p < .05$). These results indicate that neurologically healthy speakers had shorter response latencies than individuals with aphasia. Also, irrespective of the neurological status, monolingual speakers had shorter response latencies than bilingual speakers.

Furthermore, significant interaction effects (all $F > 9.70$, all $p < .05$) indicated that bilingual speakers demonstrated longer response latencies in L1 and L2 compared to monolingual speakers when they had aphasia than when they were neurologically healthy.

In order to study the research question, the differences in effects between MPWA and BPWA were analyzed in each testing condition. The mean response latencies and interference/facilitation effects of participants with aphasia by trial type (congruent, incongruent and neutral) in each language are provided in Table 14. The results of statistical analyses of these data are summarized in Table 16 and interpreted in the sections that follow.

Bilingual L1 (Tamil) versus monolingual L1 (English). The analysis revealed a significant main effect of condition but non-significant main effect of language background. These results indicate that both groups of participants experienced significantly larger effects of interference than facilitation on the Stroop task in their L1, though the total magnitude of the effects in the Stroop task did not differ based on their language background. Importantly, the analysis also showed a significant interaction effect indicating that BPWA had larger interference and smaller facilitation effects than MPWA in L1 response latency.

Bilingual L2 (English) versus monolingual L1 (English). The analysis indicated a significant main effect of condition but non-significant main effect of language background: all participants experienced a significantly larger interference effect than facilitation effect. Notably, this analysis also revealed a non-significant interaction effect, which indicates that the magnitude of the monolingual Stroop latency effects did not significantly differ from bilingual L2 Stroop latency effects in incongruent and congruent testing conditions.

To summarize the results of the Stroop tasks in PWA, BPWA differed significantly from MPWA in accuracy and speed of responses to both congruent and incongruent trials (significant interaction effects) only when completing the Stroop task in L1 (Tamil; Table 16): specifically BPWA demonstrated lower accuracy and longer response duration in incongruent trials in the native language, when compared to MPWA. BPWA had larger interference and smaller facilitation effects than MPWA in both L1 and L2 latency analyses, though the differences were significant only in L1. In order to ensure that the way the effects were calculated (relative to the neutral condition) did not influence the results, the statistical analyses were repeated with transformed accuracy and latency values of incongruent and congruent conditions as dependent variables. Results remained unchanged across all comparisons.

Additional analyses of the bilingual participants' effects comparing their L1 and L2 were also completed, using a 2-way ANOVA with language (L1, L2) and condition (congruent, incongruent) as independent variables and bilingual accuracy and latency effects as the dependent variables. Analyses of accuracy and latency differences between L1 and L2 in this sample of BPWA indicated significant main effects of condition (Accuracy: F (1, 2319) = 57.48, $p < .001$; Latency: F (1, 2319) = 313.90, $p < .001$) and non-significant main effects of language (Accuracy: F (1, 2319) = .55, $p = .47$; Latency: F (1, 2319) = .90, $p = .35$). These results indicate that though BPWA did not differ in their overall magnitude of effects between L1 and L2, they demonstrated larger effects in the incongruent condition rather than the congruent conditions. Results of these analyses also indicated non-significant interaction between language and condition in accuracy data (F (1, 2319) = 1.91, p = .17). However, unlike neurologically healthy speakers, BPWA also demonstrated non-significant interaction effects in latency analysis (F (1, 2319) = .55, p = .46). This suggests that differences in BPWA's effects in L1 and L2 in the Stroop task did not vary between incongruent and congruent testing conditions.

Discussion

The aim of this experiment was to test the BAH in IC using the Stroop task. Results of this experiment in *neurologically healthy speakers* indicated that 1) Stroop interference and facilitation effects in accuracy were not significantly different between monolingual and bilingual NH speakers, 2) relative to monolingual speakers, bilingual NH participants demonstrated only larger facilitation effects in L1 but larger interference and facilitation effects in L2 in latency analyses, and 3) Bilingual neurologically healthy speakers' interference and facilitation effects in L1 and L2 did not vary between incongruent and congruent testing conditions. Analysis of the Stroop performance of *PWA* indicated that 1) all PWA demonstrated lower accuracy and longer response latency relative to matched neurologically healthy speakers in all testing conditions, 2) relative to MPWA, BPWA had larger interference and smaller facilitation effects in both accuracy and latency analyses only in L1; no significant differences between monolingual L1 and bilingual L2 were identified, 3) the magnitude of the Stroop interference and facilitation effects did not significantly differ between BPWA's performance in L1 and L2. These findings are discussed below.

Neurologically Healthy Speakers. Results of this study found no support for bilingual advantage in IC in NH speakers. There were no observable accuracy differences in Stroop interference and facilitation effects between the bilingual and monolingual groups. This is likely because both groups of participants had a high level of accuracy in task completion (> 97%) and hence difference in accuracy could not be detected. However, on response latency analyses, it was found that the bilingual group either demonstrated comparable (in L1 – Tamil) or larger (in L2 – English) interference effects (bilingual disadvantage) relative to the monolingual group.

At least four factors are likely to have contributed to the differences in our results from previously reported bilingual Stroop advantages. The first factor that may have influenced findings is participants' age. A majority of the previously published research on bilingual advantages comes from comparisons of interference control in young adults. Given the well-documented decline in cognitive skills such as inhibition consequent to aging (e.g., Craik & Salthouse, 2008; Zacks & Hasher, 1997), it is possible that older adults do not retain the purported bilingual advantage as previously assumed. Though understudied, a bilingual advantage in interference control in the Stroop task in older adults has been previously reported (e.g., Bialystok et al., 2004, 2008; Gold, Kim, Johnson, Kriscio, & Smith, 2013). Our results however found that bilingual speakers demonstrated no bilingual advantage in interference control in L1 (bilingual versus monolingual interference effect: 61.62 versus 61.36 ms) and in fact demonstrated a bilingual disadvantage in L2 (bilingual versus monolingual interference effect: 92.03 versus 61.36 ms). These results are similar to a recent investigation by Kousaie and Philips (2012) that also failed to find a bilingual advantage in older adults. Also, in general older adults have been reported to complete the Stroop task slower and with lower accuracy than younger adults (e.g., review by MacLeod, 1991; West & Alain, 2000; Davidson et al., 2003; Rush et al., 2006). Results of this study are consistent with these findings. It has been argued that the age-sensitivity of Stroop interference may be an artifact of a general slowing in information processing speed since there is no specific evidence for specific IC declines with age (Wolf et al., 2014).

Secondly, the socio-cultural characteristics of the bilingual participants in the present study were different from both studies that reported a bilingual advantage in older adults (Bialystok et al., 2008; Zied et al., 2004). Similar to Kousaie & Philips (2012), these bilingual speakers were non-immigrants and lived in an L1 dominant society. This suggests that the previously reported bilingual advantage in Stroop tasks may have been contaminated by language exposure related to socio-cultural factors. The results of this study indicate that neurologically healthy bilingual speakers demonstrate comparable inhibitory control to matched monolingual speakers in their native L1 or a disadvantage in inhibitory control in L2. Additional correlational analyses between interference effects in L1 and L2 in bilingual speakers were not significant for accuracy (r_s = 0.40, p = .25) and latency (r_s = -0.55, p = .06) measures, although the near significance and negative correlation of latency effects in the Stroop task suggest a trade-off between L1 and L2 speed.

The difference in bilingual performance between L1 and L2 was unexpected since all participants' self-reported equally high proficiency in both languages, and the neural circuits involved in interference control in the Stroop task have been found to be independent of linguistic background (e.g., Piai et al., 2013). Previous research has found that the Stroop interference effect in bilingual speakers is influenced by language proficiency in the language of testing (Mägiste, 1985; Chen & Ho, 1986; Tzelgov et al., 1990; Francis,1999; Rosselli et al., 2002; Zied et al., 2004; Gasquoine et al., 2007). It is possible that despite their self-report, bilingual participants in this study were not truly balanced in their proficiency since their current communicative demands outside of their work environments still heavily relied on L1. This inequality in language exposure and practice could have led to differential engagement of interference control in L1 and L2. Though the larger interference effects in L2 are consistent with current theories of bilingual lexical retrieval, it is unclear whether this difference between L1 and L2 was due to enhanced cognitive control abilities while processing a seemingly more dominant L1 or less interference from the weaker L2.

The third factor that may have impacted the results of this study is the difference in script/language family between Tamil and English. It may be that when two languages have the same script, then those bilingual speakers have the need to develop stronger IC over their lifetime relative to those bilingual speakers whose languages have very different script, syntactic structures and phonological similarities. Prior research has found that in bilingual speakers, orthographic and phonemic similarity between the constituent languages has been found to influence the extent of IC that needs to be recruited (Preston & Lambert, 1969; Roelofs, 2003; Sumiya & Healy, 2004). Some previous studies have also found that non-alphabetic languages (such as Chinese) elicit smaller Stroop interference effects than alphabetic languages (e.g. van Heuven et al., 2011). If this is the case, then L1-L2 differences may not reflect cognitive control differences, but rather the effect of processing the script of the specific language (Tamil versus English). Given the distinct lack of orthographic and phonological similarity between the languages used by the bilingual speakers in this study, it is possible that the representations in the two languages may not have competed or interfered with each other to the same extent as the Indo-European Germanic languages that have been used in most previous studies.

Finally, the definition of the interference effect in this study varies from those that previously reported the bilingual advantage in older adults. In some previous reports, Stroop interference has been calculated as the difference between incongruent and congruent conditions or as the absolute values of accuracy and response latency. That is, the neutral condition is non-existent and the congruent trials are treated as the control condition. These approaches not only confound a possible facilitation effect and a possible interference effect, but also preclude study of the facilitation effects. Instead, in the present study, the effects were analyzed relative to a neutral condition, which reveals a more uncontaminated measure. To verify that the differences in calculation alone did not contribute to the observed differences from previous reports, analyses of variance were recomputed with values of interference effects obtained using transformations of absolute values of accuracy and response latency. The results of the study did not differ.

Individuals with aphasia. Results of this study found no support for the BAH in IC PWA. In this study, all PWA completed the Stroop task with high accuracy and hence the results and interpretation are reliable. Both monolingual and bilingual PWA in this study consistently demonstrated the Stroop interference and facilitation effects. Results of this study critically revealed that when compared to MPWA, BPWA demonstrated lower accuracy and longer response duration for incongruent trials in the native language. This study found an inhibitory *disadvantage* in Stroop interference effects in BPWA post-brain injury. The absence of a bilingual advantage on the Stroop task in individuals with aphasia is in line with the findings in neurologically healthy speakers in this study, but is inconsistent with the smaller case studies of Penn et al. (2010) and Green et al. (2011). These are discussed below.

Individual differences in integrity of IC post-brain damage may have also contributed to the lack of an observed bilingual advantage. Examination of individual participant's behavioral data indicates that the Stroop interference effects in BPWA with aphasia ranged from -10.96 ms to 399.38 ms in L1 and -25.47 ms to 254.80 ms in L2, indicating a wide variation in performance inhibitory control abilities. Examination of the *Z*-scores (Table 17) indicates three BPWA (BA3, BA5, and BA 8) demonstrated exaggerated interference effects of over 4 standard deviations from the population mean in L1 Stroop. These participants however failed to reveal a similar pattern in L2 Stroop. In contrast, only one MPWA demonstrated a similar pattern (MA2). Interestingly, three

BPWA (BA6, BA9 and BA 10) and four MPWA (MA1, MA 6, MA7, MA9) demonstrated no interference effect (*Z*-scores less than 1) in at least one response language, suggesting that in at least a subset of speakers with aphasia, there may either be impaired access to word meaning (thereby limiting interference) or a hyper-normal inhibitory mechanism that controls interference from irrelevant stimuli. So, irrespective of language background, there was a small group of participants with aphasia (4/20) who demonstrated IC control deficits marked by exaggerated IE and a larger cohort (7/20) who demonstrated no IC deficits.

Several participant factors are likely to have contributed to this wide range of effects in this group, including site of lesion, overall severity of deficits and impairments in reading. It would be interesting to examine if and how the sites of lesion of the participants with aphasia may have impacted their overall inhibitory control. Unfortunately, our access to lesion data was limited to gross radiological findings reported in participants' discharge reports from the hospital. Hence, a more in-depth analysis to correlate lesion data with behavioral findings could not be achieved. Yet, it is important to note here that the PWA were a relatively homogenous group in terms of aphasia sub-types (Table 6). Our limited lesion data indicates that a larger proportion of BPWA (4 out of 10) presented with lesions that also included the sub-cortical regions compared to MPWA (1 out of 10). Since the sub-cortical control circuits (specifically basal ganglia circuits) have been found to play a critical role in inhibitory control in all tasks, lesions in this area may have disproportionately impacted the overall group results. Additionally, as reviewed earlier, the LIFG has also been found to be more involved in processing incongruent trials in bilingual speakers. Hence, LIFG lesions in BPWA may have impacted IC to a greater extent than MPWA.

Table 17

Z-scores of Stroop interference effects (response latency) across participant groups

Participant	Bilingual Neurologically Healthy		Monolingual Neurologically Healthy	Bilingual Aphasia		Monolingual Aphasia
	L1	L2		L1	L2	
1	1.65	-0.35	1.96	1.04	0.78	-0.79
2	-1.76	0.66	-0.88	0.68	1.56	6.55
3	-0.27	-0.55	0.38	8.63	0.58	2.73
4	-0.33	-0.63	-0.49	1.06	0.27	0.46
5	-0.35	1.05	-0.75	4.90	0.93	2.91
6	0.62	1.17	0.05	1.72	-1.19	-1.00
7	0.68	-1.70	0.69	0.91	1.68	-4.35
8	-0.37	0.19	0.74	6.78	0.85	1.54
9	1.04	-1.00	-0.16	-1.85	-0.97	-2.75
10	-0.90	1.17	-1.54	-1.44	1.23	1.32

In conclusion, no evidence for a *bilingual advantage* was found in neurologically healthy or brain-damaged individuals on the Stroop task. In neurologically healthy speakers, it was found that the bilingual group either demonstrated comparable (in L1 – Tamil) or larger (in L2 – English) interference effects relative to the monolingual group.

Additionally, contrary to the hypothesized results, larger interference and smaller facilitation effects were noted in BPWA compared to MPWA in both accuracy and latency analyses. The absence of the bilingual advantage in individuals with aphasia is not surprising given the lack of reliable reports in current literature even in neurotypical individuals. Additionally, participant related factors such as age of the participants, language combination of the bilingual speakers and overall severity of deficits may have impacted the findings.

CHAPTER 7: AN INVESTIGATION OF NON-LEXICAL NON-LINGUISTIC INHIBITORY CONTROL

The BAH suggests that bilingual IC advantage may be a domain-general feature (e.g., Bialystok, 2006; Bialystok et al., 2004, 2008; Costa et al., 2008). But this proposition is not without controversy given the evidence from several studies that indicate that the bilingual advantage may not be pervasive across all domains (review by Hilchey & Klein, 2011; Paap and Greenberg, 2013). Though inhibitory control breakdown is frequently reported in diagnoses such as traumatic brain injury or prefrontal stroke (in which individuals present with both cognitive and language deficits), there is limited knowledge about non-linguistic IC impairments in PWA who typically present without concomitant cognitive deficits in other domains. At the present time, apart from isolated case reports, there are no group-level analyses that have systematically examined non-linguistic inhibitory control in PWA. Evidence that verifies non-linguistic IC advantages in bilingual speakers, especially in those with aphasia, would test the claim about long-term general cognitive benefits induced by language processing.

Research Question

This experiment examined the following questions and hypotheses regarding domain-general inhibitory control: **Do bilingual and monolingual speakers with aphasia differ in non-linguistically based inhibitory control as measured by the flanker task? Do bilingual and monolingual PWA exhibit similar patterns in flanker interference as matched neurologically healthy speakers?**

Hypotheses

If bilingualism has a specific influence on non-linguistic inhibition as suggested by the BAH, it is hypothesized that bilingual neurotypical speakers will demonstrate better control of interference on conflict trials of the flanker task. This would be evidenced by greater accuracy, shorter response latencies and smaller interference effects in the conflict trials by bilingual participants compared to monolingual participants. Furthermore, since aphasia is characterized by language deficits in the presence of relatively spared non-linguistic cognitive functions, it is expected that bilingual IC advantages in a non-linguistic task will not be impacted by brain injury. Evidence of bilingual advantage in the flanker task in individuals with aphasia would support the notion that the IC advantage proposed by BAH extends to non-linguistic domains, and is not specifically impacted by damage to left hemisphere language networks.

Task

The flanker task utilizes non-linguistic stimuli and requires non-verbal responses. Hence, it is particularly well-suited to examine non-linguistic IC, as a direct contrast to the Stroop task.

Method

Participants. Ten monolingual and bilingual speakers with aphasia as well ten monolingual and bilingual matched-control participants described earlier (in the *General Methods* chapter) completed this experimental task. These were the same participants who completed the Stroop and blocked naming tasks.

Stimuli. The stimuli and task testing conditions are summarized in Table 18. The symbols were typed in black “Times New Roman” bold font (size 76) on a white background. The target was a leftward (←) or rightward (→) arrow at the center of the array. The target was flanked by two arrows on either side, which either pointed in the same direction (congruent condition) or opposite direction (incongruent condition) as the central target or flanked by squares (neutral condition). For each target (← and →), there was one congruent, one incongruent and one neutral condition, resulting in a total of six items. These were repeated a number of times in such a way that there were 30 trials in each condition (congruent, incongruent and neutral; total n = 180). The order of the trials was pseudo-randomized for presentation, ensuring that no more than two trials of the same condition were presented sequentially. The same pseudo-randomized sequence of presentation was used for all participants.

Table 18

Stimuli used in the computerized non-verbal flanker task

Stimuli (30 trials per condition)	**Testing Condition**		
	Congruent	**Incongruent**	**Neutral**
→ (total n = 180)	→ → → → →	← ← → ← ←	□ □ → □ □
← (total n = 180)	← ← ← ← ←	→ → ← → →	□ □ ← □ □

Procedure. All participants in each of the groups (bilingual and monolingual PWA and bilingual and monolingual NH speakers) completed the flanker task. This task was presented via SuperLab experimental software on a windows computer and the trials were presented one at a time to the participants. The trials were grouped into two experimental blocks of 180 trials each with a mandatory rest break (2 minutes) between the blocks. Participants were asked to indicate the direction of the central arrow (*left* or *right*) while ignoring the direction of the flankers by pressing either F or J on the computer keyboard with their left index finger as quickly and accurately as they can. These keys were covered with stickers indicating left or right directions respectively. They were instructed to rest their fingers on the space bar between trials. In order to prevent an effect of the use of the non-dominant hand on response speed only in some participants with aphasia with right hemiplegia post-stroke, all participants (PWA and NH) were instructed to complete the task with their left hand. Each trial started with a fixation sign (+) presented for 500 ms at the center of the screen. After this, the stimulus was presented until the participant responded by key press or until the end of the response duration (10s for bilingual PWA and 5s for neurologically healthy controls). A response-stimulus interval of 1 second was maintained (Figure 10).

No feedback on accuracy of performance was provided during the experimental testing. Prior to initiation of the task, 20 practice trials were provided. Practice trials were repeated if needed until 80% accuracy was obtained on the practice. The task instructions for all tasks were presented to the participants in written mode on the computer and verbally, in English, and were repeated if necessary. All participants were tested individually in a quiet, well-lit room free of distractions either at the Aphasia Research Center at the University of Maryland or at their homes.

Analyses

The scoring procedures for the flanker task were identical to those used in the Stroop task described earlier. Data trimming to remove outliers that were ± two standard deviations from the individual participant's grand mean resulted in a loss of 1.1% of total data in neurologically healthy speakers and 2.3% of total data in individuals with aphasia. Only the latencies of correct responses were included in latency analysis. Similar to the Stroop task, the differences in accuracy and response latency between the incongruent and neutral trials (IC-N) were calculated as the interference effect, and congruent and neutral trials (C-N) were calculated as the facilitation effect. Data transformation and statistical analyses were identical to those described for Stroop task.

Results

Measurement reliability of the flanker task was examined using a split-half procedure. Cronbach's Alpha values ranged from 0.83 to 0.91 across conditions in neurologically healthy speakers and PWA indicating high internal consistency of the task.

Neurologically Healthy Speakers

Accuracy. The mean response accuracies by trial type (congruent, incongruent and neutral) are summarized in Table 19 for both monolingual and bilingual NH speakers. All NH speakers demonstrated mean accuracy of greater than 99% (ceiling effect; average SD = 0.05) across all conditions. Given the ceiling effect, there were no noticeable interference or facilitation effects (M = 0.00 for both groups) in the flanker task for either group. Statistical analyses were therefore not conducted in this comparison.

Table 19

Mean response accuracy (%) and latency (ms) interference and facilitation effects in neurologically healthy participants and individuals with aphasia for each condition of the flanker task; the numbers in parentheses are standard deviations

Variable	Language Background	Testing Conditions				
		Congruent	Incongruent	Neutral	IE	FE
Neurologically healthy Speakers						
Accuracy	Bilingual	99.33	99.83	99.50	0.33	-0.17
		(0.05)	(0.01)	(0.04)	(0.70)	(1.23)
	Monolingual	*99.50*	*99.33*	*99.33*	*0.00*	*0.19*
		(0.04)	*(0.03)*	*(0.04)*	*(1.11)*	*(0.95)*
Latency	Bilingual	1423.29	1449.17	1422.89	26.28	0.40
		(127.58)	(133.99)	(130.70)	(28.76)	(25.26)
	Monolingual	*1309.03*	*1333.37*	*1292.90*	*40.47*	*16.13*
		(109.20)	*(116.81)*	*(97.87)*	*(29.10)*	*(26.72)*
Speakers with Aphasia						
Accuracy	Bilingual	97.83	93.67	97.00	-0.33	0.74
		(0.12)	(0.22)	(0.15)	(2.94)	(1.42)

	Monolingual	*98.17*	*95.83*	*99.00*	*-3.17*	*-0.83*
		(0.10)	*(0.15)*	*(0.05)*	*(3.64)*	*(1.80)*
Latency	Bilingual	1564.88	1593.56	1530.68	62.88	34.21
		(239.50)	(298.35)	(235.65)	(126.16)	(80.41)
	Monolingual	*1562.05*	*1621.75*	*1522.30*	*39.75*	*99.45*
		(217.32)	*(218.19)*	*(211.31)*	*(69.44)*	*(177.51)*

IE: Interference effect = difference in accuracy/latency between the incongruent and neutral trials;

FE: Facilitation effect = difference in accuracy/latency between the congruent and neutral trials

Latency. Participants' mean response latencies by trial type (congruent, incongruent and neutral) are provided in Table 19 for both monolingual and bilingual neurologically healthy speakers. Results from the mixed effects ANOVA of (transformed) flanker interference and facilitation effects are summarized in Table 20 and interpreted in the sections below.

Table 20

Summary of results of mixed model analyses of accuracy and latency measures of neurologically healthy speakers and participants with aphasia in the flanker task

	Dependent variable[†]	Main effect of language background	Main effect of condition	Language background x Condition interaction effect
Accuracy				
Neurologically healthy speakers	Interference/ facilitation effects	n/a	n/a	n/a
Individuals with aphasia	Interference/ facilitation effects	Non-significant ($F(1, 36) = 1.08$, $p = .30$)	**Significant ($F(1, 36) = 9.76$, $p < .01$)**	Non-significant ($F(1, 36) = 1.48$, $p = .22$)
Latency				
Neurologically healthy speakers	Interference/ facilitation effects	Non-significant ($F(1, 36) = 1.24$, $p = .28$)	**Significant ($F(1, 36) = 9.89$, $p < .01$)**	Non-significant ($F(1, 36) = 0.07$, $p = .78$)
Individuals with aphasia	Interference/ facilitation effects	Non-significant	Non-significant	Non-significant ($F(1, 36) = 1.45$, $p = .23$)

		($F(1, 36) = .79$, $p = .38$)	($F(1, 36) = 4.10$, $p = .04$)

All participants demonstrated larger interference effect in the incongruent trials than facilitation effects in the congruent trials (significant main effect of condition). The overall magnitude of the flanker effects did not differ between the two participant groups (non-significant main effect of language background). Importantly, the flanker interference and facilitation effects did not significantly vary in magnitude between monolingual and bilingual NH speakers (non-significant interaction effect).

Persons with aphasia

Participants' mean response accuracies and latencies by trial type (congruent, incongruent and neutral) are provided in Table 19 for monolingual and bilingual individuals with aphasia. Results of comparisons between performance of BPWA and MPWA are summarized in Table 20 and interpreted in the sections below.

Accuracy. Results of a 2-way ANOVA (neurological status x language background) indicated a significant main effect of neurological status ($F = 27.32$, $p < .01$) and a non-significant main effect of language background ($F = 4.11$, $p =$ ns). Not surprisingly, neurologically healthy speakers were more accurate than individuals with aphasia. Monolingual overall response accuracy did not differ from bilingual overall response accuracy for neurologically healthy speakers and PWA (non-significant interaction effect: $F = 2.16$, $p = .07$).

Analysis of the flanker effects indicated that though the magnitude of the flanker effects did not differ based on language background of PWA (non-significant main effect of language background), participants experienced significantly larger flanker interference effects (lower accuracy) in the incongruent condition compared to facilitation in the congruent condition (significant main effect of testing condition). There was no significant interaction between the language background and testing condition in PWA.

Latency. Results of a 2-way ANOVA (neurological status x language background) indicated a significant main effect of neurological status ($F = 33.71$, $p < .01$) and a non-significant main effect of language background ($F = 1.66$, p = ns). Monolingual response latency did not differ from bilingual response latency for neurologically healthy speakers and PWA (non-significant interaction effect: $F = 9.43$, $p = .09$). When participants' individual *Z*-scores were analyzed, PWA had significantly larger standardized flanker interference effects (Table 21) when compared to neurologically healthy speakers of corresponding language background (both $t(9) > 2.3$), all $p < .05$) indicating an IC deficit.

Table 21

Z-scores of flanker interference effects across participant groups

Participant	Bilingual Neurologically Healthy	Monolingual Neurologically Healthy	Bilingual Aphasia	Monolingual Aphasia

1	0.91	-0.56	1.66	-0.67
2	-0.47	1.43	1.74	0.16
3	0.64	-0.82	1.84	0.19
4	-2.00	0.21	1.54	-0.62
5	-0.60	-0.41	0.94	-0.82
6	0.69	-1.68	2.10	-0.17
7	0.91	1.69	2.82	5.08
8	0.42	-0.15	0.99	-0.90
9	0.64	0.06	15.50	18.64
10	-1.15	0.21	1.89	-0.63

Mixed model ANOVA indicated non-significant main effects of language background and testing condition as well as a non-significant interaction between these factors (Table 20). This suggests that the flanker effects in congruent and incongruent conditions did not significantly differ as a function of the language background of PWA.

In order to ensure that the way the flanker effects were calculated (relative to the neutral condition) did not influence the results, the statistical analyses for both neurologically healthy and participants with aphasia were repeated with transformed accuracy and latency values of incongruent and congruent conditions as dependent variables. Results remained unchanged across all comparisons.

Discussion

This study examined if bilingual and monolingual speakers differed in domain-general (non-linguistic) inhibitory control as measured by the flanker task. Results of this experiment found no support for the bilingual advantage hypothesis in neurologically healthy speakers and participants with aphasia. The results also indicated some other interesting patterns. First, though the flanker task has been considered to tap into the same components of IC as the Stroop task, it was surprising that all participants (irrespective of neurological status) demonstrated greater mean response latencies in the flanker versus the Stroop task (despite higher response accuracy). It is difficult to explain this observation since the cognitive control processing demands of the flanker task have been suggested to be similar if not easier than the Stroop task, and hence should have resulted in shorter response latencies. A review of available literature did not reveal similar patterns of results in other studies (Bialystok, 2006; Bialystok et al., 2004; Bialystok, Craik, & Luk, 2008; Costa et al., 2008; Luk, De Sa & Bialystok, 2011; Verreyt, 2013). Despite the longer response latencies in the flanker task, the overall pattern of interference and facilitation effects was similar in both tasks as discussed below. Secondly, the overall response latencies did not significantly differ between neurologically healthy adults and PWA. This is in contrast to the significant differences noted in similar comparisons in the Stroop task. Taken together, this pattern of results suggests that linguistic deficits in PWA impact conflict resolution differently in the linguistically based IC task (Stroop) than non-linguistically based IC task (flanker).

In general, irrespective of linguistic background, all neurologically healthy participants were slowed by incongruent trials (flanker interference effect), but not facilitated by congruent trials. Statistical analyses indicated that participants' ability to inhibit interference in the non-linguistic flanker task did not differ as a function of their language background or neurological status (similar to the linguistically based Stroop task). This indicates that bilingual and monolingual speakers exhibit similar cognitive control abilities in non-linguistic conflict resolution via inhibition, at least as measured by the flanker task.

Several recent studies support these findings of the present study. For example, Kousaie and Phillips (2012) found no differences between bilingual and monolingual groups of young adults in the Stroop, Simon and flanker tasks. A similar study by Humphrey and Valian (2012) studying lifelong balanced bilingual speakers, late balanced bilingual speakers whose native language is English, late balanced bilingual speakers whose native language is not English, and trilinguals, found that their performance on the Stroop and flanker tasks were similar to monolingual speakers. Most recently, Paap and Greenberg (2013) also found no difference between bilingual and monolingual performance on a variety of nonlinguistic tasks of IC (Simon, antisaccade, flanker, color-shape switching) in groups of neurologically healthy adults. They further proposed that the individual tasks themselves might not test the same aspects of cognitive function since interference effects on the different tasks poorly correlated with each other. Kousaie & Phillips (2012) also point out that because results from a variety of studies are so contradictory and that results in favor of a bilingual advantage seem to rely on very specific tasks and conditions, this does not support a robust advantage for bilingual speakers. Green and colleagues (2010, 2011) also found unreliable evidence for domain-general IC advantages in BPWA. In two separate case studies, they found that not only could they not consistently replicate bilingual advantage in both linguistic and non-linguistic tasks, their participants also demonstrated a double dissociation between them. Green et al. (2010) found that while one participant (P1) demonstrated poorer performance in linguistic IC tasks (lexical decision and Stroop) relative to the non-linguistic IC flanker, the other participant (P2) demonstrated the opposite pattern. Yet, both these patients presented with similar recovery patterns and linguistic profiles. Using the same experimental tasks, Green et al. (2011) replicated the findings of P1 (greater impairment in language based conflict tasks with relatively intact non-linguistic control) in another highly proficient German-English-Spanish trilingual with parallel recovery.

However, findings from this study are in conflict with previously reported bilingual advantages in non-linguistic tasks (Bialystok, 2006; Bialystok et al., 2004, 2008; Costa et al., 2008; Luk, de Sa & Bialystok, 2011). Recent work by Verreyt (2013) also examined linguistic (Stroop) and non-linguistic (flanker) inhibitory control in balanced and unbalanced neurologically healthy bilingual speakers. They, however, found that balanced bilingual participants who frequently switched between languages showed smaller interference effects than both unbalanced bilingual speakers and balanced bilingual speakers who did not frequently switch between languages even though they also had very high L2 proficiency. They suggest that the bilingual advantage in the conflict resolution tasks was not necessarily a consequence of bilingual proficiency, but rather a result of the frequent need to switch between languages, and hence have more acute IC abilities. This argument supports prior findings of consistent bilingual advantages in bilingual populations that frequently code-switch as a part of daily communicative contexts such as in Canada (e.g., Bialystok et al., 2004; Bialystok, 2006; Bialystok & Feng, 2009), Spain (e.g. Costa et al., 2008, 2009) or Belgium (Verreyt, 2013). Unlike these groups, bilingual speakers in the present study and those in Paap and Greenberg's study (2013), though highly proficient, are likely to use the two languages in different communicative contexts.

In some previous reports, the flanker interference has been calculated as the difference between incongruent and congruent conditions or as the absolute values of accuracy and response latency. That is, the interference effect is not calculated relative to the neutral condition. As noted earlier, these approaches confound a possible facilitation effect and a possible interference effect. However, to verify that the differences in calculation alone did not contribute to the observed differences from previous reports, analyses of variance were recomputed with values of interference effects obtained using the two other methods of measurement. As noted in the results, the findings of the study did not change even when these methods was used. In summary, it can be concluded from the results of this small sample, as well as evidence from previous studies, there is no clear evidence for "bilingual advantage" in non-linguistic inhibition in persons with and without aphasia.

CHAPTER 8: ASSOCIATION BETWEEN LEXICALLY, LINGUISTICALLY AND NON-LINGUISTICALLY BASED INHIBITORY CONTROL: AN INDIVIDUAL DIFFERENCES APPROACH

The premise behind the bilingual advantage in inhibitory control proposed in literature is that the constant practice of an activity that involves IC, such as choosing between competing lexical entries within a bilingual lexicon, is likely to bestow superior IC skills across other tasks in bilingual speakers (relative to monolingual counterparts). Central to this proposal is the assumption that the IC mechanism, exercised in a variety of conflict resolution tasks, is a common system. In support of this assumption, several neuroimaging studies have indicated that the same brain regions associated with IC are used to complete several conflict resolution tasks, irrespective of the nature of the stimuli (lexical/linguistic/non-linguistic). As reviewed in Chapter 2, the anterior cingulate cortex (ACC), left inferior frontal gyrus (LIFG) and dorsolateral pre-frontal cortex (DLPFC) have all been implicated in these tasks in addition to the basal ganglia control circuits. However, the evidence from behavioral data is less conclusive. While some researchers (e.g., Unsworth and Spillers, 2010) have found support for shared IC resources between different conflict resolution tasks, several others have failed to confirm these findings (e.g., Fan et al., 2003; Kousaie & Phillips, 2012; Paap & Greenberg, 2013; Stins et al., 2005). In order to further study the underlying principle of the BAH, the extent to which performance on lexically, linguistically and non-linguistically based conflict resolution tasks is influenced by IC was examined using correlational analyses.

An association between lexical-semantic, linguistic and nonlinguistic inhibitory mechanisms would suggest a relationship between linguistic experience and non-linguistic cognitive processes that could be honed by factors such as bilingualism. In this chapter, the strength of the relationship between IC in lexical (semantically blocked naming), linguistic (Stroop) and non-linguistic (flanker) tasks is examined in the previously studied in participants with and without aphasia.

Research Question and Hypotheses

This analysis examined the following question: ***Are the inhibitory control mechanisms underlying lexical-semantic, linguistic and non-linguistic processing associated with each other in bilingual and monolingual speakers (irrespective of their neurological status)?***

This question was addressed using correlational analyses between measures of inhibitory control on the previously completed semantically blocked naming, Stroop and flanker tasks. It was predicted that if IC measures in the three tasks significantly correlated with each other, it would suggest that IC employed in these tasks share a common mechanism. If there were no correlation between IC in these tasks, then it would suggest that IC employed in these tasks might tap into non-overlapping networks/ resources. Furthermore, if the strength of the correlations between the nonlinguistic and language-based inhibition tasks differs between monolingual and bilingual speakers, then it could suggest that inhibitory mechanisms may be differently modulated by bilingual experience.

Analysis Procedure

The measure of IC in the semantically blocked naming task is the semantic interference effect (SIE; difference in naming latency between semantically homogenous and mixed conditions; Chapter 5). The log-transformed value of SIE in cycle 4 of the naming experiment was used for this analysis. As described in chapters 6 and 7 respectively, in both Stroop and flanker experiments, the difference in response latency between the incongruent and neutral trials (IC-N; log transformed) was calculated as the interference effect (IE), which is taken to indicate IC. Separate Spearman's correlations between the (transformed) interference effects in the three tasks (r_s) were computed for each of the four groups of participants (monolingual and bilingual neurologically healthy speakers and individuals with aphasia). For the Stroop and flanker tasks, the analyses were repeated with incongruent latencies to ensure that the method of calculation of the interference effect did not impact any observed differences. Alpha level for statistical significance was set at $p < .01$. For bilingual speakers, participants' IE and RT_{IC} values in the flanker task were correlated with corresponding values in both L1 and L2 versions of the naming and Stroop task. In each of the analyses, the scatterplots were also examined to verify association and linearity of the relationship between the variables.

Results

The SIE, IE and RT_{IC} (for Stroop and flanker only) for bilingual and monolingual participants with and without aphasia are provided in Table 22 and their correlations are summarized in Table 23.

Neurologically Healthy Speakers

None of the correlations between the interference effects in any of the tasks for bilingual and monolingual participants were statistically significant (all $r_s < .76$, $N = 10$, $p > .07$; Table 20). Analyses repeated with RT_{IC} values of Stroop and flanker confirmed the non-significant correlations.

Individuals with aphasia

Results indicated that the interference effects were not significantly correlated in between the three tasks in both bilingual and monolingual individuals with aphasia (all $r_s < .04$, $N = 10$, all $p > .08$; Table 20). It should however be noted that the correlations between transformed interference effects of L1 naming and flanker in bilingual NH speakers ($r_s = -.68$, $N = 10$, $p = .03$) and L1 Stroop and flanker in BPWA ($r_s = .74$, $N = 10$, $p = .02$) were significant when the alpha level was set at $p < .05$. Results remained unchanged when analyses were repeated with RT_{IC} values of the Stroop and flanker tasks.

Table 22

The interference effects of bilingual and monolingual participants with and without aphasia in semantically blocked cyclic naming, Stroop and flanker tasks

Language Background	Participant	Interference Effects (IE)									
		Neurologically Healthy					Aphasia				
		Naming[a]		Stroop[b]		Flanker[b]	Naming[a]		Stroop[b]		Flanker[b]
		L1	L2	L1	L2		L1	L2	L1	L2	
Bilingual	1	108.47	7.85	102.30	153.40	21.32	77.70	41.49	126.38	81.83	52.42
	2	79.68	52.55	88.26	254.80	23.72	314.62	360.53	-7.30	110.91	12.77
	3	60.82	-7.52	399.38	129.46	26.54	28.49	-99.08	50.93	76.15	44.71
	4	98.72	-47.45	103.09	98.48	17.91	268.32	-104.80	48.87	73.86	-31.1
	5	95.63	92.48	253.61	207.92	0.78	109.52	303.88	47.91	122.30	9.17
	6	81.27	3.97	128.80	16.42	34.01	143.97	-21.83	85.73	125.66	46.07
	7	63.15	91.66	97.28	197.85	54.84	-255.20	204.76	88.14	43.19	52.42
	8	82.45	-7.52	327.07	175.99	2.22	30.19	-103.60	47.08	97.40	38.45
	9	78.18	14.88	-10.96	-25.47	419.26	75.34	323.30	102.21	63.35	44.67
	10	80.65	-47.45	5.15	238.78	28.20	-161.80	111.19	26.25	125.66	- 6.75

	Mean	***829.02***	***153.45***	***1493.98***	***1447.63***	***628.8***	***631.15***	***1015.84***	***616.2***	***920.31***	***262.83***
Monolingual	*1*	*28.85*	--	*120.46*	--	*21.09*	*-21.83*	--	*160.06*	--	*24.23*
	2	*30.11*	--	*346.41*	--	*45.23*	*-143.88*	--	*17.03*	--	*82.10*
	3	*76.14*	--	*217.65*	--	*45.89*	*-60.92*	--	*80.27*	--	*16.69*
	4	*72.10*	--	*60.01*	--	*22.32*	*-79.42*	--	*36.86*	--	*46.67*
	5	*18.62*	--	*169.87*	--	*16.74*	*-188.87*	--	*23.43*	--	*28.52*
	6	*1.92*	--	*13.47*	--	*35.49*	*-44.48*	--	*63.66*	--	*- 8.35*
	7	*52.93*	--	*-122.62*	--	*188.33*	*316.87*	--	*96.22*	--	*89.79*
	8	*157.59*	--	*175.99*	--	*14.42*	*-84.07*	--	*98.52*	--	*36.01*
	9	*25.54*	--	*-85.07*	--	*582.82*	*399.85*	--	*53.32*	--	*42.35*
	10	*26.57*	--	*50.43*	--	*22.14*	*-15.66*	--	*-15.8*	--	*46.68*
	Mean	***2148.41***		***3934.56***		***2252.07***	***1339.89***		***1845.974***		***930.35***

[a] Interference effect: Mean homogenous RT – Mean Mixed RT in cycle 4; [b] Interference effect: $RT_{IC} – RT_N$; L1 = Tamil ; L2 = English for bilingual speakers

Table 23

Spearman's correlation coefficients (r_s) between interference effects in the semantically blocked cyclic naming, Stroop and flanker tasks in neurologically healthy speakers and individuals with aphasia

Language Background	Task	Neurologically Healthy					Aphasia				
		L1 Naming	L2 Naming	L1 Stroop	L2 Stroop	Flanker	L1 Naming	L2 Naming	L1 Stroop	L2 Stroop	Flanker
Bilingual	L1 Naming			.16	-.02	-.68*			-.20	.27	-.33
	L2 Naming			-.15	.25	.07			-.05	.04	.07
	L1 Stroop					-.58					.74*
	L2 Stroop					-.33					-.31
Monolingual	L1 Naming		n/a	.42	n/a	-.05		n/a	.22	n/a	.16
	L1 Stroop				n/a	-.39				n/a	-.38

For bilingual speakers, L1 = Tamil; L2 = English; for monolingual speakers, L1 = English; * significant at $p < .05$ (two-tailed *t*-test)

Discussion

The aim of this analysis was to examine if there is any association between lexical-semantic, linguistic and non-linguistic inhibitory control in bilingual and monolingual speakers with and without aphasia. The correlational analyses of the interference effects of the Stroop and flanker tasks indicated that both neurologically healthy and participants with aphasia demonstrated no significant correlation between inhibitory control scores on the tasks, irrespective of their language backgrounds. These results indicate two findings. First, contrary to some previously reported research (e.g., Unsworth and Spillers, 2010), there is little evidence of a significant relationship between lexical-semantic, linguistic and non-linguistic inhibitory control that was studied in these tasks (irrespective of an individual's language background). Secondly, the extent to which an individual is impacted by conflict trials (engaging IC) on the lexical task appears to have no predictive value on the interference effects of incongruent Stroop or flanker stimuli. Taken together, these results could be taken to indicate that lexically, linguistically and non-linguistically based inhibitory control skills are at least partially dissociated. However, the results of these analyses are to be interpreted with caution given the limited sample sizes and variability in severity of deficits amongst those with aphasia.

There are currently no studies that have directly examined the association between behavioral interference effects in a lexical task and non-lexical tasks. Neuroimaging studies have implicated shared neural resources (including the frontal executive control mechanism, anterior cingulate cortex and the sub-cortical basal ganglia control circuits) in lexical and non-lexical conflict resolution tasks. But given the general lack of consensus between neuroimaging and behavioral evidence, it has been suggested that perhaps the activation detected in neuroimaging in the different IC based tasks indicate shared areas of conflict detection and monitoring rather than conflict resolution or interference management via inhibitory control (Fan et al., 2003; Stins et al., 2005).

There are currently no available studies that have directly compared performance of PWA on lexical-semantic, linguistic and non-linguistic tasks that engage inhibitory control. Relative to neurologically healthy participants completing task in L1, the strength of the association between L1 naming and Stroop was slightly higher in BPWA but lower in MPWA. However, BPWA demonstrated lower correlation between L2 naming and Stroop relative to neurologically healthy controls. Therefore, IC deficits differently impacted use of a postulated shared inhibitory control system when completing a task with linguistic stimuli in L1 versus L2 in bilingual speakers. BPWA demonstrated similar patterns of results as MPWA when completing the task in L2. This pattern of results in not surprising given the results of Stroop task (Chapter 6) that bilingual participants demonstrated larger interference effects and smaller facilitation effects in L2 compared to L1 despite self-reports of high proficiency in both languages. Also, relative to MPWA, BPWA had larger interference and smaller facilitation effects only in L1 while no significant differences between monolingual L1 and bilingual L2 were identified. Similar to the Stroop results, the pattern of IC correlation results was similar between MPWA in L1 and BPWA in L2.

The results of this study are consistent with other recent studies that have found insufficient behavioral evidence for association between linguistic and non-linguistic inhibitory control. Fan et al. (2003) reported non-significant correlation in IC measures engaged in Stroop, Simon, and flanker tasks, though fMRI results indicated that all adults tested activated similar cortical and subcortical regions. Stins et al. (2005) compared interference effects on the Stroop, Simon, and flanker tasks in a group of 12 year-old children. Their results also revealed poor non-significant correlations of IC between the three tasks (all $r < 0.20$). Kousaie and Phillips (2012) reported similar findings in 51 young adults who completed the same three tasks. Paap and Greenberg (2013) found no evidence for correlation between inhibitory control employed in Simon, flanker and anti-saccade tasks completed by bilingual and monolingual adults. The non-significant correlations between different types of IC are however not unequivocal. A small body of behavioral evidence does report association between IC abilities in linguistic and non-linguistic tasks. For example, Friedman and Miyake (2004) report significant correlations between antisaccade and Stroop ($r = 0.23$) and between flanker and Stroop ($r = 0.18$), but no correlation between antisaccade and flanker effects ($r = 0.04$). Unsworth and Spillers (2010) also report a significant correlation (0.17) between a flanker and Stroop task in a group of 220 young adults. However, it is possible that the large sample sizes in both these studies may have contributed to the statistical significance of the small to moderate correlations.

There are two possible reasons for the non-significant association between lexical-semantic, linguistic and non-linguistic IC observed in this study. First, it is possible that the results of conflicting trials in the three tasks may employ similar, but not identical, cognitive resources or they utilize the same resources but to different extents. There are several task specific differences that may have impacted the extent to which additional cognitive resources are engaged during each of these tasks, including selective attention and working memory demands, complexity of lexical processing, and variable demands of response modality employed (the naming tasks required a verbal response while Stroop and flanker tasks required non-verbal responses). So while all the tasks tapped into IC, the use of other cognitive processes may have differently modulated the extent to which IC was used to resolve interference in the conflict trials. For example, Stins et al. (2005) found that working memory scores correlated with Stroop effects but not with Simon and flanker effects suggesting that this task probably relied more heavily on the support of working memory to succeed in conflict resolution via IC compared to the other two tasks. As Fan et al. (2003) suggest, it is also likely that while the shared neural areas implicated in these tasks in prior research may all be responsible for conflict monitoring, the actual resolution of the interference may include different types of IC that may be differently distributed within the neural networks depending on task demands. Hence the behavioral consequences of IC engagement may not correlate across tasks.

Secondly, the participants in the current study were older adults compared to the participants in the studies that report an association between linguistic and non-linguistic IC tasks. Given than IC has been found to deteriorate with advancing age, it is possible that other supportive cognitive processes may be engaged to a greater extent to supplement IC in these tasks in older adults – particularly in tasks like naming which have greater processing demands.

The goal of these analyses was to examine if the strength of association between different types of IC differed between monolingual and bilingual speakers. If bilingual speakers demonstrated stronger correlations between interference effects in the three tasks, it would provide some evidence to support the domain generality of IC that is underlying assumption of the bilingual advantage hypothesis. Results of the current study provided no evidence for differences in association between different types of inhibitory control in monolingual and bilingual speakers (irrespective of their neurological status). Irrespective of their language background, no significant correlations were found between lexical and non-lexical tasks as well as between the two non-lexical tasks. Hence, no bilingual advantage in domain generality of IC could be documented. In fact, the strength of the association between L1 naming and Stroop tasks (though non-significant) was actually higher in monolingual neurologically healthy speakers when compared to their bilingual counterparts (.42 versus .16). It is possible that the linguistic basis of the stimuli in both tasks contributed to the moderate correlation (Cohen, 1988) in monolingual speakers but it is unclear why the strength of this association is stronger than in bilingual speakers.

In summary, results of these analyses indicate that there is little evidence for association between lexical-semantic, linguistic and non-linguistic inhibitory control in both bilingual and monolingual speakers with and without aphasia.

CHAPTER 9: GENERAL DISCUSSION

The main objective of this project was to examine the influence of bilingualism on inhibitory control exercised in lexical-semantic, linguistic and non-linguistic contexts in individuals with aphasia. A secondary aim of this study was to examine any changes in inhibitory control following left hemisphere brain damage (aphasia). Ten bilingual and ten monolingual individuals with aphasia were selected to participate based on their language background and clinical presentation on a battery of pre-tests. Twenty age-matched neurologically healthy bilingual and monolingual speakers served as controls. All participants completed three experimental tasks that were used to probe lexically (semantically blocked cyclic picture naming), linguistically (color-word Stroop) and non-linguistically based (flanker) inhibitory control.

Lexical Inhibitory Control

Experiment 1 explored the role of inhibitory control in modulating semantic competition during lexical retrieval using a semantically blocking paradigm in a speeded picture naming task. As expected, all neurologically healthy controls demonstrated semantic interference effects and bilingual and monolingual healthy speakers differed in the use of IC to resolve lexical competition. However, bilingual speakers demonstrated a bilingual IC disadvantage in L1 and a bilingual IC advantage when naming in L2. Results also indicated that none of the participants with aphasia demonstrated any interference effect over successive naming cycles.

The finding of bilingual disadvantage in L1 naming by unimpaired speakers is tricky to explain within the context of their bilingual advantage in L2 naming. General disadvantage in naming latency has been frequently reported for bilingual speakers (e.g., Gollan, Bonanni, & Montoya, 2005). This has been particularly noted in bilingual speakers who are immersed in a dominant but later-learned language (e.g., Gollan, Montoya, Cera, & Sandoval, 2008) and in bilingual speakers living in a bilingual society (Ivanova & Costa, 2008). Bilingual speakers in this study fell into the latter category and hence overall slowing in response latency in these participants was not surprising. This naming disadvantage has been attributed to either a frequency effect (less frequency of use of the same words than monolingual speakers; Gollan et al., 2008) or to dual-language activation (and consequently twice the competition; Bialystok et al., 2008; Green, 1998; Linck, Kroll, & Sunderman, 2009; Luo, Luk, & Bialystok, 2010; Sandoval, Gollan, Ferreira, & Salmon, 2010), or more likely from the influence of both factors. These proposals indicate that the cognitive demands for word retrieval in bilingual speakers are likely to be higher than in monolinguals speakers. Consequently the amount of inhibition that needs to be exercised on competitors is higher. With increasingly competitive naming demands inherent to the blocked cyclic naming task, it is possible that bilingual speakers in this study required greater inhibition and consequently longer response latencies to match the monolingual accuracy of naming. This could have contributed to the bilingual disadvantage noted in L1 naming. However, the bilingual advantage in L2 naming is much more difficult to reconcile with the existing proposals of bilingual lexical retrieval. It unclear as to why bilingual speakers experience better IC than matched monolingual speakers in L2 when L2 naming is generally considered to be subject to higher levels of competition from a more dominant L1. It may be possible that the persistent activation, which underlies SIE, is so weak in L2 that it does not persist to cause interference.

Global and Local Inhibitory Control

In contrast to neurologically healthy speakers, all participants with aphasia failed to show any semantic interference effects. As discussed in chapter 5, the non-significant effects in individuals with aphasia can be accounted for by the influence of varying sites of lesion.

De Groot and Christoffels (2006) propose a distinction between global inhibition and local inhibition that is important to our understanding of the role of IC in bilingual lexical retrieval. Global inhibition refers to suppression of an entire language system (e.g., inhibiting Tamil when speaking English), and local inhibition refers to inhibition of a specific distractor, such semantically related lexical entries, including translation equivalents. While both processes are suggested to be critical for limiting cross-language interference, local inhibition alone is expected to play a critical role to resolve within-language competition. Global and local IC are also suggested to differ in their influence - local inhibition is expected to underlie linguistic performance while global inhibition is expected to impact both linguistic and cognitive performance (Bialystok et al., 2012). There is some evidence that global and local IC processes may engage different neural networks. In a functional magnetic resonance imaging study, Guo, Liu, Misra, and Kroll

(2011) observed the recruitment of dorsal left frontal gyrus and parietal cortex for global control, while local control engaged the dorsal anterior cingulate cortex and supplementary motor area in Chinese-English bilingual speakers. The unified theory of inhibitory control proposed by Munakata et al. (2011) that was discussed earlier also supports the idea of global versus local inhibitory neural substrates. Together, these proposals suggest that neurological lesions in these individuals may uniquely impact global versus local IC. It is possible that that the IC mechanisms proposed by Green (1998) to overcome within-language lexical competition may correspond with the proposed local inhibition. This is akin to IC mechanisms that limit lexical competition, which is ubiquitous within monolingual lexical retrieval as well. The global IC mechanisms proposed might underlie the functions of the supervisory attentional system that utilizes external cues to limit interference via task schemas and language tags. By this account, if the local IC were equally impacted by brain injury in MPWA and BPWA, then both groups of PWA would be expected to demonstrate similar effects of increased lexical competition. It is possible that the global IC mechanisms are relatively intact in BPWA thereby effectively limiting cross-language interference in the monolingual naming contexts in L1 and L2.

However, some proposals suggest that the role of inhibition may be overstated in bilingual lexical retrieval (Costa et al., 2006) and that inhibitory processes may not be necessary to modulate cross-language activation. Results from some experimental paradigms indicate that highly proficient bilingual speakers may be able to exploit available cues (such as script, sentence context, or language modality) to direct attention to the intended language and/or to raise activation of lexical items in the target language above the activation threshold of lexical alternatives in the non-target language (Costa et al., 2006). Within-language competition is expected to be resolved using mechanisms similar to monolingual lexical retrieval (i.e., by regulating activation strengths of targets over competitors). In such a case, the role of the IC systems (both global and local) are unnecessary for lexical retrieval, thereby eliminating the potential for development of a bilingual advantage in inhibition.

In fact, bilingual models such as the selection by proficiency model by Schweiter & Sunderman (2008) specifically propose that any dependence on IC in bilingual speakers is like to be modulated by language proficiency. Low-proficiency bilingual speakers are suggested to rely extensively on IC, while highly proficient bilinguals are proposed to facilitate word retrieval through differential activation strengths (similar to monolingual speakers). Given that all participants in this study were highly proficient bilinguals, it then not surprising that IC advantages were not detected.

Non-Lexical Inhibitory Control

Results of Stroop task (experiment 2) indicated that relative to MPWA, BPWA had larger interference and smaller facilitation effects in both accuracy and latency analyses only in L1; no significant differences between monolingual L1 and bilingual L2 interference effects were identified. This is in contrast to the results in neurologically healthy speakers where the bilingual participants demonstrated larger facilitation effects in L1 but larger interference and facilitation effects in L2 relative to monolingual speakers. The magnitude of the Stroop interference and facilitation effects did not significantly differ between BPWA's performance in L1 and L2. Results from the flanker task (experiment 3) indicated that in both PWA and NH speakers, bilingual participants did not differ from monolingual participants in non-linguistic IC exercised in the flanker task. The notion of language specific benefits in IC generalizing to domain general IC in bilingual speakers was further explored in this thesis by correlating interference effects on the blocked naming, Stroop and flanker tasks. Results indicated non-significant association between lexical-semantic, linguistic and non-linguistic inhibitory control abilities in bilingual and monolingual speakers with and without aphasia. Taken together, the results of these experiments indicate that there is no clear evidence for "bilingual advantage" in linguistic and non-linguistic inhibition in persons with and without aphasia. The relevance of these findings in the context of prior research is discussed in the following sections.

The absence of significant differences on Stroop and flanker interference effects in individuals with aphasia is in line with recent studies and reviews on unimpaired individuals of various ages on linguistic (Kousaie & Phillips, 2012) and nonlinguistic measures of inhibition (Bialystok et al., 2008; Hilchey & Klein, 2011; Paap & Greenberg, 2013). Paap and Greenberg (2013) found that not only was bilingual and monolingual performance on these tasks similar, but also that the individual tasks themselves did not test the same components of cognition. For example, the flanker effects and Simon effects, frequently seen as equal representations of inhibitory control, were not found to have a strong correlation (*r* = -0.01). Hence, the authors caution that task-specific differences may invalidate any reported bilingual advantages. Kousaie & Phillips (2012) critically note that since results from a variety of studies rely on very specific tasks and conditions and cannot be consistently replicated, there is insufficient evidence to support a robust IC advantage for bilingual speakers.

Consistent with the previously described account of global versus local inhibition, the critical difference between the two is their domain of influence - with local inhibition largely affecting linguistic performance and global inhibition affecting both linguistic and non-linguistic performance. Based on this account, it is possible that Stroop task relies to a greater extent on the local inhibition exerted to process linguistic stimuli while the flanker task engages global inhibition to a larger extent. This could then also account for relatively low correlations between IC engaged in these two tasks. It is possible that in the current sample of individuals with aphasia, the tasks used could not effectively tease apart global versus local inhibitory deficits.

It is also possible that the current sample of individuals with aphasia were not as severely impaired as to involve IC deficits. However, examination of the participants' WAB scores indicates that the participants in the current study represented a wide range of severity of deficits and they appear to be reasonably representative of the population. Unfortunately, the task demands of the different experimental tasks precluded us from recruiting participants of greater severity. Additional review of *Z*-scores of the interference effects of the individuals with aphasia also indicates that at least a subset of all individuals with aphasia may present with exaggerated interference effects, irrespective of the language background. Previous studies have also implicated different sites of lesion having differential impact on IC deficits in individuals with aphasia (Schnur et al., 2006). However, inadequate details of lesions for participants in the present study precluded more in-depth analysis to further shed light on this association.

Implications for Theories of Bilingualism

Although preliminary, the results of this study have implications for current theories of bilingual language processing that specifically highlight the role of inhibitory control. Green's (1998) inhibitory control model proposed that IC is integral to the resolution of any competition within the bilingual lexicon. This IC was critically suggested to be modulated by a supervisory attentional system (SAS) that inhibits competing stimuli based on their relative levels of activation. Speakers' frequency of usage of a word in L1 and L2 was proposed to influence the levels of within and cross-language activation. In the current study, BPWA did not demonstrate any greater interference effects in the blocked naming task compared to MPWA suggesting that the bilingual participants with aphasia did not experience as much dual lexical activation as neurologically healthy speakers or that the dual activation experienced rapidly decayed.

The ICM also hypothesizes that the SAS is a domain general system and hence modulates the influence of linguistic experience on honing non-linguistic IC. This domain general SAS forms the basis of the BAH. Results of this study failed to find any evidence in support of a bilingual advantage in IC in lexical-semantic, linguistic and non-linguistic tasks in healthy speakers and individuals with aphasia. Furthermore, there was no association between measures of IC across these tasks. While it may appear that bilingual speakers have a greater demand to regulate interference from both within and between languages, the processes employed may be similar to those used by monolingual speakers in the single-language context. Our results suggest that repeated use of the same processes to a greater extent by bilingual speakers may not be substantial enough to result in differences in cognitive control.

Alternately, it is possible that focusing on inhibitory control is the wrong level for the study of previously reported bilingual advantages. Several recent studies of inhibitory control in bilingual and monolingual speakers have questioned the bilingual advantage hypothesis. In a recent review of 31 experiments of inhibitory control in bilingual neurologically healthy speakers, Hilchey and Klein (2011) clearly documented the absence of bilingual advantage in inhibitory control. Kousaie and Phillips (2012) and Paap and Greenberg (2013) also failed to find a bilingual advantage in a variety of non-verbal linguistically and non-linguistically based tasks. The absence of bilingual advantage has been replicated in young and older adults from a variety of different language combinations with various levels of bilingual proficiency. Humphrey and Valian (2012) replicated these findings using the Simon and flanker tasks in early balanced bilingual speakers (similar to the participants in the current study), late balanced bilingual speakers whose native language is English, late balanced bilingual speakers whose native language is not English, and trilinguals. As Paap and Greenberg summarize, "when all of these new findings are added to our three Simon experiments, our flanker experiment, and our antisaccade experiment these results sum to 17 new tests yielding no advantages and one that shows a bilingual disadvantage." Taken together, these results do not support Green's theory that the SAS may extend beyond the linguistic domain.

Several researchers attempt to account for the results of prior research documenting bilingual advantages in inhibitory control by attributing these results to "general executive processing" advantages that are not specific to language processing or inhibitory control (Hilchey & Klein, 2011). Within the ICM, these general processing advantages may be accounted for by practice effects in the use of conflict monitoring via selection of task schemas and appropriate language tags. Bilingual advantages may also be found in more fundamental cognitive processes such as sustained attention and working memory that underlie a varied of executive functions. If lifelong experience with bilingualism provides bilingual speakers only a benefit in general monitoring ability, then this advantage is likely to be dependent on several other executive functions such as working memory, sustained attention, and goal maintenance. If this is the case, then the tasks utilized in this study may not be the most sensitive to identify global executive function advantages. Other well-control experimental tasks that examine these isolated cognitive processes may be able to better explain the purported bilingual advantage.

The results of this study provide an opportunity to recast the ICM to accommodate the observed absence of bilingual advantages. A growing number of researchers suggest that several cognitive control mechanisms extending beyond inhibitory control may be involved in bilingual language processing, and contribute to the elusive bilingual cognitive advantage. This idea is consistent with the view advanced by Costa and colleagues (2009), who propose that bilinguals' experience leads them to develop a more fine-tuned conflict monitoring system that generally improves the efficiency with which they allocate their attention. This has also been supported other recent research (Abutalebi et al., 2012; Hilchey & Klein, 2011). If this is the source of the bilingual advantage, then bilingual speakers should perform differently than monolingual speakers on the conflict adaptation paradigm, given that conflict adaptation indexes conflict monitoring abilities. Moreover, if bilingual speakers possess superior conflict monitoring skills, then the conflict adaptation paradigm can help determine whether they are better at conflict detection, at reactively adjusting cognitive control recruitment, or both. The conflict adaptation paradigm, in which performance is examined as a function of both preceding and current trial type, can be used to break-up conflict monitoring into its constituent components. Specifically, performance on incongruent trials followed by congruent trials assesses conflict detection abilities, because participants encounter an initial conflict in a sequence. On the other hand, performance on incongruent trials preceded by another incongruent trial is suggested to reflect adjustments in cognitive control, because participants encounter conflict after processing conflict on an immediately preceding trial. Further analyses of the data from the Stroop and flanker tasks in this study will provide the opportunity to further explore conflict monitoring using the conflict adaptation paradigm.

Colzato and colleagues (2008) also suggest that bilingual speakers differ from monolingual speakers in their ability to maintain goals in working memory, and to use these goals to more strongly activate goal-related cognitive representations. Hence this could be another potential source of the previously reported bilingual advantage. Finally, Bialystok et al. (2012) also acknowledged that inhibitory control alone may be insufficient to explain bilingual processing differences, and that conflict monitoring may work in concert with inhibitory control to produce the documented bilingual advantage effect. These proposals together with the results of the current study indicate the need to more finely differentiate the role of “response inhibition” and “interference suppression” mechanisms within the model, as well as to broaden the role of executive functions included within Green’s ICM to beyond inhibition.

Taken together, results of this study provide no evidence for a bilingual advantage in inhibitory control in neurologically healthy speakers and individuals with aphasia. However, consistent with similar previous findings and the dual account of inhibitory control (global versus local), it is possible that any bilingual advantages that might exist may be at the level of general executive processing or within more elemental executive functions such as selective attention. The tasks and the level of analyses in this study unfortunately do not provide adequate data to examine this proposal further.

Implications for aphasia

Results of this study provide interesting data to advance our understanding of the interface between IC and language processing in individuals with aphasia. All participants with aphasia in the present study had significant language deficits (as measured on the WAB-R) that were characterized by non-fluent speech and word retrieval errors. Though limited, the lesion data of the current study indicate that all participants had lesions that included either the frontal or subcortical regions that have been specifically implicated in inhibitory control. These lesion sites have been often implicated for both language processing and inhibitory control in neurologically intact and individuals with aphasia. However, PWA in this study did not consistently demonstrate IC deficits in lexical IC task. This finding was contrary to a majority of the results from the aphasia literature that indicates that the exaggerated build-up of semantic interference induced by cyclic manipulations are a defining feature of the performance of individuals with aphasia resulting from lesions in the left frontal cortical sites, including the left inferior frontal gyrus (LIFG; Broca's area; Biegler et al., 2008; McCarthy and Kartsounis, 2000; Schnur et al., 2006, 2009; Wilshire and McCarthy, 2002). However, the lack of semantic interference effects in PWA in the current study is not without precedent (e.g., Wilshire & McCarthy, 2002). As reviewed earlier, previous evidence indicates inconsistent reports of SIE depending upon participants' aphasia sub-type and is not always evident in a heterogeneous group.

The unified theory of inhibitory control proposed by Munakata et al. (2011) provides a preliminary framework to discuss these results within the context of participants' lesion data. They argue that inhibition possibly comprises of (i) targeted global inhibition and (ii) indirect competitive inhibition. It is possible that a task such as the semantically blocked picture naming relies to a lesser degree on global inhibitory control in the context of monolingual naming blocks and to a greater extent on the competitive inhibition. The sites of lesions in these patients may uniquely impact this competitive inhibition to a greater degree than global inhibition resulting in the observed non-significant results.

Methodological Considerations

It may be that methodological differences in tasks may lead to the apparent inconsistency in the findings of bilingual advantages. Task specific factors have been reported to influence interference effects in a variety of IC tasks. For instance, interference effects have been reported to be significantly smaller (almost 50% lesser) in the manual versus verbal Stroop task (MacLeod, 1991, 2005). Furthermore, inhibitory control has been proposed to function differently based on the task schemas activated (Green 1986, 1998) and interference effects have been differently noted in reading versus naming (MacLeod, 1991, 2005). Therefore, tasks that rely on verbal versus non-verbal response modalities may employ underlying cognitive control mechanisms differently. Since this study focuses on inhibitory control on lexical retrieval during word productions, keeping the response modality consistent (as verbal output) in all experimental tasks may have provided more robust data to examine bilingual advantages. However, to avoid confounds of paraphasic errors, the manual Stroop and flanker were selected in this study. Additionally, Costa et al. (2009) used a series experiments to find that the right proportion of congruent trials in the experimental paradigm was critical to obtaining the bilingual advantage in the flanker task. On a series of experiments employing 8%, 25%, 50% and 75% of congruent trials respectively, they found that the more congruent trials in the task, the larger the conflict effect they obtained. They also found that any bilingual advantages were temporary and appeared selectively only in early blocks. In the current study, about 30% of the trials were congruent (the rest were incongruent and neutral). This lower proportion of congruent trials may have impacted the magnitude and the robustness of flanker effects. However, despite using the exact same methodology of trial proportions and blocking as Costa et al. (2009), Kousaie and Phillips (2012) and Paap and Greenberg (2013) could not replicate the reported bilingual advantage.

Another factor that has been suggested to influence the results is the languages used by the bilingual speakers. Prior research has found that in bilingual speakers, and orthographic similarity between the constituent languages has been found to influence the extent of IC that needs to be recruited (Preston & Lambert, 1969; Roelofs, 2003; Sumiya & Healy, 2004). Some previous studies have also found that non-alphabetic languages (such as Chinese) elicit smaller Stroop interference effects than alphabetic languages (e.g. van Heuven, Conklin, Coderre, Guo & Dijkstra, 2011). Similar results have also been reported in English-Greek (Brauer, 1998), Japanese-English (Sumiya and Healy, 2004), and Hebrew-English bilingual speakers (Goldfarb and Tzelgov, 2007). Given the distinct lack of orthographic and phonological similarity between the languages used by the bilingual speakers in this study, it is possible that the representations in the two languages may not have competed or interfered with each other to the same extent as the Indo-European Germanic languages that have been used in the majority of previous studies. Less similarity between the two languages (e.g., Tamil and English) may result in lesser interference relative to more closely related language pairs (e.g., Spanish and English). It has thus been proposed that more disparate languages may rely largely on external suppression systems (global inhibition) and rely to a lesser extent on modulation of cognitive control via the internal inhibitory system (local inhibition) as postulated by

Green (2005). Hence, bilingual IC advantages may be present only in structurally similar languages.

A third factor that may influence the results is the cultural context in which the two languages of the bilingual are acquired and used. Highly proficient Tamil-English bilingual speakers residing in India tend to use the two languages in distinctly different communicative contexts (greater use of English in professional communication and Tamil at home). This may lead to development of unique communication profiles in these bilingual speakers that may impact the extent of reliance on internal inhibitory mechanisms.

Limitations of the Present Study

Despite their contribution to our knowledge of the nature of inhibitory control in bilingual language processing, the results of the studies in this dissertation should be viewed in the context of their limitations. Though this study was an attempt to study this population in larger samples than single case reports, the sample size was relatively small and it is possible that larger groups may have revealed more significant findings. The lack of homogeneity amongst the participants of this study in terms of lesion size, location, severity and type of aphasia may have also limited the robustness of the findings. Another important limitation is that only inhibitory control was tested. Given that IC has been proposed to be intricately associated with other executive functions such as attention, conflict identification, etc., it is unclear to what extent deficits in these other executive function domains may have impacted the findings. Another previously mentioned factor that may have impacted the findings is the language pair (Tamil-English) that was included in the present study. Given the relative distinction in all linguistic aspects of the two languages, it is possible that the bilingual experience of the participants in this study didn't rely on the recruitment of IC in the same way that more similar languages (e.g., Spanish-Catalan) might engage it. Methodological limitations also extend to the repetition of stimuli within each of the tasks. It might be impossible to ascertain the effect that the high number of repetition of stimuli within each task might have had on the patterns of results we obtained. However, two precautions were taken to minimize the impact of stimulus repetitions on the results: (i) stimuli were all presented in pseudo-randomized and counterbalanced sequences, and (ii) stimuli were presented in blocks with rest breaks within and between sessions. Bilingual speakers also completed the Tamil and English version of the tasks on different days.

Directions for Future Research

Notwithstanding its limitations, the research presented in this thesis can serve as a basis and motivation for future research aimed at deepening our understanding of the role of inhibitory control in bilingual language production, particularly in individuals with aphasia. The results suggest that much could be gained by further use of an individual difference approach combining the measurement of within- and cross language competition during spoken language production and the measurement of the influence of several executive function abilities, ideally in a variety of situations creating different cognitive demands for bilingual versus monolingual speakers (e.g., change in language contexts, more complex language material).

Though larger than other group level studies, this study still only included ten monolingual and ten bilingual PWA. Replication of the data on larger samples would increase statistical power and may help identify differences that are too subtle to notice within the current group. Furthermore, given the evidence for the influence of script based differences in bilingual IC and lexical retrieval, extending this study with replication of the experiments in bilingual speakers who share structural similarity between their languages will add vital information to our understanding of BAH. Also, since the results of the study suggest that global executive functioning abilities and not IC differences may be the source of previously reported bilingual advantages, a more systematic study of the executive function profiles of individuals with aphasia within the context of lexical retrieval is important. To address this, Paap and Greenberg (2013) recommend obtaining "new and compelling evidence that follows the protocol for the following hypothetical study: (1) identify the specific component(s) of executive processing that should be enhanced by managing two languages, (2) show a bilingual advantage in an indicator of that component across two different tasks, (3) show that the indicators correlate with one another and have some degree of convergent validity, (4) show no differences between the two groups on a pure block of easy choice-RT trials, (5) match the groups on SES and (6) minimize cultural differences between the groups." Finally, lesion data is critical to interpretation of the behavioral results in order to understand the interface between neural substrates and lexical/cognitive processing. The unavailability of detailed lesion data limits the interpretation of our results.

Future research in this area should address limitations and concerns as discussed above. Investigations into components of executive function that may be specifically influenced by linguistic experience are the main goals of ongoing research. Structural and functional neuroimaging data will be critical to refine the current study and expand its scope. Ongoing research is also necessary to identify the influence of age, language similarities and aphasia subtypes on any differences in bilingual versus monolingual language processing.

Conclusions

This study is the largest group level systematic comparison of the bilingual advantage hypothesis in individuals with aphasia till date. Results of this study provide critical information to inform our understanding of bilingual lexical retrieval and the interface between inhibitory control and language processing. First, results of this study shed light on the role of IC in lexical retrieval. Global and local components of the IC system appear to have unique influences on successful lexical retrieval in all speakers, irrespective of the language background. Secondly, results of this study indicate that linguistic experience does not differently modulate inhibitory control abilities across lexical-semantic, linguistic and non-linguistic domains of processing. There was also no evidence of association between IC across the different domains. In conclusion, findings from this study provided no support for bilingual inhibitory control advantages in neurologically healthy speakers and individuals with aphasia.

APPENDIX A

Northwestern Bilingualism & Psycholinguistics Research Laboratory
Marian, Blumenfeld, & Kaushanskaya (2007). The Language Experience and Proficiency Questionnaire (LEAP-Q): Assessing language profiles in bilinguals and multilinguals. *Journal of Speech Language and Hearing Research, 50* (4), 940-967.
Adapted to pencil-and-paper version by Marilyn Logan

Language Experience and Proficiency Questionnaire (LEAP-Q)

Last name		First name		Today's Date	
Age		Date of Birth		Male ☐	Female ☐

(1) Please list all the languages you know **in order of dominance**:

1	2	3	4	5

(2) Please list all the languages you know **in order of acquisition** (your native language first):

1	2	3	4	5

(3) Please list what percentage of the time you are *currently* and *on average* exposed to each language.
(*Your percentages should add up to 100%*):

List language here:					
List percentage here:					

(4) When choosing to read a text available in all your languages, in what percentage of cases would you choose to read it in each of your languages? Assume that the original was written in another language, which is unknown to you. (*Your percentages should add up to 100%*):

List language here:					
List percentage here:					

(5) When choosing a language to speak with a person who is equally fluent in all your languages, what percentage of time would you choose to speak each language? Please report percent of total time.
(*Your percentages should add up to 100%*):

List language here					
List percentage here:					

(6) Please name the cultures with which you identify. On a scale from zero to ten, please rate the extent to which you identify with each culture. (Examples of possible cultures include US-American, Chinese, Jewish-Orthodox, etc.):

Culture: _______________

0 1 2 3 4 5 6 7 8 9 10

No identification — Very low identification — Moderate identification — Complete identification

Culture: ______________

0	1	2	3	4	5	6	7	8	9	10
No identification	Very low identification				Moderate identification					Complete identification

Culture: ______________

0	1	2	3	4	5	6	7	8	9	10
No identification	Very low identification				Moderate identification					Complete identification

Culture: ______________

0	1	2	3	4	5	6	7	8	9	10
No identification	Very low identification				Moderate identification					Complete identification

Culture: ______________

0	1	2	3	4	5	6	7	8	9	10
No identification	Very low identification				Moderate identification					Complete identification

(7) How many years of formal education do you have? ________________________________

Please check your highest education level (or the approximate US equivalent to a degree obtained in another country):

☐ Less than High School ☐ Some College ☐ Masters
☐ High School ☐ College ☐ Ph.D./M.D./J.D.
☐ Professional Training ☐ Some Graduate School ☐ Other:

(8) Date of immigration to the USA, if applicable ____

If you have ever immigrated to another country, please provide name of country and date of immigration here.

____

(9) Have you ever had a vision problem☐, hearing impairment☐, language disability☐, or learning disability ☐? (Check all applicable).

If yes, please explain (including any corrections):

____

Language:

This is my (**native** **second** **third** **fourth** **fifth**) language.

(1) Age when you…

began acquiring this language:	*became fluent in this language:*	*began reading in this language:*	*became fluent reading in this language:*

(2) Please list the number of years and months you spent in each language environment:

	Years	Months
A country where this language is spoken		
A family where this language is spoken		
A school and/or working environment where this language is spoken		

(3) Please circle your *level of **proficiency*** in speaking, understanding, and reading in this language:

Speaking

0	1	2	3	4	5	6	7	8	9	10
None	Very low	Low	Fair	Slightly less than adequate	Adequate	Slightly more than adequate	Good	Very good	Excellent	Perfect

Understanding spoken language

0	1	2	3	4	5	6	7	8	9	10
None	Very low	Low	Fair	Slightly less than adequate	Adequate	Slightly more than adequate	Good	Very good	Excellent	Perfect

Reading

0	1	2	3	4	5	6	7	8	9	10
None	Very low	Low	Fair	Slightly less than adequate	Adequate	Slightly more than adequate	Good	Very good	Excellent	Perfect

(4) Please circle how much the following factors contributed to you learning this language:

Interacting with friends

0	1	2	3	4	5	6	7	8	9	10
Not a contributor	Minimal contributor				Moderate contributor					Most important contributor

Interacting with family

0	1	2	3	4	5	6	7	8	9	10
Not a contributor	Minimal contributor				Moderate contributor					Most important contributor

Reading

0	1	2	3	4	5	6	7	8	9	10
Not a contributor	Minimal contributor				Moderate contributor					Most important contributor

Language tapes/self-instruction

0	1	2	3	4	5	6	7	8	9	10
Not a contributor	Minimal contributor				Moderate contributor					Most important contributor

Watching TV

0	1	2	3	4	5	6	7	8	9	10
Not a contributor	Minimal contributor				Moderate contributor					Most important contributor

Listening to the radio

0	1	2	3	4	5	6	7	8	9	10
Not a contributor	Minimal contributor				Moderate contributor					Most important contributor

(5) Please circle to what extent you are currently exposed to this language in the following contexts:

Interacting with friends

0	1	2	3	4	5	6	7	8	9	10
Never	Almost Never				Half of the time					Always

Interacting with family

0	1	2	3	4	5	6	7	8	9	10
Never	Almost Never				Half of the time					Always

Watching TV

0	1	2	3	4	5	6	7	8	9	10
Never	Almost Never				Half of the time					Always

Listening to radio/music

0	1	2	3	4	5	6	7	8	9	10
Never	Almost Never				Half of the time					Always

Reading

0	1	2	3	4	5	6	7	8	9	10
Never	Almost Never				Half of the time					Always

Language-lab/self-instruction

0	1	2	3	4	5	6	7	8	9	10
Never	Almost Never				Half of the time					Always

(6) In your perception, how much of a foreign accent do you have in this language?

0	1	2	3	4	5	6	7	8	9	10
None	Almost none	Very light	Light	Some	Moderate	Considerable	Heavy	Very heavy	Extremely heavy	Pervasive

(7) Please circle how frequently others identify you as a non-native speaker based on your accent in this language:

0	1	2	3	4	5	6	7	8	9	10
Never	Almost Never				Half of the time					Always

APPENDIX B

WAB – R scores of monolingual and bilingual participants with aphasia

Participant	Language	Naming (max 60)	Word Fluency (max 20)	Sentence Comprehension (max 10)	Responsive Speech (max 10)	Word finding (max 100)	Aphasia Quotient	Aphasia Type
MA1	English	32	4	6	2	44	65.8	Broca's
MA2	English	26	4	6	3	39	65.4	Broca's
MA3	English	37	5	5	3	50	67.8	Broca's
MA4	English	21	3	5	2	31	52.2	Broca's
MA5	English	40	7	8	5	60	84.9	Broca's
MA6	English	20	3	4	2	29	45.6	Broca's
MA7	English	33	5	6	4	48	72.9	Broca's
MA8	English	42	5	7	4	58	80.5	Broca's
MA9	English	36	6	5	5	52	77.6	Broca's
MA10	English	41	5	6	4	56	87.2	Broca's
BA1	Tamil	34	5	5	2	46	72.2	Broca's
BA2	Tamil	39	4	5	2	50	72.6	Broca's
BA3	Tamil	41	6	8	4	59	88.6	Broca's
BA4	Tamil	22	4	6	5	37	63.4	Broca's
BA5	Tamil	35	5	5	3	48	73.8	Broca's
BA6	Tamil	38	4	4	2	48	69.4	Broca's
BA7	Tamil	43	6	8	4	61	82.2	Broca's
BA8	Tamil	21	3	4	0	28	56.9	Trans-cortical Motor
BA9	Tamil	42	5	6	5	58	79.4	Broca's
BA10	Tamil	45	7	7	6	65	89.8	Broca's
BA1	English	32	4	4	3	43	63.5	Broca's
BA2	English	38	6	5	4	53	74.6	Broca's
BA3	English	27	4	4	2	37	57.4	Broca's
BA4	English	22	5	6	4	37	67.3	Broca's
BA5	English	38	5	6	4	53	72.8	Broca's
BA6	English	31	4	5	2	42	65.6	Broca's
BA7	English	37	5	5	4	51	70.2	Broca's
BA8	English	24	6	4	2	36	55.4	Trans-cortical Motor
BA9	English	37	5	5	3	50	62.9	Broca's
BA10	English	33	5	6	4	48	73.5	Broca's

APPENDIX C

Stimuli characteristics identified from norming procedures *

Target Stimulus	Category	Mean Naming Agreement Score [a]	Mean Word Familiarity Score [b]	Categorical Identity Score [c]
Earring	Accessories	96%	6.76	100%
Hat	Accessories	100%	6.60	96%
Necklace	Accessories	96%	6.20	100%
Ring	Accessories	100%	5.76	100%
Watch	Accessories	100%	6.28	100%
Cat	Animals	100%	7.00	100%
Cow	Animals	100%	6.72	100%
Dog	Animals	100%	7.00	100%
Lion	Animals	100%	6.68	100%
Monkey	Animals	100%	6.72	100%
Duck	Birds	96%	7.00	100%
Owl	Birds	100%	6.72	100%
Peacock	Birds	100%	6.68	100%
Swan	Birds	100%	5.80	100%
Turkey	Birds	100%	6.62	100%
Ear	Body parts	100%	7.00	100%
Eye	Body parts	100%	7.00	100%
Hand	Body parts	100%	7.00	100%
Leg	Body parts	96%	7.00	100%
Nose	Body parts	100%	7.00	100%
Balcony	Home	92%	6.52	100%
Door	Home	100%	7.00	100%
Floor	Home	100%	7.00	100%
Roof	Home	100%	7.00	100%
Window	Home	100%	7.00	100%
Lightning	Nature	100%	6.44	100%
Mountain	Nature	100%	7.00	100%
Rain	Nature	100%	6.72	100%
Rainbow	Nature	100%	6.52	100%
Sun	Nature	100%	7.00	100%
Circle	Shapes	100%	7.00	100%
Heart	Shapes	100%	7.00	100%
Square	Shapes	100%	7.00	100%

Star	Shapes	100%	7.00	100%
Triangle	Shapes	100%	7.00	100%
Ball	Toys	96%	7.00	100%
Doll	Toys	100%	7.00	100%
Kite	Toys	100%	6.24	100%
Swing	Toys	100%	5.84	100%
Top	Toys	100%	5.72	100%
Bowl	Utensils	100%	7.00	100%
Knife	Utensils	100%	7.00	100%
Plate	Utensils	100%	7.00	100%
Pot	Utensils	92%	5.88	100%
Spoon	Utensils	100%	7.00	100%
Corn	Vegetables	100%	6.80	100%
Mushroom	Vegetables	100%	6.20	100%
Onion	Vegetables	100%	7.00	100%
Peas	Vegetables	100%	7.00	100%
Potato	Vegetables	100%	7.00	100%
Boat	Vehicles	100%	6.84	100%
Bus	Vehicles	100%	7.00	100%
Rocket	Vehicles	100%	6.24	100%
Tractor	Vehicles	100%	6.16	100%
Train	Vehicles	100%	7.00	100%
Arrow	Weapons	100%	6.64	100%
Ax	Weapons	100%	6.52	100%
Cannon	Weapons	92%	6.04	100%
Gun	Weapons	100%	6.92	100%
Sword	Weapons	100%	6.90	100%

* All scores were obtained from 25 Tamil (L1) –English (L2) bilingual neurologically healthy speakers aged 41 to 73 years.

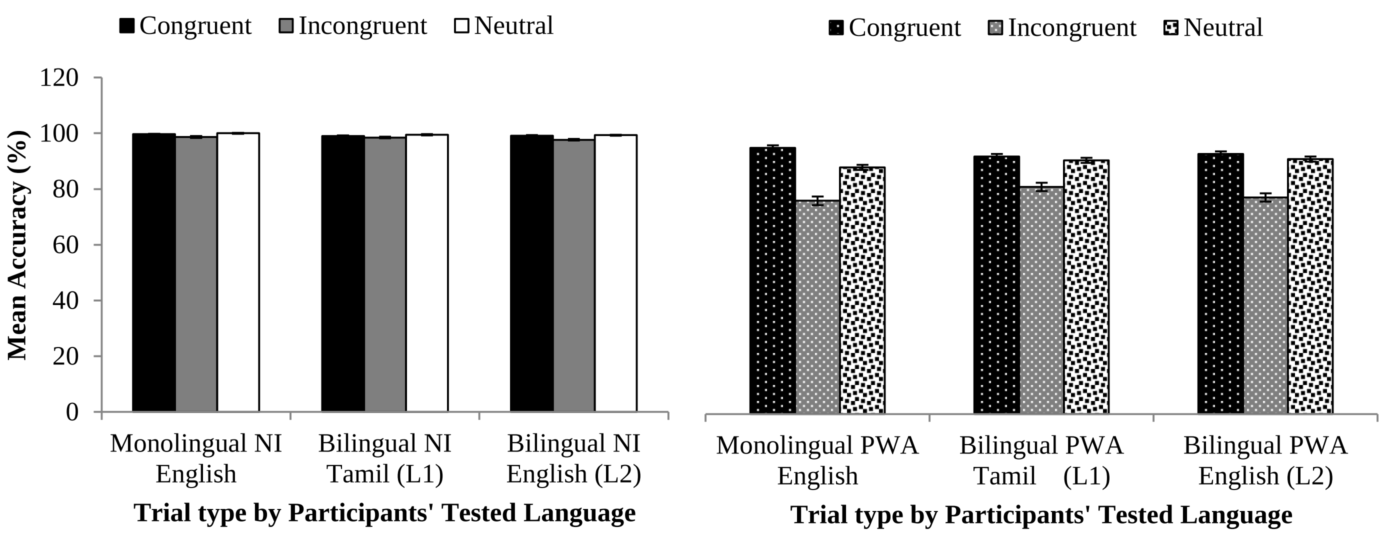
[a] Mean Naming Agreement Score: Mean percentage of name agreement based on naming responses to pictured targets

[b] Mean Word Familiarity Score: Mean familiarity score of the targets in English on a seven-point likert rating

[c] Categorical Identity Score: Mean percentage of participants who identified the exemplar as belonging to the semantic category

APPENDIX D

Mean response accuracy (%) of monolingual and bilingual neurologically healthy (NH) speakers and persons with aphasia (PWA) in each response language in a computerized adaptation of the color-word Stroop task (Stroop, 1945). Error bars represent standard errors.



REFERENCES

Abrahams, S., Goldstein, L. H., Simmons, A., Brammer, M. J., Williams, S. C., Giampietro, V. P., ... & Leigh, P. N. (2003). Functional magnetic resonance imaging of verbal fluency and confrontation naming using compressed image acquisition to permit overt responses. *Human brain mapping*, *20*(1), 29-40.

Abutalebi, J. (2008). Neural aspects of second language representation and language control. *Acta Psychologia, 128,* 466–478.

Abutalebi, J., & Green, D. (2007). Bilingual language production: The neurocognition of language representation and control. *Journal of Neurolinguistics, 20,* 242–275.

Abutalebi, J., & Green, D.W. (2008). Control mechanisms in bilingual language production: Neural evidence from language switching studies. *Language and Cognitive Processes*, *23*, 556581.

Abutalebi, J., Annoni, J. M., Zimine, I., Pegna, A. J., Seghier, M. L., Lee-Jahnke, H., ... & Khateb, A. (2008). Language control and lexical competition in bilinguals: an event-related fMRI study. *Cerebral Cortex*, *18*(7), 1496-1505.

Abutalebi, J., Della Rosa P. A. D., Green D. W., Hernández M., Scifo P., Keim R.,…Costa, A. (2011). Bilingualism tunes the anterior cingulate cortex for conflict monitoring. *Cerebral Cortex,* Epub ahead of print retrieved December 12, 2011, from http://cercor.oxfordjournals.org/content/early/2011/10/25/cercor.bhr287

Abutalebi, J., Della Rosa, P. A. D., Tettamanti, M., Green, D. W. & Cappa, S. F. (2009). Bilingual aphasia and language control: A follow-up fMRI and intrinsic connectivity study. *Brain and language, 109,* 141-156.

Abutalebi, J., Miozzo, A., & Cappa, S. F. (2000). Do subcortical structures control language selection in bilinguals? Evidence from pathological language mixing. *Neurocase, 6,* 101–106.

Adelman, A., Moser-Mercer, B. & Golestani, N. (2011). Executive control of language in the bilingual brain: Integrating the evidence from neuroimaging to neuropsychology. *Frontiers in Psychology, 2,* 234, 1- 8.

Adi-Japha,E., Berberich-Artzi,J., & Libnawi,A. (2010). Cognitive flexibility in drawings of bilingual children. *Child Development*, *81,* 1356–1366.

Altarriba, J. & Heredia, R.R. (2008). *An introduction to bilingualism: Principles and processes.* Mahwah, NJ: Erlbaum.

Alvarez, J. A., & Emory, E. (2006). Executive function and the frontal lobes: a meta-analytic review. *Neuropsychology review*, *16*(1), 17-42.

Ansaldo, A. I., & Marcotte, K. (2007). Language switching in the context of Spanish–English bilingual aphasia. In J. G. Centeno, R. T. Anderson, & L. K. Obler (Eds.), *Communication disorders in Spanish speakers: Theoretical, research, and clinical aspects* (pp. 214–230). Clevedon, UK: Multilingual Matters.

Ansaldo, A., Marcotte, K., Scherer, L., & Raboyeau, G. (2008). Language therapy and bilingual aphasia: clinical implications of psycholinguistic and neuroimaging research. *Journal of Neurolinguistics, 21,* 539–557.

Ansaldo, A. I., Saidi, L. G., & Ruiz, A. (2010). Model-driven intervention in bilingual aphasia: Evidence from a case of pathological language mixing. *Aphasiology, 24,* 309–324.

Aristei, S., Melinger, A., & Rahman, R. A. (2011). Electrophysiological chronometry of semantic context effects in language production. *Journal of Cognitive Neuroscience*, *23*(7), 1567-1586.

Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2014). Inhibition and the right inferior frontal cortex: one decade on. *Trends in cognitive sciences*, *18*(4), 177-185.

Augustinova, M., & Ferrand, L. (2014). Automaticity of Word Reading Evidence From the Semantic Stroop Paradigm. *Current Directions in Psychological Science, 23*(5), 343-348.

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language, 59*(4), 390-412.

Baddeley, A. D. (1986). *Working memory*. Oxford: Oxford University Press.

Barkley, R. A. (1997b). Behavioral inhibition, sustained attention, and executive functions: Towards a unifying theory of ADHD. *Psychological Bulletin, 121,* 65–94.

Bélanger, S., Belleville, S., & Gauthier, S. (2010). Inhibition impairments in Alzheimer's disease, mild cognitive impairment and healthy aging: Effect of congruency proportion in a Stroop task. *Neuropsychologia*, *48*(2), 581-590.

Belke, E. (2008). Effects of working memory load on lexical-semantic encoding in language production. *Psychonomic bulletin & review*, *15*(2), 357-363.

Belke, E. (2013). Long-lasting inhibitory semantic context effects on object naming are necessarily conceptually mediated: Implications for models of lexical-semantic encoding. *Journal of Memory and Language*, *69*(3), 228-256.

Belke, E., & Stielow, A. (2013). Cumulative and non-cumulative semantic interference in object naming: Evidence from blocked and continuous manipulations of semantic context. *The Quarterly Journal of Experimental Psychology*, *66*(11), 2135-2160.

Belke, E., Brysbaert, M., Meyer, A. S., & Ghyselinck, M. (2005). Age of acquisition effects in picture naming: evidence for a lexical-semantic competition hypothesis. *Cognition*, *96*(2), B45-B54.

Belke, E., Meyer, A. S., & Damian, M. F. (2005). Refractory effects in picture naming as assessed in a semantic blocking paradigm. *Quarterly Journal of Experimental Psychology Section A – Human Experimental Psychology, 58(4),* 667–692.

Berg, E. A. (1948). A simple objective technique for measuring flexibility in thinking. *The Journal of general psychology*, *39*(1), 15-22.

Bialystok, E. (1986). Factors in the growth of linguistic awareness. *Child Development, 57,* 498-510.

Bialystok, E. (1988). Levels of bilingualism and levels of linguistic awareness. *Developmental Psychology, 24,* 560-567.

Bialystok, E. (1992). Attentional control in children's metalinguistic performance and measures of field independence. Developmental Psychology, 28, 654-664.

Bialystok, E. (1998). Beyond binary options: Effects of two languages on the bilingual mind. *Studia Anglica Posnaniensia, 33,* 47-60.

Bialystok, E. (1999). Cognitive complexity and attentional control in the bilingual mind. *Child development*, *70*(3), 636-644.

Bialystok, E. (2001). Metalinguistic aspects of bilingual processing. *Annual Review of Applied Linguistics, 21,*169-181.

Bialystok, E. (2006). Effect of bilingualism and computer video game experience on the Simon task. *Canadian Journal of Experimental Psychology*, 60, 68–79.

Bialystok, E. (2007). Cognitive effects of bilingualism: How linguistic experience leads to cognitive change. *International Journal of Bilingual Education and Bilingualism*, *10*(3), 210-223.

Bialystok, E. (2009). Bilingualism: The good, the bad, and the indifferent. *Bilingualism: Language and Cognition*, *12*(01), 3-11.

Bialystok, E. (2011). Coordination of executive functions in monolingual and bilingual children. *Journal of Experimental Child Psychology, 110,* 461–468.

Bialystok E., Barac R., Blaye A., Poulin-Dubois D. (2010). Word mapping and executive functioning in young monolingual and bilingual children. *Journal of cognitive development. 11,* 485–508.

Bialystok, E., & Craik, F. I. (2010). Cognitive and linguistic processing in the bilingual mind. *Current directions in psychological science*, *19*(1), 19-23.

Bialystok, E., Craik, F. I. M., & Freedman, M. (2007). Bilingualism as a protection against the onset of symptoms of dementia. *Neuropsychologia, 45,* 459–464.

Bialystok, E., Craik, F. I., Grady, C., Chau, W., Ishii, R., Gunji, A., & Pantev, C. (2005). Effect of bilingualism on cognitive control in the Simon task: evidence from MEG. *NeuroImage*, *24*(1), 40-49.

Bialystok, E., Craik, F. I., Green, D. W., & Gollan, T. H. (2009). Bilingual minds. *Psychological Science in the Public Interest*, *10*(3), 89-129.
Bialystok, E., Craik, F. I., Green, D. W., & Gollan, T. H. (2009). Bilingual minds. *Psychological Science in the Public Interest*, *10*(3), 89-129.
Bialystok E., Craik F. I., Klein R., Viswanathan M. (2004). Bilingualism, aging, and cognitive control: evidence from the Simon task. *Psychology of Aging, 19,* 290–303.

Bialystok, E., Craik, F. I. M., & Luk, G. (2008). Cognitive control and lexical access in younger and older bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34,* 859–873.

Bialystok, E., Craik, F. I. M., & Luk, G. (2012). Bilingualism: consequences for mind and brain. *Trends in Cognitive Science, 16, 4,* 240-250.

Bialystok E., Craik F. I., Ryan J. (2006). Executive control in a modified antisaccade task: effects of aging and bilingualism. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 1341–1354.

Bialystok, E., & DePape, A-M. (2009). Musical expertise, bilingualism, and executive functioning. *Journal of Experimental Psychology: Human Perception and Performance*, *35*, 565-574.

Bialystok, E., & Luk, G. (2012). Receptive vocabulary differences in monolingual and bilingual adults. *Bilingualism: Language and Cognition*, *15*(02), 397-401.

Bialystok, E., Luk, G., Peets, K. F., & Yang, S. (2010). Receptive vocabulary differences in monolingual and bilingual children. *Bilingualism: Language and Cognition*, *13*(04), 525-531.

Bialystok, E., & Martin, M. M. (2004). Attention and inhibition in bilingual children: Evidence from the dimensional change card sort task. *Developmental science*, *7*(3), 325-339.

Bialystok, E., Martin, M. M., & Viswanathan, M. (2005). Bilingualism across the lifespan: The rise and fall of inhibitory control. *International Journal of Bilingualism*, *9*(1), 103-119.

Bialystok, E., & Senman, L. (2004). Executive processes in appearance-reality tasks: The role of inhibition of attention and symbolic representation. *Child Development, 75,* 562-579.

Biegler, K. A., Crowther, J. E., & Martin, R. C. (2008). Consequences of an inhibition deficit for word production and comprehension: Evidence from the semantic blocking paradigm. Cognitive Neuropsychology, 25, 493–527.

Bijeljac-Babic, R., Biardeau, A., & Grainger, J. (1997). Masked orthographic priming in bilingual word recognition. *Memory & Cognition*, *25*(4), 447-457.

Bloem, I., van den Boogaard, S., & La Heij, W. (2004). Semantic facilitation and semantic interference in language production: Further evidence for the conceptual selection model of lexical access. *Journal of Memory and Language, 51*(2), 307-323.

Blumenfeld, H. K., & Marian, V. (2011). Bilingualism influences inhibitory control in auditory comprehension. *Cognition*, *118*(2), 245-257.

Boehler C.N, Appelbaum, L. G., Krebs, R. M., Hopf, J-M, Woldorff, M. G. (2010). Pinning down response inhibition in the brain - conjunction analyses of the Stop-signal task. *NeuroImage. 52(4),* 1621-1632.

Boersma, P. and Weenink, D. Praat: doing phonetics by computer (Version 5.1.12), [Computer program], http://www.praat.org/, 2009.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological review*, *108*(3), 624.

Bowles, N. L. (1994). Age and rate of activation in semantic memory. *Psychology and Aging, 9 (3),* 414-429.

Brass, M., & von Cramon, D. Y. (2004). Decomposing components of task preparation with functional magnetic resonance imaging. *Journal of Cognitive Neuroscience, 16,* 609–620.

Bruyer, R., & Scailquin, J. C. (1999). Assessment of visuo- spatial short-term memory and effect of aging. *European Review of Applied Psychology, 49,* 175-181.

Calabria, M., Hernández, M., Branzi, F. M., & Costa, A. (2012). Qualitative differences between bilingual language control and executive control: evidence from task-switching. *Frontiers in psychology*, *2*, 1-10.

Caramazza, A. (1997) How many levels of processing are there in lexical access? Cognitive *Neuropsychology, 14,* 177-208.

Carlson, S.M., & Meltzoff, A.N. (2008). Bilingual experience and executive functioning in young children. *Developmental Science, 11,* 279-295.

Centeno, J. (2009). Issues and principles in service delivery to communicatively impaired minority bilingual adults in neurorehabilitation. *Seminars in Speech and Language, 30,* 139-152.

Chang, C., Crottaz-Herbette, S., & Menon, V. (2007). Temporal dynamics of basal ganglia response and connectivity during verbal working memory. *Neuroimage, 34(3),* 1253-1269.

Chen, A., Tang, D., & Chen, X. (2013). Training reveals the sources of stroop and flanker interference effects. *PloS one*, *8*(10), e76580.

Chen, H. & Leung, Y. (1989) Semantic facilitation and translation priming effects in Chinese-English bilingual speakers. *Memory and Cognition,* 17, 454-462.

Chen, H. C., & Ho, C. (1986). Development of Stroop interference in Chinese-English bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *12*(3), 397-401.

Chengappa, S., Daniel, K. E. & Bhat, S. (2004). Language mixing and switching in Malayalam - English bilingual aphasics. *Asia-Pacific Disability Rehabilitation Journal, 15*, 2, 68-76.

Chertkow, H., Whitehead, V., Phillips, N., Wolfson, C., Atherton, J., & Bergman, H. (2010). Multilingualism (but not always bilingualism) delays the onset of Alzheimer disease: evidence from a bilingual community. *Alzheimer Disease & Associated Disorders*, *24*(2), 118-125.

Coderre, E. L., & van Heuven, W. J. (2014). The effect of script similarity on executive control in bilinguals. *Frontiers in psychology*, *5*, 1-16.

Cohen, J. (1988). Set correlation and contingency tables. *Applied Psychological Measurement*, *12*(4), 425-434.

Colcombe, S. J., Kramer, A. F., Erickson, K. I., & Scalf, P. (2005). The implications of cortical recruitment and brain morphology for individual differences in inhibitory function in aging humans. *Psychology and aging*, *20*(3), 363.

Colomé, A. (2001). Lexical activation in bilingual speakers' speech production: Language-specific or language-independent? *Journal of Memory and Language, 45*, 721-736.

Colomé, A., & Miozzo, M. (2010). Which words are activated during bilingual word production*? Journal of Experimental Psychology: Learning, Memory and Cognition*, *36(1),* 96-109.

Costa, A., & Caramazza, A. (1999). Is lexical selection in bilingual speech production language-specific? Further evidence from Spanish-English and English-Spanish bilingual speakers. *Bilingualism: Language and Cognition*, *2*, 231-244.

Costa, A., Caramazza, A., & Sebastián-Gallés, N. (2000). The cognate facilitation effect: Implications for models of lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*, 1283-1296.

Costa, A., Colomé, À., & Caramazza, A. (2000). Lexical access in speech production: The bilingual case. *Psicológica*, *21*(2), 403-437.

Costa, A., Colomé, A., & Gómez, O., & Sebastián-Gallés, N. (2003). Another look at cross-language competition in bilingual speech production: Lexical and phonological factors. *Bilingualism: Language and Cognition, 6,* 167-179.

Costa, A., Hernández, M., Costa–Faidella, J., & Sebastián–Gallés, N. (2009). On the bilingual advantage in conflict processing: Now you see it, now you don’t. *Cognition*, *113,* 135–149.

Costa, A., Hernández, M., & Sebastián-Gallés, N. (2008). Bilingualism aids conflict resolution: Evidence from the ANT task. *Cognition*, *106*(1), 59-86.

Costa, A., La Heij, W., & Navarrete, E. (2006). The dynamics of bilingual lexical access. *Bilingualism: Language and Cognition, 9,* 137-151.

Costa, A., Miozzo, M., & Caramazza, A. (1999). Lexical selection in bilingual speakers: Do words in the bilingual's two lexicons compete for selection? *Journal of Memory and Language, 41*, 365-397.

Costa, A., Roelstraete, B., & Hartsuiker, R. J. (2006). The lexical bias effect in bilingual speech production: Evidence for feedback between lexical and sublexical levels across languages. *Psychonomic Bulletin & Review*, *13*(6), 972-977.

Costa, A., & Santesteban, M. (2004). Lexical access in bilingual speech production: Evidence from language switching in highly proficient bilingual speakers and L2 learners. *Journal of Memory and Language*, *50,* 491-511.

Costa, A., Santesteban, M. & Ivanova, I. (2006). How do highly proficient bilinguals control their lexicalization process? Inhibitory and language-specific selection mechanisms are both functional. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32,* 1057–1074.

Craik, F. I., & Bialystok, E. (2006). Cognition through the lifespan: mechanisms of change. *Trends in cognitive sciences*, *10*(3), 131-138.

Craik, F. I., & Salthouse, T. A. (Eds.). (2011). *The handbook of aging and cognition*. Psychology Press.

Crinion, J., Turner, R., Grogan, A., Hanakawa, T., Noppeney, U., Devlin, J. T., ... & Price, C. J. (2006). Language control in the bilingual brain. *Science*, *312*(5779), 1537-1540.

Crinion, J., Turner, R., Grogan, A., Hanakawa, T., Noppeney, U., Devlin, J. T.,… Price C. J. (2006). Language control in the bilingual brain. *Science, 312,* 1537–1540.

Croft, S., Marshall, J., Pring, T. & Hardwick, M. (2011). Therapy for naming difficulties in bilingual aphasia: which language benefits? *International journal of communication disorders*, *46,* 1, 48 – 62.

Crowther, J. E., & Martin, R. C. (2014). Lexical selection in the semantically blocked cyclic naming task: the role of cognitive control and learning. *Frontiers in human neuroscience*, *8*.

Dabul B. *Apraxia Battery for Adults*, Second ed. Austin, Tx: Pro-Ed;, 2000.

Damian, M. F. (2003). Articulatory duration in single word speech production. *Journal of experimental Psychology: Learning, Memory, and Cognition, 29,* 416-431.

Damian, M. F., & Als, L. C. (2005). Long-lasting semantic context effects in the spoken production of object names. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*(6), 1372.

Damian, M. F., & Bowers, J. S. (2003). Locus of semantic interference in picture-word interference tasks. *Psychonomic Bulletin & Review*, *10*(1), 111-117.

Damian, M. F., & Martin, R. C. (1999). Semantic and phonological codes interact in single word production. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*(2), 1-18.

Damian, M. F., Vigliocco, G., & Levelt, W. J. (2001). Effects of semantic context in the naming of pictures and words. *Cognition*, *81*(3), B77-B86.

Davis, E. T., Fujawa, G., & Shikano, T. (2002). Perceptual Processing and Search Efficiency of Young and Older Adults in a Simple-Feature Search Task A Staircase Approach. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *57*(4), P324-P337.

De Groot, A. M. (2011). *Language and cognition in bilinguals and multilinguals: An introduction*. Psychology Press.

De Groot, A., Borgwaldt, S., Bos, M., & van den Eijnden, E. (2002). Lexical decision and word naming in bilinguals: Language effects and task effects. *Journal of Memory and Language*, *47*(1), 91-124.

De Groot, A. M., Dannenburg, L., & van Hell, J. G. (1994). Forward and backward word translation by bilinguals. *Journal of memory and language*, *33*(5), 600-629.

De Groot, A., & Kroll, J. (1997). *Tutorials in bilingualism: psycholinguistic perspectives*. New York: Lawrence Erlbaum Associates.

De Renzi, E., & Nichelli, P. (1975). Verbal and non-verbal short-term memory impairment following hemispheric damage. *Cortex*, *11*, 341-354.

de Zubicaray, G. I., McMahon, K. L., Eastburn, M. M., & Wilson, S. J. (2002). Orthographic/phonological facilitation of naming responses in the picture–word task: An event-related fMRI study using overt vocal responding. *Neuroimage*, *16*(4), 1084-1093.

de Zubicaray, G., McMahon, K., Eastburn, M., & Pringle, A. (2006). Top-down influences on lexical selection during spoken word production: A 4T fMRI investigation of refractory effects in picture naming. *Human brain mapping*, *27*(11), 864-873.

Dell, G. S. (1986). A spreading-activation theory of retrieval in sentence production. *Psychological review*, *93*(3), 283.

Dell, G. S., Oppenheim, G. M., & Kittredge, A. K. (2008). Saying the right word at the right time: Syntagmatic and paradigmatic interference in sentence production. *Language and cognitive processes*, *23*(4), 583-608.

Dempster, F. N. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental review*, *12*(1), 45-75.

Dijkstra, T., & Van Heuven, W. J. (1998). The BIA model and bilingual word recognition. *Localist connectionist approaches to human cognition*, 189-225.

Douglas, J.M. (2010). Relation of executive functioning to pragmatic outcome following severe traumatic brain injury. *Journal of Speech, Language, and Hearing Research, 53*, 365-382.

Drewe, E. A. (1975). Go-no go learning after frontal lobe lesions in humans. *Cortex*, *11*(1), 8-16.

Duyck, W., Van Assche, E., Drieghe, D., Hartsuiker, R.J. (2007). Visual word recognitions by bilinguals in a sentence context: Evidence for nonselective access. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33,* 663–679.

Elsinger, P., J., Zappalà, G., Chakara, F., & Barrett, A. M. (2011). Cognitive Impairments After TBI. In : Zasler N. D., Katz, D. I., Zafonte, R. D. (Eds.). *Brain Injury medicine: Principles and Practice*. New York: Demos Medical Publishing.

Emmorey, K., Luk, G., Pyers, J. E., & Bialystok, E. (2008). The source of enhanced cognitive control in bilinguals evidence from bimodal bilinguals. *Psychological Science*, *19*(12), 1201-1206.

Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. *Psychology of learning and motivation*, *44*, 145-200.

Eriksen, B. A. & Eriksen, C. W. (1974). Effects of noise letters upon identification of a target letter in a non- search task. *Perception and Psychophysics. 16*, 143–149.

Fabbro, F. (1999). *The neurolinguistics of bilingualism: An introduction*. Hove, UK: Psychology Press.

Fabbro, F. (2000). The bilingual brain: Bilingual aphasia. *Brain and Language, 79*, 201–210.

Fabbro, F. (2001). The bilingual brain: Cerebral representation of languages. *Brain and Language, 79,* 211–222.

Fabbro, F., & Paradis, M. (1995). Differential impairments in four multilingual patients with subcortical lesions. In M. Paradis (Ed.), *Aspects of bilingual aphasia* (pp. 139–176). Oxford, UK: Pergamon.

Fabbro, F., Skrap, M., & Aglioti, S. (2000). Pathological switching between languages after frontal lesions in a bilingual patient. *Journal of Neurology, Neurosurgery, and Psychiatry, 68,* 650–652.

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (2001). Changes of error related ERPs with age. *Experimental Brain Research, 138,* 258–262.

Fan, J., Flombaum, J. I., McCandliss, B. D., Thomas, K. M., & Posner, M. I. (2003). Cognitive and brain consequences of conflict. *NeuroImage, 18(1),* 42-57.

Fernandez-Duque, D., & Black, S. E. (2006). Attentional networks in normal aging and Alzheimer’s disease. *Neuropsychology, 20,* 133–143.

Finkbeiner, M., Almeida, J., Janssen, N., & Caramazza, A. (2006). Asymmetrical costs of language switching: Is this evidence of language suppression? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32,* 1075-1089.

Finkbeiner, M., & Caramazza, A. (2006). Now you see it, now you don't: On turning semantic interference into facilitation in a Stroop-like task. *Cortex*, *42*(6), 790-796.

Finkbeiner, M., Gollan, T. H., & Caramazza, A. (2006). Lexical access in bilingual speakers: What's the (hard) problem? *Bilingualism: Language and Cognition, 9,* 153-166.

Francis, W. S. (1999). Cognitive integration of language and memory in bilinguals: semantic representation. *Psychological bulletin*, *125*(2), 193 – 222.

Freedman, M., Martin, R.C., & Beigler, K. (2004). Semantic relatedness effects in conjoined noun phrase production: Implications for the role of short-term memory. *Cognitive Neuropsychology, 21,* 245-265.

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: a latent-variable analysis. *Journal of experimental psychology: General*, *133*(1), 101-135.

Garbin, G., Costa, A., Sanjuan, A., Forn, C., Rodriguez-Pujadas, A., Ventura, N., ... & Avila, C. (2011). Neural bases of language switching in high and early proficient bilinguals. *Brain and language*, *119*(3), 129-135.

Garbin, G., Sanjuan, A., Forn, C., Bustamante, J. C., Rodriguez-Pujadas, A., Belloch, V., ... & Ávila, C. (2010). Bridging language and attention: Brain basis of the impact of bilingualism on cognitive control. *NeuroImage, 53*(4), 1272-1278.

Gasquoine, P. G., Croyle, K. L., Cavazos-Gonzalez, C., & Sandoval, O. (2007). Language of administration and neuropsychological test performance in neurologically intact Hispanic American bilingual adults. *Archives of Clinical Neuropsychology, 22*(8), 991-1001.

Gold, B. T., Kim, C., Johnson, N. F., Kryscio, R. J., & Smith, C. D. (2013). Lifelong bilingualism maintains neural efficiency for cognitive control in aging. *The Journal of Neuroscience*, *33*(2), 387-396.

Gollan, T. H., & Acenas, L. A. R. (2004). What is a TOT? Cognate and translation effects on tip-of-the-tongue states in Spanish-English and tagalog-English bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *30*(1), 246.

Gollan, T. H., Fennema-Notestine, C., Montoya, R. I., & Jernigan, T. L. (2007). The bilingual effect on Boston Naming Test performance. *Journal of the International Neuropsychological Society*, *13*(02), 197-208.

Gollan, T. H., Montoya, R. I., & Bonanni, M. P. (2005). Proper names get stuck on bilingual and monolingual speakers' tip of the tongue equally often. *Neuropsychology, 19*(3), 278.

Gollan, T. H., Montoya, R. I., Cera, C., & Sandoval, T. C. (2008). More use almost always means a smaller frequency effect: Aging, bilingualism, and the weaker links hypothesis. *Journal of Memory and Language*, *58*(3), 787-814.

Gollan, T. H., Montoya, R. I., Fennema-Notestine, C., & Morris, S. K. (2005). Bilingualism affects picture naming but not picture classification. *Memory & Cognition*, *33*(7), 1220-1234.

Gollan, T. H., Montoya, R. I., & Werner, G. A. (2002). Semantic and letter fluency in Spanish-English bilinguals. *Neuropsychology*, *16*(4), 562.

Gollan, T. H., & Silverberg, N. B. (2001). Tip-of-the-tongue states in Hebrew–English bilinguals. *Bilingualism: language and cognition*, *4*(01), 63-83.

Goral, G., Levy, E., & Kastl, R., (2009) Cross-language treatment generalization: a case of trilingual aphasia. *Brain and Language, 103*, 1-18

Goral, M., Levy, E. S., & Kastl, R. (2010). Cross-language treatment generalisation: A case of trilingual aphasia. *Aphasiology*, *24*(2), 170-187.

Goral, M., Levy, E. S., Obler, L. K., Cohen, E. (2006). Lexical connections in the multilingual lexicon. *Brain and Language*, *98*, 235–247.

Gotts, S., della Rocchetta, A. I., & Cipolotti, L. (2002). Mechanisms underlying perseveration in aphasia: evidence from a single case study. *Neuropsychologia, 40,* 1930-1947.

Grahn, J.A., Parkinson, J.A., & Owen, A.M. (2008). The cognitive functions of the caudate nucleus. *Progress in neurobiology, 86,* 141-155.

Green, D. W. (1986). Control, activation and resource. *Brain and Language, 27,* 210-223.

Green, D. W. (1993). Towards a model of L2 comprehension and production. In R. Schreuder & B. Weltens (Eds.), *The bilingual lexicon* (pp. 249-277). Amsterdam/Philadelphia: John Benjamins.

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

Green, D. W. (2005). The neurocognition of recovery patterns in bilingual aphasics. In J. F. Kroll & A. M. B. de Groot (Eds.), *Handbook of bilingualism: psycholinguistic approaches* (pp. 516–530). Oxford, UK: Oxford University Press.

Green, D. W. (2008). Bilingual aphasia: Adapted language networks and their control. *Annual Review of Applied Linguistics, 28,* 1–23.

Green, D. W., Grogan, A., Crinion, J., Ali, N., Sutton, C., & Price, C. (2010). Language control and parallel recovery of language in individuals with aphasia. *Aphasiology, 24*, 2, 188-209.

Green, D. W., & Price, C. J. (2001). Functional imaging in the study of recovery patterns in bilingual aphasics. *Bilingualism: Language and Cognition, 4,* 191–201.

Green, D. W., Ruffle, L., Grogan, A., Ali, N., Ramsden, S., Schofield, T.,…Price, C. J. (2011). Parallel recovery in a trilingual speaker: the use of the Bilingual Aphasia Test as a diagnostic complement to the Comprehensive Aphasia Test. *Clinical linguistics and phonetics, 25,* 6-7, 449-512.

Grosjean, F. (1988). Exploring the recognition of guest words in bilingual speech. Language and Cognitive Processes, 3, 233–274.

Grosjean, F. (1997). The bilingual individual. *Interpreting*, *2*(1-2), 163-187.

Grosjean, F. (1998). Studying bilinguals: Methodological and conceptual issues. *Bilingualism: Language and Cognition, 1,* 131-149.

Grosjean, F. (2001). The bilingual's language modes. In J. L. Nicol (Ed.), *One Mind, two languages: Bilingual language processing* (p. 49-71). Cambridge, MA: Blackwell Publishers.

Grosjean, F. (2010). *Bilingual: life and reality*. Oxford: Oxford University Press

Guerreiro, M. J., Murphy, D. R., & Van Gerven, P. W. (2010). The role of sensory modality in age-related distraction: a critical review and a renewed view. *Psychological bulletin*, *136*(6), 975.

Guo, T., Liu, H., Misra, M., & Kroll, J. F. (2011). Local and global inhibition in bilingual word production: fMRI evidence from Chinese-English bilinguals. *NeuroImage, 56,* 2300-2309.

Hamilton, A.C., & Martin, R.C. (2005). Dissociations among tasks involving inhibition: A single case study. *Cognitive, Affective, and Behavioral Neuroscience, 5,* 1-13.

Hamilton, A. C., & Martin, R. C. (2007). Proactive interference in a semantic short-term memory deficit: Role of semantic and phonological relatedness. *Cortex*, *43*(1), 112-123.

Harnishfeger, K. K. (1995). The development of cognitive inhibition. *Interference and inhibition in cognition*, 175-204.

Hartley, A. A. (1993). Evidence for the selective preservation of spatial selective attention in old age. *Psychology and aging*, *8*(3), 371.

Hartman, M., & Hasher, L. (1991). Aging and suppression: memory for previously relevant information. *Psychology and aging*, *6*(4), 587.

Hasher, L., Lustig, C., Zacks, R.T. (2007). Inhibitory mechanisms and the control of attention. In: Conway, A.R.A., Jarrold, C., Kane, M.J., Miyake, A., Towse, J.N.

(Eds.), Variation in Working Memory. Oxford University Press, New York, NY, USA, pp. 227–249.

Hasher, L., Stoltzfus, E. R., Zacks, R. T., & Rypma, B. (1991). Age and inhibition. *Journal of experimental psychology: Learning, memory, and cognition*, *17*(1), 163.

Hedden, T. & Gabrieli, J. D. (2010) Shared and selective neural correlates of inhibition, facilitation, and shifting processes during executive control. *Neuroimage, 51(1)*, 421-431.

Helm-Estabrooks, N. (2001). Cognitive Linguistic Quick Test. Austin, TX: Pro-Ed.

Hermans, D. (2000). *Word production in a foreign language.* Unpublished doctoral dissertation, University of Nijmegen, Nijmegen, The Netherlands.

Hermans, D., Bongaerts, T., De Bot, K., & Schreuder, R. (1998). Producing words in a foreign language: Can speakers prevent interference from their first language? *Bilingualism: Language and Cognition, 1,* 213-229

Hernandez, M., Costa, A., Fuentes, L. J., Vivas, A. B., & Sebastian-Galles, N. (2010). The impact of bilingualism on the executive control and orienting networks of attention. *Bilingualism: Language and Cognition*, *13*(03), 315-325.

Hernández, M., Costa A., & Humphreys G. W. (2012). Escaping capture: Bilingualism modulates distraction from working memory. *Cognition. 122(1),* 37 - 50.

Hernandez, A. E., Dapretto, M., Mazziotta, J. & Bookheimer, S. (2001). Language switching and language representation in Spanish-English bilinguals: an fMRI study. *NeuroImage, 14,* 510–520.

Hernandez, A. E., & Kohnert, K. (1999). Aging and language switching in bilinguals. *Aging, Neuropsychology and Cognition, 6,* 2, 69–83.

Hernandez, A., Martinez, A., & Kohnert, K. (2000). In search of the language switch: An fMRI study of picture naming in Spanish-English bilinguals. *Brain and Language, 73*, 421–431.

Hervais-Adelman, A. G., Moser-Mercer, B., & Golestani, N. (2011). Executive control of language in the bilingual brain: integrating the evidence from neuroimaging to neuropsychology. *Frontiers in psychology*, *2*.

Hilchey, M. D. & Klein, R. M. (2011). Are there bilingual advantages on non-linguistic interference tasks? Implications for plasticity of executive control processes, *Psychonomic Bulletin & Review, 18*, 625- 658.

Hodgson, C., Schwartz, M. F., Brecher, A., & Rossi, N. (2003). Effects of relatedness, repetition, and rate: Further investigations of context-sensitive naming. *Brain and Language*, *87*(1), 31-32.

Homack, S., & Riccio, C. A. (2004). A meta-analysis of the sensitivity and specificity of the Stroop Color and Word Test with children. *Archives of Clinical Neuropsychology*, *19*(6), 725-743.

Hoshino, N. & Kroll, J. F. (2008). Cognate effects in picture naming: Does cross-language activation survive a change of script? *Cognition, 106,* 501–511.

Howard, D. & Patterson, K. (1992). *Pyramids and palm trees: a test of semantic access from pictures and words*. Bury St Edmunds, Suffolk: Thames Valley Test Company.

Howard, D., Nickels, L., Coltheart, M., & Cole-Virtue, J. (2006). Cumulative semantic inhibition in picture naming: experimental and computational studies. *Cognition, 100(3),* 464-482.

Humphrey A. D. & Valian V. V. (2012) *Multilingualism and cognitive control: Simon and Flanker task performance in monolingual and multilingual young adults*, in Paper Presented at the 53rd Annual Meeting of the Psychonomic Society (Minneapolis, MN).

Ide, J. S., & Li, C. S. (2011). A cerebellar thalamic cortical circuit for error-related cognitive control. *NeuroImage, 54,* 455464.

Ijalba, E., Obler, L. K., & Chengappa, S. (2004). Bilingual aphasia. In T. K. Bhatia & W. C. Ritchie (Eds.), *The handbook of bilingualism* (pp. 71-89). Malden, MA: Blackwell.

Indefrey, P., & Levelt, W. J. (2004). The spatial and temporal signatures of word production components. *Cognition*, *92*(1), 101-144.

Ivanova, I., & Costa, A. (2008). Does bilingualism hamper lexical access in speech production?. *Acta psychologica*, *127*(2), 277-288.

Jackson, G. M, Swainson, R., Cunnington, R., Jackson, S. R. (2001). ERP correlates of executive control during repeated language switching. *Bilingualism: Language and Cognition, 4,* 169–178.

Janssen, N., Schirm, W., Mahon, B. Z., & Caramazza, A. (2008). Semantic interference in a delayed naming task: evidence for the response exclusion hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(1), 249.

January, D., Trueswell, J. C., & Thompson-Schill, S. L. (2009). Co-localization of stroop and syntactic ambiguity resolution in Broca's area: implications for the neural basis of sentence processing. *Journal of Cognitive Neuroscience*, *21*(12), 2434-2444.

Jared, D., & Kroll, J. (2001). Do bilingual speakers activate phonological representations in one or both of their languages when naming words? *Journal of Memory & Language, 44,*

Jennings, J. M., Dagenbach, D., Engle, C. M., & Funke, L. J. (2007). Age-related changes and the attention network task: An examination of alerting, orienting, and executive function. *Aging, Neuropsychology, and Cognition, 14, 353–369.*

Kamijo, K., Hayashi, Y., Sakai, T., Yahiro, T., Tanaka, K., & Nishihira, Y. (2009). Acute effects of aerobic exercise on cognitive function in older adults. *Journals of*

Gerontology: Series B: Psychological Sciences and Social Sciences, 64, P356–P363.

Kan, I. P. & Thompson-Schill, S. L. (2004). Selection from perceptual and conceptual representations. *Cognitive, Affective, & Behavioral Neuroscience, 4,* 466-482.

Kane, M. J., & Engle, R. W. (2003). Working-memory capacity and the control of attention: the contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology: General*, *132*(1), 47.

Keil, K., & Kaszniak, A. W. (2002). Examining executive function in individuals with brain injury: A review. *Aphasiology*, *16*(3), 305-335.

Kerns, J. G., Cohen, J. D., MacDonald, A. W., Cho, R. Y., Stenger, V. A., & Carter, C. S. (2004). Anterior cingulate conflict monitoring and adjustments in control. *Science, 303*(5660), 1023-1026.

Kertesz, A. (2006). Western Aphasia Battery: Revised. San Antonio: PsychCorp.

Khng, K. H., & Lee, K. (2014). The Relationship between Stroop and Stop-Signal Measures of Inhibition in Adolescents: Influences from Variations in Context and Measure Estimation. *PloS one*, *9*(7), e101356.

Kim, J., & Davis, C. (2003). Task effects in masked cross-script translation and phonological priming. *Journal of Memory and Language*, *49*(4), 484-499.

Kim, J., & Davis, C. (2003). Task eVects in masked cross-script translation and phonological priming. *Journal of Memory and Language*, *49,* 484–499.

Kiran, S., & Lebel, K. (2007). Crosslinguistic semantic and translation priming in normal bilingual individuals and bilingual aphasia. *Clinical Linguistics & Phonetics, 21,* 277–303.

Kohnert, K. (2004). Cognitive and cognate-based treatments for bilingual aphasia: a case study. *Brain and Language, 91,* 294–302.

Kousaie, S., & Phillips, N. A. (2012). Ageing and bilingualism: Absence of a "bilingual advantage" in Stroop interference in a nonimmigrant sample. *The Quarterly Journal of Experimental Psychology*, *65*(2), 356-369.

Krikorian, R., Bartok, J., & Gay, N. (1994). Tower of London procedure: A standard method and developmental data. *Journal of Clinical and Experimental Neuropsychology*, *16,* 840 -850.

Kroliczak, G. & Frey, S.H. (2009). A Common Network in the Left Cerebral Hemisphere Represents Planning of Tool Use Pantomimes and Familiar Intransitive Gestures at the Hand-Independent Level, *Cerebral Cortex, 19(10),* 2396-410.

Kroll, J. F., Bobb, S. C., Misra, M. & Guo T. (2008). Language selection in bilingual speech: Evidence for inhibitory processes. *Acta Psychologica, 128,* 416–430.

Kroll, J. F., Bobb, S. & Wodniecka, Z. (2006). Language selectivity is the exception, not the rule: Arguments against a fixed locus of language selection in bilingual speech. *Bilingualism: Language and Cognition, 9,* 119–135

Kroll, J. F.& Curley, J. 1988. Lexical memory in novice bilinguals: The role of concepts in retrieving L2 words. In M. Gruneberg et al.(eds.), 389-95, *Practical aspects of memory,* Vol. 2. London: Wiley.

Kroll, J. F., & Stewart, E. (1994). Category interference in translation and picture naming: Evidence for asymmetric connections between bilingual memory representations. *Journal of Memory and Language, 33,* 149-174.

Kroll, J. F., Sumutka, B. M., & Schwartz, A. I. (2005). A cognitive view of the bilingual lexicon: Reading and speaking words in two languages. *International Journal of Bilingualism*, *9*(1), 27-48.

Kumar, A. (2007). *Western Aphasia Battery – Tamil Translation.* Unpublished test.

La Heij, W. L., Kuipers, J. R., & Starreveld, P. A. (2006). In defense of the lexical-competition account of picture-word interference: A comment on Finkbeiner and Caramazza (2006). *Cortex*, *42*(7), 1028-1031.

Lalor, E., & Kirsner, K. (2001). The representation of “false cognates” in the bilingual lexicon. *Psychonomic Bulletin & Review*, *8*(3), 552-559.

Lambon-Ralph, M.A., Sage, K., & Roberts, J. (2000). Classical Anomia: A neuropsychological perspective on speech production. *Neuropsychologia, 38,* 186-202.

Levelt, W. (1989). *Speaking: From intention to articulation*. Cambridge, MA: MIT Press.

Levelt, W. J. M. (2001). Spoken word production: a theory of lexical access. *Proceedings of the National Academy of Sciences, 98,* 23, 13464-13471.

Levelt, W. J., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and brain sciences*, *22*(01), 1-38.

Levy, B.J., McVeigh, N.D., Marful, A., & Anderson, M.C. (2007). Inhibiting your native language: The role of retrieval-induced forgetting during second language acquisition. *Psychological Science, 18,* 29-34.

Li, P. (1996). The temporal structure of spoken sentence comprehension in Chinese. *Perception and Psychophysics, 58,* 571–586.

Libben, M. R., & Titone, D. A. (2009). Bilingual lexical access in context: evidence from eye movements during reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*(2), 381.

Linck, J. A., Hoshino, N. & Kroll, J. F. (2008). Cross-language lexical processes and inhibitory control. *Mental Lexicon, 3,* 349–374.

Linck, J. A., Kroll, J. F., & Sunderman, G. (2009). Losing access to the native language while immersed in a second language: Evidence for the role of inhibition in second-language learning. *Psychological Science*, *20*(12), 1507-1515.

Liotti, M., Woldorff, M. G., Perez III, R., & Mayberg, H. S. (2000). An ERP study of the temporal course of the Stroop color-word interference effect. *Neuropsychologia*, *38*(5), 701-711.

Logan, G. D. (1994). On the ability to inhibit thought and action: A users' guide to the stop signal paradigm. In D. Dagenbach, & T. H. Carr (Eds.), *Inhibitory processes in attention, memory, and*

Lorenzen, B. & Murray, L. (2008). Bilingual aphasia: a theoretical and clinical review. *American Journal of Speech Language Pathology, 17*, 299-317.

Luk, G., Anderson, J. A., Craik, F. I., Grady, C., & Bialystok, E. (2010). Distinct neural correlates for two types of inhibition in bilinguals: Response inhibition versus interference suppression. *Brain and cognition*, *74*(3), 347-357.

Luk, G., De Sa, E., & Bialystok, E. (2011). Is there a relation between onset age of bilingualism and enhancement of cognitive control?. *Bilingualism: Language and Cognition*, *14*(04), 588-595.

Luk, G., Green, D.W., Abutalebi, J. & Grady, C. (2011). Cognitive control for language switching in bilinguals: A quantitative meta-analysis of functional neuroimaging studies. *Language and Cognitive Processes, 27,* 1479– 1488.

Machado, L., Devine, A., & Wyatt, N. (2009). Distractibility with advancing age and Parkinson's disease. *Neuropsychologia, 47,* 1756–1764.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109,* 163-203.

MacLeod, C. M. (2005). The Stroop task in cognitive research. In A. Wenzel & D. C. Rubin (Eds.), *Cognitive methods and their application to clinical research* (pp. 17-40). Washington, DC: American Psychological Association.

Madden, D. J., & Gottlob, L. R. (1997). Adult age differences in strategic and dynamic components of focusing visual attention. *Aging, Neuropsychology, and Cognition, 4,* 185–210.

Maess, B., Friederici, A. D., Damian, M., Meyer, A. S., & Levelt, W. J. M. (2002). Semantic category interference in overt picture naming: Sharpening current density localization by PCA. *Journal of Cognitive Neuroscience, 14(3),* 455-462.

Mägiste, E. (1985). Development of intra-and interlingual interference in bilinguals. *Journal of Psycholinguistic Research*, *14*(2), 137-154.

Mahon, B. Z., Costa, A., Peterson, R., Vargas, K. A., & Caramazza, A. (2007). Lexical selection is not by competition: a reinterpretation of semantic interference and facilitation effects in the picture-word interference paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*(3), 503.

Marangolo, P., Rizzi, C., Peran, P., Piras, F. & Sabatini, U. (2009). Parallel recovery in a bilingual aphasic: a neurolinguistic and fMRI study. *Neuropsychology, 23,* 405–409.

Marian, V., Blumenfeld, K. H., & Kaushanskaya, M. (2007). The Language Proficiency and Experience Questionnaire (LEAP-Q): Assessing language profiles in bilinguals and multilinguals. *Journal of Speech, Language, and Hearing, 50,* 940–967.

Marí-Beffa, P., Hayes, A. E., Machado, L., & Hindle, J. V. (2005). Lack of inhibition in Parkinson's disease: evidence from a lexical decision task. *Neuropsychologia*, *43*(4), 638-646.

Mariën P., Abutalebi, S., Engelborghs S., & De Deyn P. P. (2005). Pathophysiology of language switching and mixing in an early bilingual child with subcortical aphasia. *Neurocase, 11*, 6, 385–398.

Martin-Rhee, M. M., & Bialystok, E. (2008). The development of two types of inhibitory control in monolingual and bilingual children. *Bilingualism: Language and Cognition*, *11*(01), 81-93.

Maruff, P., Thomas, E., Cysique, L., Brew, B., Collie, A., Snyder, P., & Pietrzak, R. H. (2009). Validity of the CogState brief battery: relationship to standardized tests and sensitivity to cognitive impairment in mild traumatic brain injury, schizophrenia, and AIDS dementia complex. *Archives of Clinical Neuropsychology*, *24*(2), 165-178.

Mathewson, K. J., Dywan, J., & Segalowitz, S. J. (2005). Brain bases of error-related ERPs as influenced by age and task. *Biological Psychology, 70,* 88–104.

May, C. P., Hasher, L., & Kane, M. J. (1999). The role of interference in memory span. *Memory and Cognition, 27,* 759-767.

May, C. P., Hasher, L., & Stoltzfus, E. R. (1993). Optimal time of day and the magnitude of age differences in memory. *Psychological Science*, *4*(5), 326-330.

McCann, C., Lee, T., Purdy, S. C., & Paulin, A. K. (2012). The use of the Bilingual Aphasia Test with a bilingual Mandarin–New Zealand English speaker with aphasia. *Journal of Neurolinguistics*, *25*(6), 579-587.

McCarthy, R. A., & Kartsounis, L. D. (2000). Wobbly words: Refractory anomia with preserved semantics. *Neurocase, 6,* 487–497.

McClelland, J. L., & Rumelhart, D. E. (1988). *Explorations in parallel distributed processing: A handbook of models, programs, and exercises.* Cambridge, MA: MIT Press.

McDowd, J. M., Oseas-Kreger, D. M., & Filion, D. L. (1995). Inhibitory processes in cognition and aging. In: Dempster, F.N., Brainerd, C.J. (Eds.), *Interference and inhibition in cognition*, Academic Press, San Diego, CA, USA, pp. 363-400.

Melcher, T., & Gruber, O. (2009). Decomposing interference during Stroop performance into different conflict factors: An event-related fMRI study. *Cortex, 45*, 189–200.

Meuter, R. F. I., & Allport, A. (1999). Bilingual language switching in naming: Asymmetrical costs of language selection. *Journal of Memory and Language, 40*, 25-40.

Meyer, A. S., & Schriefers, H. (1991). Phonological facilitation in picture-word interference experiments: Effects of stimulus onset asynchrony and types of interfering stimuli. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*(6), 1146.

Mezzacappa E. (2004). Alerting, orienting, and executive attention: Developmental properties and socio-demographic correlates in an epidemiological sample of young, urban children. *Child Development, 75*, 1-14.

Michael, E. B. & Gollan, T. H. (2005). Being and becoming bilingual: Individual differences and consequences for language production. In Kroll & de Groot (eds.), *Handbook of bilingualism*. Oxford. pp. 389–407.

Milham, M. P., Banich, M. T., & Barad, V. (2003). Competition for priority in processing increases prefrontal cortex's involvement in top-down control: an event-related fMRI study of the Stroop task. *Cognitive brain research*, *17*(2), 212-222.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual review of neuroscience*, *24*(1), 167-202.

Miozzo, M., & Caramazza, A. (2003). When more is less: a counterintuitive effect of distractor frequency in the picture-word interference paradigm. *Journal of Experimental Psychology: General*, *132*(2), 228.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive psychology*, *41*(1), 49-100.

Mohamed Zied, K., Phillipe, A., Karine, P., Valerie, H. T., Ghislaine, A., Arnaud, R., & Gall Didier, L. (2004). Bilingualism and adult differences in inhibitory mechanisms: Evidence from a bilingual Stroop task. *Brain and cognition*, *54*(3), 254-256.

Munakata, Y., Herd, S. A., Chatham, C. H., Depue, B. E., Banich, M. T., & O'Reilly, R. C. (2011). A unified framework for inhibitory control. *Trends in cognitive sciences, 15*(10), 453-459.

Munoz, D. P., & Everling, S. (2004). Look away: the anti-saccade task and the voluntary control of eye movement. *Nature Reviews Neuroscience*, *5*(3), 218-228.

Nieuwenhuis, S., Ridderinkhof, K. R., Talsma, D., Coles, M. G. H., Holroyd, C. B., Kok, A., & Van der Molen, M. W. (2002). A computational account of altered error processing in older age: Dopamine and the error-related negativity. *Cognitive, Affective, & Behavioral Neuroscience, 2,* 19–36.

Norman, D. A., & Shallice, T. (1986). *Attention to action* (pp. 1-18). Springer US.

Novick, J. M., Kan, I. P., Trueswell, J. C., & Thompson-Schill, S. L. (2009). A case for conflict across multiple domains: Memory and language impairments following damage to ventrolateral prefrontal cortex. *Cognitive Neuropsychology*, *26*(6), 527-567.

Novick, J.M., Trueswell, J.C., and Thompson-Schill, S.L. (2005). Cognitive control and parsing: Re-examining the role of Broca's area in sentence comprehension. *Journal of Cognitive, Affective, and Behavioral Neuroscience, 5(3),* 263-281.

Novick, J. M., Trueswell, J. C., & Thompson-Schill, S. L. (2010). Broca's area and language processing: Evidence for the cognitive control connection. *Language and Linguistics Compass*, *4*(10), 906-924.

Nusbaum, H. C., Pisoni, D. B., & Davis, C. K. (1984). *Sizing up the Hoosier mental lexicon: Measuring the familiarity of 20,000 words* (Research on Speech Perception Progress Report No. 10). Bloomington: Indiana University, Psychology Department, Speech Research Laboratory.

Oppenheim, G. M., Dell, G. S., & Schwartz, M. F. (2007). Cumulative semantic interference as learning. *Brain and Language*, *103*(1), 175-176.

Oppenheim, G. M., Dell, G. S., & Schwartz, M. F. (2010). The dark side of incremental learning: A model of cumulative semantic interference during lexical access in speech production. *Cognition*, *114*(2), 227-252.

Paap, K. R., & Greenberg, Z. I. (2013). There is no coherent evidence for a bilingual advantage in executive processing. *Cognitive psychology*, *66*(2), 232-258.

Paradis, M. (1977) Bilingualism and Aphasia. In H. Whitaker and H.A. Whitaker (Eds.), *Studies in Neurolinguistics*, vol.3, New York: Academic Press. 65-121.

Paradis, M. (1987). *The assessment of bilingual aphasia*. Hillsdale, NJ: Erlbaum.

Paradis, M. (1995). Bilingual aphasia: 100 years later: Consensus and controversies. In M. Paradis (Ed.), *Aspects of bilingual aphasia* (pp. 211–223). Oxford: Pergamon Press.

Paradis, M. (1998). Language and communication in multilinguals. In B. Stemmer & H. Whitaker (Eds.), *Handbook of neurolinguistics* (pp. 417–430). San Diego, CA: Academic Press.

Paradis, M. (2001). Bilingual and polyglot aphasia. In R. S. Berndt (Ed.), *Handbook of neuropsychology: Vol. 3, Language and aphasia* (2nd ed., pp. 69–91). Amsterdam: Elsevier Science.

Paradis, M. (2004). *A neurolinguistic theory of bilingualism*. Amsterdam/Philadelphia: John Benjamins Publishing Company.

Paradis, M., Goldblum, M. C., & Abidi, R. (1982). Alternate antagonism with paradoxical translation behavior in two bilingual aphasic patients. *Brain and Language*, *15*, 55–69.

Penn, C., Frankel, T., Watermeyer, J., & Russell, N. (2010). Executive function and conversational strategies in bilingual aphasia. *Aphasiology, 24(2)*, 288-308

Percival, P. (2000). *English-Tamil dictionary*. Asian Educational Services, India.

Perquin, M., Vaillant, M., Schuller, A. M., Pastore, J., Dartigues, J. F., Lair, M. L., ... & MemoVie Group. (2013). Lifelong exposure to multilingualism: new evidence to support cognitive reserve hypothesis. *PloS one*, *8*(4), e62030.

Peterson, B. S., Kane, M. J., Alexander, G. M., Lacadie, C., Skudlarski, P., Leung, H. C., ... & Gore, J. C. (2002). An event-related functional MRI study comparing interference effects in the Simon and Stroop tasks. *Cognitive Brain Research*, *13*(3), 427-440.

Piai, V., Roelofs, A., Acheson, D. J., & Takashima, A. (2013). Attention for speaking: domain-general control from the anterior cingulate cortex in spoken word production. *Frontiers in human neuroscience*, *7*, 1-14.

Piai, V., Roelofs, A., & van der Meij, R. (2012). Event-related potentials and oscillatory brain responses associated with semantic and Stroop-like interference effects in overt naming. *Brain research*, *1450*, 87-101.

Pickard, J., Brandon, M., Hodgson, C., Schwartz, M., & Thompson-Schill, S. (2003, March). *Facilitating and interfering effects of context on picture naming*. Poster presented at the 10th Annual Meeting of the Cognitive Neuroscience Society, New York.

Picton, T. W., Stuss, D. T., Alexander, M. P., Shallice, T., Binns, M. A., & Gillingham, S. (2007). Effects of focal frontal lesions on response inhibition. *Cerebral Cortex*, *17*(4), 826-838.

Pisoni, A., Papagno, C., & Cattaneo, Z. (2012). Neural correlates of the semantic interference effect: New evidence from transcranial direct current stimulation. *Neuroscience*, *223*, 56-67.

Poarch, G. J., & van Hell, J. G. (2012). Executive functions and inhibitory control in multilingual children: Evidence from second-language learners, bilinguals, and trilinguals. *Journal of experimental child psychology*, *113*(4), 535-551.

Pompon, R. H. (2013). *Examining inhibition during spoken word production in aphasia* (Doctoral dissertation, University of Washington).

Portocarrero, J. S., Burright, R. G., & Donovick, P. J. (2007). Vocabulary and verbal fluency of bilingual and monolingual college students. *Archives of Clinical Neuropsychology, 22*(3), 415-422.

Potter, M.C., So, K.-F., Von Eckardt, B. & Feldman, L.B. (1984) Lexical and conceptual representation in beginning and more proficient bilinguals. *Journal of Verbal Learning and Verbal Behavior, 23,* 23-38.

Poulisse, N. (1999). *Slips of the tongue: Speech errors in first and second language production.* Amsterdam, Philadelphia: John Benjamins.

Poulisse, N., & Bongaerts, T. (1994). First language use in second language production. *Applied Linguistics, 15,* 36–57.

Prather, P., Zurif, E., Stern, C., & Rosen, T. J. (1992). Slowed lexical access in nonfluent aphasia: A case study. *Brain and Language, 43*(2), 336-348.

Preston, M. S., & Lambert, W. E. (1969). Interlingual interference in a bilingual version of the Stroop color-word task. *Journal of Verbal Learning and Verbal Behavior, 8*(2), 295-301.

Price, C. J., Green, D. W. & Von Studnitz, R. (1999). A functional imaging study of translation and language switching. *Brain, 122,* 2221–2235.

Prior, A., & MacWhinney, B. (2010). Beyond inhibition: a bilingual advantage in task switching. *Bilingualism: Language and cognition, 13,* 253-262.

Purdy, M. (2002). Executive function ability in persons with aphasia. *Aphasiology, 16*(4-6), 549-557.

Purmann, S., & Pollmann, S. (2015). Adaptation to recent conflict in the classical color-word Stroop-task mainly involves facilitation of processing of task-relevant information. *Frontiers in human neuroscience*, *9,* 88, 1-11.

Rahman, R. A., & Melinger, A. (2007). When bees hamper the production of honey: lexical interference from associates in speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*(3), 604.

Ridderinkhof, K. R., van der Molen, M. W., Band, G. P., & Bashore, T. R. (1997). Sources of interference from irrelevant information: A developmental study. *Journal of experimental child psychology*, *65*(3), 315-341.

Robbins, T. W. (2007). Shifting and stopping: fronto-striatal substrates, neurochemical modulation and clinical implications. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *362*(1481), 917-932.

Roberts, P., & Deslauriers, L. (1999). Picture naming of cognate and non-cognate nouns in bilingual aphasia. *Journal of Communication Disorders, 32,* 1–23.

Robinson, G., Shallice, T., & Cipolotti, L. (2005). A failure of high level verbal response selection in progressive dynamic aphasia. *Cognitive Neuropsychology*, *22*(6), 661-694.

Rodriguez-Fornells, A., Van Der Lugt, A., Rotte, M., Britti, B., Heinze, H. J., & Münte, T. F. (2005). Second language interferes with word production in fluent bilinguals: brain potential and functional imaging evidence. *Journal of Cognitive Neuroscience*, *17*(3), 422-433.

Roelofs, A. (1992). A spreading-activation theory of lemma retrieval in speaking. *Cognition*, *42*(1), 107-142.

Roelofs, A. (2003). Shared phonological encoding processes and representations of languages in bilingual speakers. *Language and Cognitive Processes*, *18*(2), 175-204.

Roelofs, A. (1998). Lemma selection without inhibition of languages in bilingual speakers. *Bilingualism: language and cognition, 1*, 94–95.

Roelofs, A., Piai, V., & Rodriguez, G. G. (2011). Attentional inhibition in bilingual naming performance: evidence from delta-plot analyses. *Frontiers in psychology*, *2*, 1-10.

Rosselli, M., Ardila, A., Santisi, M. N., Arecco, M. D. R., Salvatierra, J., & Conde, A. (2002). Stroop effect in Spanish–English bilinguals. *Journal of the International Neuropsychological Society*, *8*(06), 819-827.

Rueda, M. R., Fan, J., McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., & Posner, M. I. (2004). Development of attentional networks in childhood. *Neuropsychologia*, *42*(8), 1029-1040.

Runnqvist, E., Strijkers, K., Alario, F., & Costa, A. (2012). Cumulative semantic interference is blind to language: Implications for models of bilingual speech production. *Journal of Memory and Language*, *66*(4), 850-869.

Rush, B. K., Barch, D. M., & Braver, T. S. (2006). Accounting for cognitive aging: context processing, inhibition or processing speed?. *Aging, Neuropsychology, and Cognition*, *13*(3-4), 588-610.

Ryskin, R. A. (2012). *Does bilingualism confer perspective-taking advantages in language use?* Unpublished Doctoral dissertation, University of Illinois at Urbana-Champaign.

Salthouse, T. A., & Meinz, E. J. (1995). Aging, inhibition, working memory, and speed. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *50*(6), P297-P306.

Schnur, T. T. (2014). The persistence of cumulative semantic interference during naming. *Journal of Memory and Language*, *75*, 27-44.

Schnur, T.T., Lee, E., Coslett, H.B., Schwartz, M.F., & Thompson-Schill, S.L. (2005). When lexical selection gets tough, the LIFG gets going: A lesion analysis study of interference during word production. *Brain and Language, 95 (1),* 12-13.

Schnur, T.T., Schwartz, M.F., Brecher, A., & Hodgson, C. (2006). Semantic interference during blocked-cyclic naming: Evidence from aphasia. *Journal of Memory and Language, 54 (2),* 199-227.

Schnur, T.T., Schwartz, M.F., Kimberg, D., Hirshorn, E., Coslett, H.B., & Thompson-Schill, S.L. (2009). Localizing interference during naming: Convergent neuroimaging and neuropsychological evidence for the function of Broca's area. *Proceedings of the National Academy of Sciences, 106 (1),* 322- 327.

Schriefers, H., Meyer, A. S., & Levelt, W. J. (1990). Exploring the time course of lexical access in language production: Picture-word interference studies. *Journal of memory and language*, *29*(1), 86-102.

Schwartz, A.I. & Kroll, J.F. (2006). Bilingual lexical activation in sentence context. *Journal of Memory and Language, 55,* 197–212.

Schwartz, M. F., & Hodgson, C. (2002). A new multiword naming deficit: Evidence and interpretation. *Cognitive Neuropsychology*, *19*(3), 263-288.

Schwieter, J. W. & Sunderman, G. (2008). Language switching in bilingual speech production: In search of the language-specific selection mechanism. *The Mental Lexicon, 3*, 2, 214-238.

Scott, R. M., & Wilshire, C. E. (2010). Lexical competition for production in a case of nonfluent aphasia: Converging evidence from four different tasks. *Cognitive neuropsychology*, *27*(6), 505-538.

Shallice, T., Burgess, P., & Robertson, I. (1996). The domain of supervisory processes and temporal organization of behaviour [and discussion]. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, *351*(1346), 1405-1412.

Shao, Z., Roelofs, A., & Meyer, A. S. (2012). Sources of individual differences in the speed of naming objects and actions: The contribution of executive control. *The Quarterly Journal of Experimental Psychology*, *65*(10), 1927-1944.

Shaw, R. J. (1991). Age-related increases in the effects of automatic semantic activation. *Psychology and Aging, 6,* 595–604.

Simon, J. R., & Rudell, A. P. (1967). Auditory SR compatibility: the effect of an irrelevant cue on information processing. *Journal of Applied Psychology*, *51*(3), 300 – 304

Singh, N., & Mishra, R. K. (2012). Does language proficiency modulate oculomotor control? Evidence from Hindi–English bilinguals. *Bilingualism: Language and Cognition*, *15*(04), 771-781.

Singh, N., & Mishra, R. K. (2013). Second language proficiency modulates conflict-monitoring in an oculomotor Stroop task: evidence from Hindi-English bilinguals. *Frontiers in psychology*, *4,* 322-332.

Sinopoli, K. J., & Dennis, M. (2012). Inhibitory control after traumatic brain injury in children. *International Journal of Developmental Neuroscience*, *30*(3), 207-215.

Sommer, T., Fossella, J., Fan, J., & Posner, M. I. (2003). Inhibitory control: cognitive subfunctions, individual differences and variation in dopaminergic genes. *The Cognitive Neuroscience of Individual Differences*, 27-44.

Spalek, K., & Thompson-Schill, S. L. (2008). Task-dependent semantic interference in language production: An fMRI study. *Brain and language*, *107*(3), 220-228.

Starreveld, P. A. (2000). On the interpretation of onsets of auditory context effects in word production. *Journal of Memory and Language*, *42*(4), 497-525.

Starreveld, P. A., & La Heij, W. (1995). Semantic interference, orthographic facilitation, and their interaction in naming tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*(3), 686.

Starreveld, P. A., & La Heij, W. (1996). Time-course analysis of semantic and orthographic context effects in picture naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*(4), 896.

Stins, J. F., Polderman, J. T., Boomsma, D. I., & de Geus, E. J. (2007). Conditional accuracy in response interference tasks: Evidence from the Eriksen flanker task and the spatial conflict task. *Advances in cognitive psychology*, *3*(3), 409.

Stocco, A., Yamasaki, B., Natalenko, R., & Prat, C. S. (2014). Bilingual brain training: A neurobiological framework of how bilingual experience improves executive function. *International Journal of Bilingualism*, *18*(1), 67-92.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*, 643–662.

Stuss, D. T. (2011). Functions of the frontal lobes: relation to executive functions. *Journal of the international neuropsychological Society*, *17*(05), 759-765.

Stuss, D. T., Gallup, G. G., & Alexander, M. P. (2001). The frontal lobes are necessary fortheory of mind'. *Brain*, *124*(2), 279-286.

Sumiya, H., & Healy, A. F. (2004). Phonology in the bilingual Stroop effect. *Memory & cognition*, *32*(5), 752-758.

Sung, J. E., Kim, J. H., Jeong, J. H., & Kang, H. (2012). Working memory capacity and its relation to stroop interference and facilitation effects in individuals with mild cognitive impairment. *American Journal of Speech-Language Pathology*, *21*(2), S166-S178.

Szekely, A., Jacobsen, T., D'Amico, S., Devescovi, A., Andonova, E., Herron, D.,…Bates, E. (2004). A new on-line resource for psycholinguistic studies. *Journal of Memory and Language, 51,* 247-250.

Teubner-Rhodes, Mishler, Corbett, Novick, Barrachina, Sanz-Torrent et al. (March 2012). *Poster presented at the twenty-fifth annual CUNY conference on human sentence processing.* New York, NY.

Thangarajan, R. & Natarajan, A. M. (2008). Syllable based continuous speech recognition for Tamil. *South Asian language review, 18,* 1, 2008.

Thompson-Schill, S.L., Aguirre, G.K., D'Esposito, M., and Farah, M.J. (1999). A neural basis for category and modality specificity of semantic knowledge. *Neuropsychologia, 37*, 671–676.

Thompson-Schill, S. L., D'Esposito, M., Aguirre, G. K., & Farah, M. J. (1997). Role of left inferior prefrontal cortex in retrieval of semantic knowledge: A reevaluation. *Proceedings of the National Academy of Sciences*, *94*(26), 14792-14797.

Thompson-Schill, S.L., & Gabrieli, J.D.E. (1999). Priming of visual and functional knowledge on a semantic classification task. *Journal of Experimental Psychology: Learning, Memory and Cognition. 25,* 41–53.

Thompson-Schill, S. L., Jonides, J., Marshuetz, C., Smith, E. E., D'Esposito, M., Kan, I. P., ... & Swick, D. (2002). Effects of frontal lobe damage on interference effects in working memory. *Cognitive, Affective, & Behavioral Neuroscience*, *2*(2), 109-120.

Thothathiri, M., Schwartz, M. F., & Thompson-Schill, S. L. (2010). Selection for position: The role of left ventrolateral prefrontal cortex in sequencing language. *Brain and language*, *113*(1), 28-38.

Tzelgov, J., Henik, A., & Leiser, D. (1990). Controlling Stroop interference: Evidence from a bilingual task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*(5), 760-771.

Unsworth, N., & Spillers, G. J. (2010). Working memory capacity: Attention control, secondary memory, or both? A direct test of the dual-component model. *Journal of Memory and Language*, *62*(4), 392-406.

van Hell, J. G., & de Groot, A. (1998). Conceptual representation in bilingual memory: Effects of concreteness and cognate status in word association. *Bilingualism: Language and Cognition*, *1*(03), 193-211.

van Hell, J. G. & de Groot, A. M. B. (2008). Sentence context affects lexical decision and word translation. *Acta Psychologica*, *128*, 431-451.

van Hell, J. G., & Dijkstra, A. (2002). Foreign language knowledge can influence native language performance in exclusively native contexts. *Psychonomic Bulletin and Review, 9,* 780-789.

van Hell, J. G., & Tanner, D. (2012). Second Language Proficiency and Cross-Language Lexical Activation. *Language Learning*, *62*(s2), 148-171.

van Heuven, W.J.B., Conklin, K., Coderre, E.L, Guo, T., & Dijkstra, T. (2011). The influence of cross-language similarity on within- and between-language Stroop effects in trilinguals. *Frontiers in Psychology, 2*, 1-15.

van Maanen, L., van Rijn, H., & Borst, J. P. (2009). Stroop and picture—word interference are two sides of the same coin. *Psychonomic Bulletin & Review*, *16*(6), 987-999.

van Veen, V., Cohen, J. D., Botvinick, M. M., Stenger, V. A., & Carter, C. S. (2001). Anterior cingulate cortex, conflict monitoring, and levels of processing. *Neuroimage*, *14*(6), 1302-1308.

Verbruggen, F., & Logan, G. D. (2009). Models of response inhibition in the stop-signal and stop-change paradigms. *Neuroscience & Biobehavioral Reviews*, *33*(5), 647-661.

Verhaeghen, P., & De Meersman, L. (1998). Aging and the Stroop effect: a meta-analysis. *Psychology and Aging*, *13*(1), 120.

Verreyt, N. (2013). *The underlying mechanism of selective and differential recovery in bilingual aphasia* (Doctoral dissertation, Ghent University).

Viera, A. J., & Garrett, J. M. (2005). Understanding interobserver agreement: the kappa statistic. *Fam Med*, *37*(5), 360-363.

Walraff, B. (2000). What global language? *The Atlantic Monthly, Vol. 286 (Nov.).* (pp. 52-66) Boston, MA: The Atlantic Monthly Group.

Walton, C. C., Shine, J. M., Mowszowski, L., Gilat, M., Hall, J. M., O'Callaghan, C., ... & Lewis, S. J. (2014). Impaired cognitive control in Parkinson's disease patients with freezing of gait in response to cognitive load. *Journal of Neural Transmission,* 1-8.

Wang, Y., Kuhl, P. K., Chen, C., & Dong, Q. (2009). Sustained and transient language control in the bilingual brain. *NeuroImage*, *47*(1), 414-422.

Wang, Y., Xue, G., Chen, C., Xue, F., & Dong, Q. (2007). Neural bases of asymmetric language switching in second-language learners: An ER-fMRI study. *NeuroImage*, *35*(2), 862-870.

Watamori, T. S. & Sasanuma, S. (1978). The recovery processes of two English-Japanese bilingual aphasics. *Brain and language, 6*, 2, 127-140.

Weir, C., Bruun, C., & Barber, T. (1997). Are backward words special for older adults?. *Psychology and aging*, *12*(1), 145.

West, R., & Alain, C. (2000). Age-related decline in inhibitory control contributes to the increased Stroop effect observed in older adults. *Psychophysiology*, *37*(2), 179-189.

West, R., & Baylis, G. C. (1998). Effects of increased response dominance and contextual disintegration on the Stroop interference effect in older adults. *Psychology and aging*, *13*(2), 206 -217.

Whitney, C., Grossman, M., & Kircher, T. T. J. (2009). The Influence of Multiple Primes on Bottom-up and Top-down Regulation during Meaning Retrieval: Evidence for Two Distinct Neural Networks. *Neuroimage*, *47,* S164.

Wiecki, T. V., & Frank, M. J. (2013). A computational model of inhibitory control in frontal cortex and basal ganglia. *Psychological review*, *120*(2), 329.

Wiener, D., Tabor Connor, L., & Obler, L. (2004). Inhibition and auditory comprehension in Wernicke's aphasia. *Aphasiology*, *18*(5-7), 599-609.

Wild-Wall, N., Falkenstein, M., & Hohnsbein, J. (2008). Flanker interference in young and older participants as reflected in event-related potentials. *Brain Research*, *1211*, 72–84.

Wilshire, C. E. (2008). Cognitive neuropsychological approaches to word production in aphasia: Beyond boxes and arrows. *Aphasiology*, *22*(10), 1019-1053.

Wilshire, C. E., & McCarthy, R. A. (2002). Evidence for a context-sensitive word retrieval disorder in a case of nonfluent aphasia. *Cognitive Neuropsychology*, *19*, 165–186.

Wiltshire, C. & Harnsberger, J. D. (2006). The influence of Gujarati and Tamil L1s on Indian English: A Preliminary Study. *World Englishes*, *25*, 91 – 104.

Wolf, D., Zschutschke, L., Scheurich, A., Schmitz, F., Lieb, K., Tüscher, O., & Fellgiebel, A. (2014). Age-related increases in stroop interference: Delineation of general slowing based on behavioral and white matter analyses. *Human brain mapping*, *35*(5), 2448-2458.

Xue, G., Aron, A. R., & Poldrack, R. A. (2008). Common neural substrates for inhibition of spoken and manual responses. *Cerebral Cortex*, *18*(8), 1923-1932.

Yang, S., & Lust, B. (2004, November). Testing effects of bilingualism on executive attention: comparison of cognitive performance on two non-verbal tests. In *Boston University Conference on Language Development* (pp. 5-7).

Yang, S., Yang, H., & Lust, B. (2011). Early childhood bilingualism leads to advances in executive attention: Dissociating culture and language. *Bilingualism: Language and Cognition*, *14*(03), 412-422.

Ye, Z., & Zhou, X. (2009). Conflict control during sentence comprehension: fMRI evidence. *Neuroimage*, *48*(1), 280-290.

Zacks, R., & Hasher, L. (1997). Cognitive gerontology and attentional inhibition: A reply to Burke and McDowd. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *52*(6), P274-P283.

Zelazo, P. D., Craik, F. I., & Booth, L. (2004). Executive function across the life span. *Acta psychologica*, *115*(2), 167-183.