

EXPLORATION OF CODE-SWITCHING AS A MECHANISM UNDERLYING EXECUTIVE
FUNCTION PERFORMANCE IN 8-YEAR-OLD ENGLISH-CHINESE BILINGUALS

A Dissertation

Presented to the Faculty of the Graduate School

Of Cornell University

In Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy

By

Pei Shan Carissa Kang

May 2017

© 2017 Pei Shan Carissa Kang

EXPLORATION OF CODE-SWITCHING AS A MECHANISM UNDERLYING EXECUTIVE FUNCTION PERFORMANCE IN 8-YEAR-OLD ENGLISH-CHINESE BILINGUALS

Pei Shan Carissa Kang, Ph. D.
Cornell University 2017

Previous studies of bilingual adults have suggested that bilinguals' experience with code-switching contributes to superior executive function (EF) abilities, although this claim is debated to this date. This thesis tested the hypothesis that the relationship between CS and EF may be a non-necessary one, especially in a homogeneous and highly bilingual population in Singapore where CS occurs pervasively. Accordingly, CS and EF measures were obtained from 43 English-Chinese 8-year-old children (27 females, $M = 8.33$ years). Spontaneous CS was measured with a novel task, and EF was measured in terms of verbal and non-verbal task-switching (e.g., Semantic Fluency, Hearts and Flowers) and verbal inhibitory control (e.g., Stroop task). Contrary to previous work with adults, children's CS performance did not significantly predict general EF performance. On the other hand, some aspects of bilingual language proficiency did predict EF performance. Chinese school exam scores predicted Semantic Fluency switch cost (higher Chinese scores, higher switch cost), while English school exam scores predicted English Stroop Interference (higher English scores, lower Stroop Interference). In addition, correlational analyses also showed that broad bilingual language proficiency (measured in terms of school exam Oral and Written components) did correlate with EF performance. For Semantic Fluency, higher Oral Chinese scores were correlated with more items produced on the Pure Chinese block as well as lower switch cost. Higher Written and Oral English scores also correlated with more items produced on the Mixed Language blocks as well as lower switch cost. For Stroop, higher Written English and English EI scores correlated with lower English Stroop Interference. Thus,

we conclude that the relationship between CS and EF may be non-necessary in this particular population. These results suggest that in a proficient bilingual population that frequently engages in CS, the relationship between CS and EF may be an indirect one, even in a developmental population where EF and bilingual language proficiency are still developing.

BIOGRAPHICAL SKETCH

Carissa Kang Pei Shan was born in Singapore. She received her a Bachelor's degree in Social Sciences (B.Sc.) from the Singapore Management University and went on to complete her Master's in Education (Ed.M.) at the Harvard University Graduate School of Education. She then joined the doctorate program at Cornell University (School of Human Ecology) in 2011 and joined the Cornell Language Acquisition Lab, where she was interested in studying bilingual language and cognitive development in children. She also joined the Cornell Early Childhood Cognition Lab in her second year and became interested in examining how culture influences children's beliefs about free will.

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation and gratitude to my committee chair and advisor, Dr. Barbara Lust, for believing in me even before I came to Cornell. Thank you for your encouragement and your invaluable guidance over the past six years. I have grown so much as a researcher and as an individual, thanks to your patient nurturing. I would also like to thank the rest of my committee: Dr. Qi Wang, Dr. Felix Thoemmes, and Dr. Gita Martohardjono for their insightful comments which helped to widen my research from various perspectives. Finally, I am also very thankful to Dr. Tamar Kushnir for welcoming me warmly into her lab and for her enthusiasm and guidance over the past few years.

My sincere thanks also go to the principal and teachers at Hongwen Primary School in Singapore, without whom I would not have been able to conduct this research. I would also like to express my sincerest thanks to all the parents and children who participated in this study. My research assistants have also been very helpful every step of the way – Nandita Mathur, Elizabeth Kaufman, Jing Zheng, Ying Xuan Chen and Cynthia Li. I would also like to thank the Cognitive Science program and Julie Simmons-Lynch for all the travel and research grants as well as the support over the years.

I would also like to thank my wonderful and supportive family and friends back home in Singapore for showering me with endless love. To the friends I have made at Cornell – thank you all for being my second family here. To Michael, thank you for always believing in me and for all the emotional support. Last but not least, to the most important person in my life – my mother, thank you for being my constant pillar of support throughout these years. Without you, all these would not have been possible.

TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION	1
CHAPTER TWO: BACKGROUND	7
2.1. How bilinguals manage both languages	7
2.2. Executive Function (EF) and its components	7
2.3. What is code-switching (CS)?	8
2.3.1. Definition of CS	9
2.3.2. Motivations underlying bilinguals' CS	10
2.4. How are task-switching & language switching related?	11
2.4.1. Definition of task-switching	11
2.4.2. Task-switching paradigms: Local switch cost and Mixing cost	13
2.4.3. Inconsistent findings on local switch cost and mixing cost advantages	14
2.4.4. Mechanisms underlying task- and language-switching	15
2.5. Issues to consider	18
2.5.1. Measurement of CS.....	19
2.5.2. Taking bilingual language proficiency into consideration.....	20
CHAPTER THREE: RATIONALE FOR CURRENT STUDY	23
3.1. Motivation	23
3.1.1. Why Singapore?.....	23
3.1.2. Why study a developmental population?	24
3.1.3. Motivation for EF tasks	26
3.1.4. Motivation for novel CS task.....	28
3.1.5. Motivation for measuring bilingual language proficiency.....	29
3.2. Hypotheses	29
CHAPTER FOUR: METHOD	31
4.1 Participants	31
4.2. Tasks	31
4.2.1. Family & Language Background.....	31
4.2.2. Elicited Imitation (EI) Task	34
4.2.3. Code-Switching (CS) tasks	35
4.2.4. Semantic Fluency task	37
4.2.5. Stroop task	39
4.2.6. Hearts and Flowers task.....	40
4.3 Procedure	41
4.4. Data Analysis	42
CHAPTER FIVE: RESULTS	44
5.1. Family & Language Background	44
5.2. Elicited Imitation	45
5.2.1. Comparison within English and Chinese EIs.....	46
5.2.2. Types of mistakes on the EI.....	47

5.3.1. Discourse-level Performance (Inter-CS).....	49
5.3.2. CS Fluency	49
5.4. Semantic Fluency	53
5.5. Stroop Task.....	53
5.6. Hearts and Flowers Task.....	54
5.8.1. How do both CS and language proficiency predict Semantic Fluency performance? 57	
5.8.2. How do individual CS components correlate with Semantic Fluency?	58
5.8.3. How does language proficiency correlate with Semantic Fluency components?	59
5.8.4. How do CS and language proficiency predict Stroop Interference Effect?	59
5.8.5. How do CS components correlate with Stroop Interference Effects?	60
5.8.6. How does language proficiency correlate with Stroop Interference Effect?	61
5.8.7. How do CS and language proficiency predict Hearts and Flowers performance?	61
5.8.8. How do CS components correlate with Hearts and Flowers Performance?	62
5.8.9. How does language proficiency correlate with Hearts and Flowers Performance? ...	63
5.9. Summary of results	63
CHAPTER SIX: DISCUSSION.....	66
6.1. Critical results of this thesis	66
6.1.1. Significant relationship between language proficiency and EF	70
6.2. Anomalies in Results.....	72
6.3. Limitations & suggestions for future research.....	74
6.4. Importance of current thesis.....	77
REFERENCES.....	79
Appendix.....	92
Appendix A: Analysis of CS Fluency data.....	92
Appendix B: Modified English and Chinese Stroop tasks	93
Appendix C: English and Chinese Elicited Imitation Sentences	94
Appendix D: Scoring Criteria for Elicited Imitation Task	95

LIST OF TABLES

Table 1. Examples of experimenter’s questions in Inter- and Intra-CS. Italicized words are literal glosses.	36
Table 3. <i>English and Chinese EI performance ranked.</i>	46
Table 4. Examples of children’s CS insertions in the intra-CS condition.	50
Table 5. Average number of correct responses in the blocked- and mixed-language conditions of the Semantic Fluency Task.	53
Table 6. Summary of components of English and Chinese Stroop task.	54
Table 8. Accuracy and RT across 3 conditions of Hearts and Flowers task.	55
Table 9. Summary of Multiple Regression Analyses for Variables predicting Semantic Fluency Switch Cost and Stroop Interference Effect Accuracy (both languages).	60
Table 10. Summary of Multiple Regression Analyses for Variables predicting critical components of Hearts and Flowers (HF) task.	62

CHAPTER ONE: INTRODUCTION

The bilingual cognitive advantage has been heavily documented, with many studies showing that bilingualism offers a host of positive cognitive consequences across the lifespan (see Adesope, Lavin, Thompson & Ungerleider, 2010 for a meta-analysis). Some of these cognitive consequences include advantages in switching flexibly between two different rule sets, being able to focus and ignore distracting information, etc. These are also broadly known as advantages in Executive Function (EF). EF is very generally defined as the conscious control of action and thought (Posner & Rothbart, 2000). EF is dependent on neural systems in the prefrontal cortex (PFC) (Luria, 1966). The widely accepted model of EF comprises three main components – shifting between mental sets or tasks (i.e., task switching or cognitive flexibility), monitoring and updating information (i.e., active manipulation of information in working memory), and inhibition of pre-potent responses (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000).

The bilingual EF advantage has been found across the lifespan – in infants (e.g., Kovács & Mehler, 2009; Sebastian-Galles et al., 2012; Weikum et al., 2007), children between four and eight (e.g., Adi-Japha, Berberich-Artzi, & Libnawi, 2010; Carlson & Meltzoff, 2008; Martin-Rhee & Bialystok, 2008), in adults (e.g., Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Luk, De Sa, & Bialystok, 2011) as well as in the aging population (e.g., Bialystok, Craik, & Freedman, 2007; Alladi et al., 2013). This bilingual EF advantage has often been attributed to bilinguals having to manage two languages daily – for example, having to select the relevant language and inhibit the irrelevant language (Green, 1998; Meuter & Allport, 1999; Abutalebi & Green, 2007). The executive control systems that are required for monitoring languages (i.e., switching between languages, inhibition of irrelevant language) are similar to those used

generally for selective attention in non-verbal EF tasks (Luk, Green, Abutalebi & Grady, 2012). As a result of this additional practice, bilinguals have been found to use these networks more efficiently than monolinguals (Luk et al., 2012). This has been further supported by studies showing that higher bilingual language proficiency, earlier L2 (second language) acquisition, and more balanced use of both languages positively influences bilinguals' EF performance (e.g., Bialystok et al., 2006; Carlson & Meltzoff, 2008; Costa et al., 2009; Iluz-Cohen & Armon-Lotem, 2013). All of these studies highlight the role of bilingual language proficiency and use in improving bilinguals' EF performance.

On the other hand, many others have also argued that bilingualism is not consistently correlated with superior EF, or that bilingual EF advantages are only limited to very specific and undetermined conditions (e.g., Hilchey & Klein, 2011; Paap, Johnson & Sawi, 2015; Valian, 2015). Furthermore, the exact underlying mechanisms of bilingualism that correlate with cognitive advantages have not been identified (Prior & Gollan, 2011; Valian, 2015). Thus, it is now necessary to urge the field to examine the constellation of control mechanisms that are engaged by bilingualism to better understand which aspects of the bilingual language experience may produce which constellation of cognitive consequences (Kroll & Bialystok, 2013; Kroll, Dussias, Bice & Perotti, 2015).

More recent findings of the bilingual advantage provided evidence that bilinguals are better able to switch between different rule sets in non-linguistic tasks more efficiently than monolinguals (e.g., Garbin et al., 2010; Gold, Kim, Johnson, Kryscio & Smith, 2013; Prior & MacWhinney, 2010). Researchers argued that if bilingual advantages are even found under conditions in which performance does not directly depend on language use, then this suggests that bilingualism generally affects the brain networks that engage in cognitive control (Kroll et

al., 2015). Intuitively, this task-switching advantage seems most naturally linked to language- or code-switching (CS; both terms used interchangeably in this thesis), a cognitively demanding skill unique to bilinguals (Prior & Gollan, 2011). Thus, this thesis focuses on CS as one aspect of the bilingual experience that may be directly related to EF. CS is defined loosely as the spontaneous switching between two languages, or the mixing of elements from both languages within a single speech event (Appel & Muysken, 1987). CS is a common and natural part of bilinguals' everyday lives. Oftentimes, CS occurs unconsciously and the speaker's fluency is not hindered through mixing (Bhatia & Ritchie, 1999). Furthermore, neurocognitive mechanisms underlying bilinguals' language- and task-switching have been found to be shared partially, showing similar neural substrates for both (Abutalebi & Green, 2007; Garbin et al., 2010). This suggests that CS and EF may share the same cognitive control mechanisms.

However, the bilingual task-switching advantage literature is also inconsistent, even in bilinguals who report frequently switching between languages (Hernandez, Martin, Barcelo & Costa, 2013; Paap & Greenberg, 2013; Paap & Sawi, 2014). Thus, the link between CS and EF (specifically task-switching) is not entirely clear. Moreover, although many studies have examined the relationship between task-switching and language-switching (see Hartanto & Yang, 2016 for a review), these have all been conducted with adults, and no/little work has been conducted to examine the CS-EF relations in a developmental population. In order to establish causal connections between bilingualism and enhanced EF, longitudinal data is needed (Soveri, Rodriguez-Fornells, & Laine, 2011). Thus, studying the CS-EF relationship in children will provide insight into the relationship between bilingualism and EF in the early stages. This thesis investigates the CS-EF relationship in a developmental population to examine if and how one aspect of the bilingual experience – CS – may influence EF in development.

The present thesis required development of existing methodologies. Most previous studies measure language-switching using either bilinguals' self-reports of CS frequency or an experimental language switching paradigm. Self-reports of CS may be particularly inaccurate, especially since CS often occurs unconsciously such that the individual may not even realize it. Moreover, in these lab-based psycholinguistic studies, the language switching tasks used are typically naming tasks where subjects are required to name objects or numbers presented on the screen based on the external cues (e.g., different background colors signaling the cue language to name the item). This measure of language switching does not reflect CS in bilinguals' natural discourse for many reasons. First, natural CS in discourse is often generated internally, but in these cued language switching paradigms, participants are forced to switch based on external cues, making the process highly artificial (Gollan, Kleinman & Wierenga, 2015; Kootstra, 2015; Kleinman & Gollan, 2016). Second, this task has reduced CS to single words, an occurrence that hardly ever occurs in natural CS, which often involves switching between or within clauses or other language constituents beyond the single word.

Thus, to test more precisely if CS and EF are related, this thesis sought to develop a novel CS task that attempts to measure CS in a way that is more similar to the CS that bilinguals engage in their daily lives. To this end, a discourse-based CS task that affords participants the choice and flexibility to engage in CS (or not) was developed. In addition, the majority of previous studies have only focused on the relationship between CS and task-switching (with the exception of Soveri et al. (2011) which examined the relationship between CS and all 3 components of EF – inhibition, working memory and task-switching). To explore the cognitive mechanisms underlying superior EF performance in bilingual children, this thesis examines the relationship between CS, and EF more generally (i.e., task-switching and inhibitory control).

Since bilingual children have been shown to outperform monolinguals on inhibitory control tasks (Biaystok & Martin, 2004; Martin-Rhee & Bialystok, 2008), this thesis also examines if CS may be one aspect of the bilingual language experience that contributes to superior inhibitory control performance.

Lastly, the role of participants' daily language use is also an important factor to consider when studying CS (Kootstra, 2015; Soveri et al., 2011). The sociolinguistic environment plays a significant role in contributing to the CS norms and patterns that emerge (Gardner-Chloros, 2009). For example, participants' tendency and frequency to CS or to match the CS of their conversational partner(s) is influenced by sociolinguistic norms (e.g., how 'normal' it is for participants to CS in their daily lives) (Kootstra, 2015). Bilinguals from communities where CS is a socially-established discourse mode may be less aware of code-switching and this may be reflected cognitively as ambiguous mental boundaries between languages (Kootstra, 2015; Yakpo, 2015).

Therefore, this thesis studied the nature of the CS-EF relation in Singapore, a multilingual society where CS occurs pervasively. Due to the interaction of the various ethnic groups and high prevalence of CS, the English language has been adapted to the local needs and has evolved into what is known as Singlish. Singlish is a variety of English spoken in Singapore that is a product of language contact between the local languages and vernacular languages (e.g., Chinese, Hokkien, Cantonese, Malay, and a lesser extent Tamil) (Bao & Wee, 1999). Given this sociolinguistic milieu where bilinguals engage regularly in CS, they might display efficient language switching abilities. The CS-EF relationship is studied in a new population of children in a multilingual society, Singapore, where CS occurs pervasively in society. The results from this thesis first demonstrate that bilingual children in a highly bilingual population are capable of

switching effortlessly and efficiently between both languages. In this sample of highly proficient bilinguals who engage in CS frequently, CS proficiency did not predict or correlate with several aspects of EF. This may perhaps help explain inconsistent findings in the field regarding the relationship between CS and task-switching in adults, providing evidence for an indirect and non-necessary CS-EF relationship. Finally, the methodology developed here provides a new approach for measuring CS in children in a naturalistic manner and highlights the finding that bilingual language experience may influence EF differently across different bilingual contexts and communities.

Overview of the structure of this thesis

Chapter Two covers five sections – how bilinguals manage both languages, a brief background on EF and its components, definition of CS and motivations underlying CS, relationship between task- and language-switching, as well as issues to consider in light of the current literature. Chapter Three lays out the rationale for this study, presenting the hypotheses and the motivations for using the various tasks, explaining how this current approach can help to resolve ongoing debate in the field. Chapter Four introduces the tasks used in this study while results are presented in Chapter Five where the background measures revealed that this sample comprise highly proficient bilinguals who engage in CS frequently. The results for the CS and each of the three EF tasks are first presented individually, followed by results from regression and correlational analyses revealing the relationship between CS, bilingual language proficiency and EF. Chapter Six summarizes the main findings and discusses the implications of this study's results for issues regarding mechanisms involved in the relation between CS and EF, as well as those that may underlie EF advantages in bilingualism. Alternative hypotheses are also debated; limitations of this thesis, and suggestions for future research are raised.

CHAPTER TWO: BACKGROUND

2.1. How bilinguals manage both languages

To better understand the bilingual EF advantage, we first need to understand how bilinguals negotiate dual language processing. Overwhelming evidence from behavioral (Beauvillain & Grainger, 1987; Hernandez, Bates, & Avilla, 1996; Kroll & De Groot, 1997), neuroimaging (Marian, Spivey & Hirsch, 2003; Wu & Thierry, 2010) and patient studies (see Kroll, Dussias, Bogulski, & Valdes Kroff, 2012 for a review) has established that both languages are jointly activated during language processing, even when only one language is being used. These findings support the hypothesis that CS should be a natural occurrence for bilinguals. The joint activation of languages results in competition for selection that must be resolved either at the structural level (Kroll, Bobb & Wodniekca, 2006) or the lexical level (Green, 1998). During language processing, bilinguals are required to monitor and control the non-relevant language using general EF mechanisms to reduce or avoid interference from the non-relevant language (Abutalebi & Green, 2008; Green, 1998). Consequently, the constant practice that bilinguals get from negotiating between their two languages allows them to develop a higher level of cognitive control compared to their monolingual counterparts (Kroll, Bobb & Hoshino, 2014).

Before considering the literature on the relationship between CS and EF, the next two sections cover EF and its components, followed by how this thesis defines CS, including the motivations behind bilinguals' CS.

2.2. Executive Function (EF) and its components

The bilingual cognitive advantage has been found in executive function, or executive control. These two terms have often been used interchangeably in the literature, but the term “executive function” (EF) will be used in this thesis. EF comprises inter-related high-level

cognitive abilities like planning, decision-making, overcoming habitual actions, problem solving, thinking flexibly and detecting errors (Posner & Fan, 2004). The development of EF is extended over a long period of time, but a child's self-control over his or her thoughts, emotions and behaviors increases considerably during the preschool period (Carlson & Meltzoff, 2008).

The prefrontal cortex has a critical role to play in developing EF skills (Bialystok, Craik & Ryan, 2005). It has been argued that EF has 3 primary components – Inhibition, Updating (i.e., working memory), and Shifting (i.e., cognitive flexibility) (Miyake et al., 2000). Inhibition is defined as how one controls his/her behavior, emotions, and attention, ignoring irrelevant information and focusing on the task at hand. Updating is defined by how an individual holds information in the mind and mentally works with it. Lastly, shifting is the ability to switch flexibly between tasks, mental sets, or strategies (Miyake et al., 2000). The importance of studying EF is highlighted by empirical evidence suggesting links between EF and academic achievement in math, reading and writing in preschoolers and kindergarteners (e.g., Blair & Razza, 2007; McClelland et al., 2007).

2.3. What is code-switching (CS)?

Grosjean and other scholars first advanced the idea that a bilingual's language use moves along a continuum, from the monolingual mode where only one language is used, to a bilingual mode where communication occurs in both languages, leading to a higher probability of switching between languages (Grosjean, 1982; Grosjean & Miller, 1994). CS is viewed as an informal speech pattern found in multilingual societies that reflects a natural performance internally-generated in the bilingual, and is used to varying degrees by bilingual speakers (Yim & Bialystok, 2013). Notably, CS can also occur without conscious intent especially if frequent CS is the norm in the broader sociolinguistic environment.

2.3.1. Definition of CS

Within the CS literature, there is still no common consensus regarding the definition/terminology for the types of code-switches that occur in bilingual speech. For the purposes of this thesis, CS is defined in two general types – intra- and inter-sentential switches. Intra-sentential CS is similar to Muysken’s (2000) use of “insertions”, when elements from one language are inserted or mixed into another language. In the phrase, “My favorite time of the year is 新年(*xin nian*; *Chinese New Year*)”, “新年” is a Chinese noun phrase (NP) insertion in an English sentence. On the other hand, inter-sentential CS, or alternations, usually involve many constituents with greater complexity and length (Muysken, 2000). Some have argued that alternations are more frequently observed in balanced bilinguals who are proficient in both their languages’ grammars because both lexicon and grammar are involved during alternation, and there needs to be some form of compatibility of the two grammars at the point in which the switch occurs (Gardner-Chloros, 2009; Muysken, 2000). An example of an alternation/inter-sentential CS is, “我喜欢去动物园 (*wo xi huan qu dong wu yuan*; *I like to go to the zoo*). I like it because I like riding the ponies there.” In this example, the child switches between Chinese and English clauses.

Others believe that intra-sentential switches (insertions) are usually attributed to the lack of language proficiency because the speaker might not have that necessary vocabulary in that language, hence the need to “borrow” the particular word from the other language to fill the lexical gap. On the other hand, because inter-sentential switches (alternations) are often greater in complexity and length, they usually indicate higher degree of bilingual proficiency, suggesting that the speaker has the basic knowledge of both language structures and does not violate grammatical constraints in his/her CS (Eifring & Theil, 2005). However, it is not necessarily so

that the presence of intra-sentential switches indicates lack of language proficiency. Intra-sentential switches may occur due to several other reasons – for example, a word in one particular language may be better at capturing the essence of that word’s semantic content compared to the word in the other language that the bilingual is currently communicating in, thereby resulting in an insertion. Other times, accessibility issues (as mentioned above) may result in insertions, especially when a bilingual uses a particular word more in one language. Furthermore, it is difficult to define what “grammatical violations” are in inter-sentential switches (or alternations), especially if one views CS as a creative interaction of both languages. For example, if both languages have different grammatical rules, the alternation of speech between the two should not technically be governed by any particular grammatical rule in either language. Hence, the frequency of use of inter- or intra-sentential switches is not an accurate indicator of a bilingual’s language proficiency level. Given the differences in inter- and intra-sentential CS, this thesis will consider both types of CS in the CS measure developed.

2.3.2. Motivations underlying bilinguals’ CS

Bilinguals vary greatly in terms of how they use both languages and the frequency in which they code-switch (CS tendencies may be dependent on several factors – cognitive (e.g., cognitive flexibility, personality traits, general cognitive skills) (Grosjean, 1982; Rodriguez-Fornells, Kramer, Lorenzo-Seva, Festman & Munte, 2012) or socio-psychological factors (e.g., sociolinguistic norms, identity and/or values). CS may be used as a communicative strategy and is sometimes an indicator of an individual’s identity and values (Myers-Scotton, 1993). Higher CS frequency could also be favored in mixed-language environments where both languages are highly activated (Rodriguez-Fornells et al., 2005). Accessibility of a lexical item is an example of both a cognitive and linguistic factor. That is, bilinguals might switch if a particular word or

concept they wish to express has greater accessibility in the one language over the other (e.g., if he/she uses that word more in one language than the other, or in cases where words in the dominant language are more accessible).

Other linguistic factors influencing CS tendency are language proficiency, word semantics and language similarity (Grosjean, 1982; Poulisse & Bongaerts, 1994; Genesee et al., 2004). For language proficiency, sometimes, a lack of knowledge of words in the language being used at the time may motivate insertion of other-language words (Grosjean, 1982). This pattern of switching has been observed in bilingual children who code-switch to fill lexical gaps (Genesee et al., 2004). In general, the different reasons underlying bilinguals' CS are important to take into consideration when studying bilinguals' CS, since high frequency of CS may be due to completely different reasons (e.g., lack of language proficiency or intentional communicative strategy).

2.4. How are task-switching & language switching related?

2.4.1. Definition of task-switching

Task-switching is one component of EF (e.g., Miyake et al., 2000). It requires an individual to focus attention to a single task when faced with two potential options to make a correct task-specific response (Wiseheart, Viswanathan & Bialystok, 2016). In task-switching, switching between stimulus dimensions incurs costs reflected in both accuracy and RT (e.g., Meiran & Marciano, 2002). The individual has to keep two sets of rules active and shift attention between these two rule sets in order to perform the task accurately. A typical task-switching paradigm has two sets of rules – e.g., sorting stimuli by shape and color. For example, when a participant sees a color wheel, he/she has to sort the target stimulus by color, and when a star-shaped object appears, he/she has to sort it according to shape. Task switching paradigms

typically comprise three blocks – two Pure blocks and one Mixed block. In the first Pure block, participants sort the stimulus by a single rule (e.g., shape). The second Pure block then requires participants to sort the stimulus by another single rule (e.g., color). Finally, in the Mixed block, participants sort the stimulus either by shape or color. As the cues appear randomly during this condition, performance here is typically slower and/or less accurate. A switch cost is then calculated using the difference between accuracy and RT on blocked conditions and accuracy on mixed condition.

A switch cost is commonly incurred during performance on switching tasks. Some have argued that the inhibition process required in task-switching is highly similar to that required during language switching (Linck, Schwieter, & Sunderman, 2012; Meuter & Allport, 1999). Language switching paradigms are usually modeled after task-switching paradigms. In a language switching task, participants are told to name digits in either 1 of 2 languages depending on the cue on the screen (e.g., either using different flags, or different colors for each language). Meuter & Allport (1999) found a paradoxical asymmetrical switch costs on mixed conditions, when low proficiency bilinguals were asked to switch between naming digits in their two languages in accordance with the background color of a picture. Smaller switch costs were observed when bilinguals switched from their dominant L1 to their less proficient L2, compared to the other way round. They reasoned that this is because naming in the weaker L2 necessitates the active inhibition of the more dominant L1 competitor, and the inhibition persists into the next switch trial, thereby resulting in greater RT to name the digit in the bilingual's L1 (Meuter & Allport, 1999).

2.4.2. Task-switching paradigms: Local switch cost and Mixing cost

Task-switching paradigms measure local switch cost and mixing cost, both of which are associated with different control mechanisms (Braver, Reynolds & Donaldson, 2003). Local switch cost is the cost of switching between two task sets. It is calculated as the difference in performance between switch and non-switch (repeat) trials in the Mixed block. Within the mixed block, performance is usually worse after switch trials (that require switching of relevant stimulus dimension) compared to non-switch trials (repetition of relevant stimulus dimension). On the other hand, mixing cost (global switch cost) reflects the cost of monitoring and regulating different streams of incoming information. It is calculated as the difference in performance between pure blocks and non-switch (repeat) trials in Mixed blocks. In pure blocks, only one stimulus dimension is relevant, compared to Mixed blocks which requires participants to switch between two stimulus dimensions. Thus, performance is usually worse for the non-switch trials in mixed blocks, compared to non-switch trials in pure blocks.

Local switch cost arises from local control mechanisms that require transient task-set reconfiguration such as goal updating or associating task cues with the correct response mappings (Braver et al., 2003; Rogers & Monsell, 1995) and proactive interference from the previous trial (Wylie & Allport, 2000). Furthermore, it has also been related to subsequent memory-based carry-over effects (e.g., Allport & Wylie, 1999). On the other hand, mixing costs do not entail transient carryover effects from trial to trial, but more sustained and general effects (Rubin & Meiran, 2005), since they reflect the need to overcome interference caused by targets on every trial. Furthermore, while local switch costs are generally comparable across younger and older participants, mixing costs have been found to change dramatically across the lifespan – with older adults incurring larger mixing costs than young adults (e.g., Kray, Eber &

Lindenberger, 2004). Lastly, fMRI and ERP studies have shown that both costs have distinct neural correlates (e.g., Braver et al., 2003; Goffaux, Phillips, Sinai, & Pushkar, 2006). This suggests that both local switch costs and mixing costs rely on different neural networks and/or relate to different stages of task processing (Hartanto & Yang, 2016).

2.4.3. Inconsistent findings on local switch cost and mixing cost advantages

Due to the theoretical overlap between language and task-switching, many have hypothesized that bilingualism may reduce task-switching costs (see Hartanto & Yang, 2016 for review). However, findings regarding the bilingual advantage on task-switching are inconsistent. While some studies found bilingual advantages in switch costs, others found bilingual advantages in mixing costs (see Hartanto & Yang, 2016 for a review), and some did not find any bilingual advantage in either switch costs or mixing costs (Hernandez, Martin, Barcelo, & Costa, 2013; Paap & Greenberg, 2013; Paap & Sawi, 2014).

One possible reason for the discrepant results has been attributed to the variations in task demands of different task switching paradigms that influence bilinguals' performance substantially (Hartanto & Yang, 2016). For example, the type of response mapping – how the response keys for two different tasks (color, shape) are arranged – has produced mixed results. For non-overlapping response-stimulus sets, there exist separate response keys that are mapped to different answers for both task sets. Studies using these sets did not find any bilingual advantage in mixing costs (e.g., Prior & Gollan, 2011; Hernandez et al, 2014; Paap & Greenberg, 2013). In contrast, studies using overlapping response-stimulus sets (i.e., same response keys are (re)mapped onto both tasks) found bilingual advantages in mixing costs (or global costs) but not local switch costs (eg., Cepeda, Kramer, & Gonzalez de Sather, 2008; Costa, Hernández & Sebastián-Gallés, 2008; Soveri et al., 2011; Gold et al., 2013; Wiseheart et al., 2016). It has been

argued that the tasks with overlapping response mapping are more taxing and hence more sensitive in detecting the bilingual advantage in mixing costs (Mayr, 2001). This is because the overlapping response mapping results in higher task interference, thereby resulting in greater competition of response associated with the tasks (Gade & Koch, 2007).

2.4.4. Mechanisms underlying task- and language-switching

If CS and task-switching recruit similar general control processes, then we would expect to see a domain-general relationship between CS and task-switching measures. This means that CS performance might correlate with performance on both verbal and non-verbal task-switching measures. However, if control over CS is a domain-specific relationship, then we would expect CS performance to be related only to verbal task-switching measures. Finally, another possibility is that if CS and task-switching involve independent cognitive mechanisms (especially in proficient bilinguals who code-switch pervasively), then we would not expect to see any significant relationship between the two. Teasing this apart will clarify the association between CS and task-switching. This section reviews evidence for both domain-general and domain-specific relationship.

We first review evidence for the domain-general relationship between CS and task-switching. Evidence from fMRI studies suggest that the executive control systems used in selective attention during non-verbal EF tasks are similar to the ones used when bilinguals switch between languages (see Luk et al., 2012 for meta-analysis). In line with this, several behavioral research studies have argued for similar mechanisms underlying task- and language switching. In one study, 30- to 75-year-old Finnish-Swedish adult bilinguals completed various EF tasks – inhibition, updating, set shifting (Soveri et al., 2011). This study investigated whether performance on EF tasks could be predicted by: a) frequency of language switches on a daily

basis (as measured by self-reports), b) L2 acquisition age, and/or c) self-estimated degree of usage of both languages daily. The most reliable effects were observed for the set shifting measure (e.g., number-letter task), where higher self-reported daily CS frequency predicted smaller mixing cost. In this number-letter task, a number-letter combination (e.g., 4B) appeared in one of two squares in the center of the screen. Participants determined if the number was even/odd, or if the letter was a vowel/consonant, depending on which square the number-letter pair appeared. If the number-letter pair appeared in the upper box, the task was to focus on the number, while the task for the appearance of the pair in the bottom box was to focus on the letter. There were three blocks in total, with the first two blocks being a single-trial block – that is, the number-letter pair would appear in the same square. In the mixed-trials block, the number-letter pair might appear randomly in the top or bottom square, and repetition trials in this block would mean that the number-letter pair appeared in the same box position in two consecutive trials. A mixing cost is calculated based on the difference in performance on single-task trials compared to the repetition trials in the mixed-tasks block. Results revealed that individuals who reported switching more daily incurred smaller mixing costs (Soveri et al., 2011). These results provided further support that set shifting in bilinguals is influenced by lifelong experience in switching between languages (Soveri et al., 2011).

In another study examining the relationship between language and task switching, English monolinguals were compared to two bilingual groups – Spanish-English bilinguals who reported a high frequency of daily language switching, and Mandarin-English bilinguals who reported less language-switching (Prior & Gollan, 2011). Participants completed a non-linguistic task-switching and a language-switching measure (based on the task-switching paradigm). For the non-linguistic task-switching, participants were asked to make color and shape judgments

using buttons to indicate their responses. The cue for the color task was a color gradient while the cue for the shape task was a row of black shapes. A target would appear on the screen, together with the cue which indicates whether to respond by color or shape. There were two single-task blocks (pure-color and pure-shape blocks) followed by mixed-task blocks (both color and shape presented together), and two single-task blocks at the end. The language-switching measure was set up exactly as the task-switching paradigm, except that the stimuli were single digits (1-9). Participants had to name the digit aloud as fast as they can, according to the cues indicating which language to respond (e.g., American flag for English, Mexican flag for Spanish and Chinese flag for Mandarin).

On the non-linguistic task-switching measure, Spanish-English bilinguals incurred smaller task-switching costs (RT) compared to the Mandarin-English bilinguals and monolinguals, but similar mixing costs (RT). As for the language-switching task, Spanish-English bilinguals again had smaller language-switching costs compared to the Mandarin-English bilinguals. Thus, the authors concluded that Spanish-English bilinguals who reported switching frequently between languages displayed smaller task-switching costs compared to monolinguals, unlike the Mandarin-English bilinguals who reported less frequent language switching. They hypothesized that the habitual language-switching (self-reports) results in more efficient switching in both linguistic and non-linguistic tasks because language and cognitive control share an underlying mechanism. Thus, greater experience with language switching would improve general switching abilities in bilinguals across both linguistic and non-linguistic domains. However, they also pointed out that another necessary pre-requisite for the positive relationship between language switching and task switching could be high proficiency in both languages as well (Prior & Gollan, 2011).

On the other hand, others have also argued for a domain-specific relationship between CS and task-switching. That is, language-switching is only associated with linguistic and not non-linguistic task-switching. In one study, highly proficient Catalan-Spanish bilinguals had symmetrical switch costs during language switching using a picture naming task, but not during non-linguistic task-switching (e.g., sorting cards using 2 rule sets) (Calabria, Hernandez, Branzi & Costa, 2012). Thus, the authors argued that the cognitive control required for non-linguistic task-switching and language-switching may rely on different systems.

In a more recent study, Yim & Bialystok (2012) studied the link between the frequency of code-switching and performance on verbal and non-verbal task switching in Cantonese-English adult bilinguals and found a similar dissociation. More details about the tasks used in this study are discussed in the next section. In general, Yim & Bialystok (2012) found that higher CS frequency was only linked to lower switch costs in verbal (linguistic) but not non-verbal (non-linguistic) task-switching. In line with this, they argued that this difference in the relationship between CS and verbal and non-verbal task-switching reveals a domain-specific relationship for the task-switching mechanisms (i.e., language-switching should only positively influence linguistic but not non-linguistic task-switching).

2.5. Issues to consider

In light of the background presented on CS and task-switching and the open issues in the literature, this thesis will cover the issues to consider in studying the relationship between CS and EF. In particular, issues related to the measurement of CS and the importance of taking bilingual language proficiency into consideration are highlighted.

2.5.1. Measurement of CS

Most Psycholinguistic studies measure language/code-switching only with bilinguals' self-reports of CS frequency. Self-reports of CS may be particularly inaccurate, especially since CS may occur unconsciously and naturally in habitual code-switchers such that the individuals may not take notice of it. As for the language-switching task, this is typically a naming task where subjects are required to name objects or numbers presented on the screen based on the external cues. This measure of language-switching does not reflect CS in bilinguals' natural discourse. First, natural CS is generated internally, but in this language switching paradigm, participants are forced to switch based on external cues, making the process highly artificial. Moreover, as this measure of language-switching mirrors the task-switching paradigms that researchers use, it is unsurprising that performance in both tasks are highly correlated.

One critical limitation of the traditional language-switching task that most studies use is that it has reduced 'CS' to single words. This hardly ever occurs in natural CS, which often involves switching between or within clauses. Thus, to address this methodological concern, Yim & Bialystok (2012) attempted to measure code-switching using a more natural method in English-Cantonese adults. In their study, CS was measured using a semi-structured conversation, where participants were instructed to talk about various topics. To prime CS, the experimenter intentionally introduced a topic in both languages – English and Cantonese – and the content of topics were Chinese-themed (e.g. experiences during Chinese New Year) to encourage switching between both languages. Participants also completed three other task-switching measures: one verbal task-switching (semantic fluency) and two non-verbal task-switching (2D switching task and a Faces task). Since task-switching taps on EF, the authors assumed that it required similar cognitive mechanisms as CS – because it requires an individual to keep two sets of rule active

while shifting attention between both rules such that both tasks will be performed accurately (Yim & Bialystok, 2012). They examined how CS frequency (i.e., number of times participants switch language during the experimental CS task) is correlated with verbal and non-verbal task switching in Cantonese-English bilingual undergraduates. Results revealed that participants with higher CS frequency in the conversational task incurred smaller costs during verbal task switching, compared to those who switched less often. However, performance on the non-verbal switching tasks did not correlate with the degree of conversational CS. Hence, the authors concluded that there is a dissociation between the domains pertaining to the mechanism of task switching. Only the switch cost in the verbal task-switching measure (not the non-verbal task-switching measure) was negatively correlated with CS frequency in the conversational CS task.

Given the lack of experimental CS measures that mirror bilinguals' natural CS in the field, this thesis sets forth to develop a novel CS task that measures CS in a discourse format that promotes internally-generated CS. That is, participants will be free to choose whether or not they want to switch between languages, just like how they would do so in a natural conversational setting.

2.5.2. Taking bilingual language proficiency into consideration

Higher levels of bilingual language proficiency as well as more balanced use of both languages has been found to have positive effects on bilinguals' EF – for example in inhibitory control and task-switching abilities (e.g., Bialystok et al., 2006; Carlson & Meltzoff, 2008). In addition, Costa et al. (2009) argued that the bilingual EF advantage may be associated with the degree to which bilinguals use both languages in conversations daily. In Barac & Bialystok's (2012) study, level of language proficiency was associated with performance on metalinguistic tasks, but the length of time spent in an immersion program was correlated with performance on

EF tasks. However, assessing the nature and degree of bilingualism in children is a challenging task. There is a lack of a shared definition of bilingualism (Grosjean, 2010) and there exists wide individual variance in the factors involved in a single child's multiple language acquisition (Kim, Park & Lust, 2016; Lust et al., 2016). In general while it is difficult to quantify bilingualism, the minimum criteria determining proficiency involve an interaction of language proficiency and usage (Fishman & Cooper, 1969; Hakuta, Bialystok, & Wiley, 2003). Luk & Bialystok (2013) argued that bilingualism should not be treated as a categorical variable. In their study, they used daily usage and onset age of active bilingualism to assess bilingual usage as fully as possible.

Another study investigated whether linguistic competence increases children's EF abilities in multilingual children with different levels of linguistic competence (Videsott, Rosa, Wiater, Franceschini & Abutalebi, 2012). 118 early-acquisition multilingual children ($M = 10.9$ years) from Italy completed the Attentional Network Test (ANT) that examines three major aspects of attention – alerting (i.e., achieve and maintain state of readiness for effortful information processing), orienting (i.e., shift focus from one stimulus to another) and executive control (i.e., resolving conflict) (Posner & Peterson, 1990). To assess children's proficiency levels, they collected self-evaluation from the children and an external evaluation by teachers (based on children's school grades). Results revealed that proficiency levels in early multilingual children played an important role in the development and enhancement of all three components of the attentional system, but most significantly for the alerting component. They argued that proficiency level might determine the cognitive ability of multilinguals to better detect and react faster to a given target stimulus found in the ANT. In sum, these studies highlight the importance of considering and measuring bilingual language proficiency when assessing effects of EF (Luk & Bialystok, 2013).

Summary of background review

Results from the above studies so far have several unanswered questions. First, there is a need to examine the CS-EF relationship in a developmental population, where both EF and language proficiency are still developing. Next, given the issues with the measurement of CS, there is a need to develop a new CS task in a discourse format, such that it more accurately mirrors the CS that bilinguals engage in their daily lives. Finally, given the evidence pertaining to how bilingual language proficiency plays an important role in shaping bilinguals' EF performance, this thesis will examine how proficiency may influence the CS-EF relationship.

CHAPTER THREE: RATIONALE FOR CURRENT STUDY

3.1. Motivation

The current thesis is a multi-faceted investigation of a highly proficient bilingual developing population, which will both elicit and evaluate CS, EF and bilingual proficiency and how the three relate to each other. This thesis tests if the CS-EF relationship relies on shared underlying mechanisms by investigating how CS performance relates to EF. This is done through measuring conversational CS in a naturalistic way, measuring several components of EF (verbal inhibitory control, verbal and non-verbal task-switching), adopting a broad concept of bilingual proficiency (using both direct and indirect methods as well as academic measures) and examining how proficiency predicts EF performance. A homogenous highly proficient sample was recruited in Singapore, a place where CS occurs pervasively both at the individual and sociolinguistic level.

3.1.1. Why Singapore?

English-Chinese bilingual children were recruited in Singapore. One practical motivation for the current study of measuring CS in Singaporean children is due to Singapore's sociolinguistic environment. Singapore is a multilingual, multi-racial island in Southeast Asia with four major ethnic groups – Chinese (74.2%), Malays (13.3%), Indians (9.1%), and “Others” (Eurasians, Arabs, etc.) (Singapore Department of Statistics, 2013). Singapore also has a mandatory bilingual education policy that requires all children to be proficient in English and their “mother tongue”. English is the official medium of instruction, and children learn this at the “first language level (L1)” in school. One's “Mother Tongue” is assigned based on one's father's ethnicity (i.e., Mandarin for Chinese) and is learned at the “second language level (L2)”.

Singapore's rich linguistic environment makes it an especially ripe area for studying CS. Earlier studies revealed prevalent CS in Singaporeans – among children (e.g., 71% of Primary Five (11-year-old) reported habitual CS habits (Aman et al., 2007)) and adults (e.g., 76% of Chinese Singaporeans surveyed in an earlier study reported that they frequently code-switch (Xu, Chew & Chen, 1998)). Prior to this study, we collected audio and video naturalistic recordings of Singaporean English-Chinese preschoolers across two preschools in Singapore during lesson and playtime at school (Kang, Yow, Li & Lust, 2015). Preliminary analyses revealed that the types of CS that were observed in this population were prolific and complex. Children were code-switching pervasively, without any force external to their social context. Interestingly and importantly, some of the code-switches that the children made also indicated that they were integrating grammatical knowledge from both their languages. They were not merely inserting nouns from another language into their conversations. Rather, these switches were often complex (e.g., use of functional categories in children's code-switches) and revealed that they were using structural components from both languages to express themselves. Results from this naturalistic study further highlight the pervasiveness of code-switching in Singapore, even in young children (Kang et al., 2015).

Evidence from these studies revealed that CS seems to be a predominant discourse strategy in Singapore. Thus, conducting this study in Singapore will allow us to establish if the CS-EF relationship holds in Singapore, a place where bilinguals are highly proficient and CS is pervasive both at the individual and broader sociolinguistic level.

3.1.2. Why study a developmental population?

While the relationship between CS and task-switching has been studied in adults, no such study has been conducted with bilingual children. To better understand the cognitive

mechanisms underlying the supposed bilingual EF advantage, there is a need to track the developmental trajectory of the cognitive consequences of bilingualism across the lifespan. Studying the CS-EF relationship in development allows us to better understand the fundamental interactions and mechanisms that form the basis of the nature of the final adult state. Additionally, it will provide information about if and whether CS does impact EF development during childhood, where EF is still developing. Earlier in the days when there was a dearth of work on child language research, Bloomfield (1933) and Leopold (1948) argued for the importance of studying child language development. Bloomfield (1933) characterized language learning in infants as a ‘slow-motion picture of ordinary processes of speech’ (p. 81). On the other hand, every adult speaker continuously adapts his/her speech-habits to align with his/her interlocutors – giving up forms he/she has been using while adopting new ones (Bloomfield, 1933). Thus, Leopold (1948) argued that there is no better situation to study these adaptations than in child language development. During these years, changes happen more rapidly and more prominently while the child strives to conform to his/her surrounding speech. Therefore, every language process is revealed in child language development in its budding state, in more tangible and coarser shapes compressed into a shorter time period and is thus more observable (Leopold, 1948).

In line with this argument, evidence from both cognitive and neuropsychological assessments have revealed that while EF emerges in the first few years of life, it still develops significantly and strengthens throughout childhood and adolescence (see Best & Miller, 2011 for review). Therefore, it is crucial to study how CS relates to EF in development. If the CS-EF relationship is highly similar in children and adults, this might reveal important information as to how control in language processing maps onto domain-general EF processes. Alternatively, it is

also possible that the CS-EF relationship may differ in children. If EF is already developing significantly in children (both monolingual and bilingual), we could expect the role of CS might to be minimal or negligible in the development of EF.

3.1.3. Motivation for EF tasks

Inhibitory Control

In order to better understand how CS engages cognitive control in bilinguals, it is necessary to examine how CS relates to different components of EF. Most adult studies have only focused on the relationship between CS and task-switching, with the exception of Soveri et al. (2011), who examined the relationship between CS and all 3 components of EF (as proposed by Miyake et al., 2000) in 30- to 75-year-old Finnish-Swedish bilinguals. In this study, CS performance only predicted task-switching but not inhibitory control nor working memory. However, since that study tested older bilinguals, it is not known how the relationship between CS and inhibitory control may differ in a developmental population.

On another note, several studies have found an inhibitory control advantage in bilingual children compared to their monolingual peers (e.g., Bialystok, 1999; Bialystok & Martin, 2004). This advantage has been attributed to bilinguals' need to exercise inhibitory control over the non-relevant language so that the target language can guide performance when both languages are activated in parallel (Green, 1998). In studies examining language and task-switching, asymmetrical switch costs have been found in both paradigms. For example, switching from easier (or dominant language) to a more challenging task (or less proficient language) often incurred smaller switch costs than switching in the other direction (Meuter & Allport, 1999). For both of these cases, the asymmetry has been attributed to having to inhibit the language or task-set that was activated on the previous trial (Green, 1998; Gollan & Ferreira, 2009; Verhoef,

Roelofs, & Chwilla, 2009; Yeung & Monsell, 2003). This suggests that inhibitory control skills may also be involved in language switching.

Importantly, as EF is highly integrated (Miyake et al., 2000), it is likely that if language switching benefits one aspect of EF, this advantage may be carried over to other components of EF. If a significant correlation is found between CS and inhibition, then this suggests that switching between languages also requires inhibitory control to reduce interference of the non-relevant language during switching. If a significant correlation between CS and inhibition is not found, then perhaps CS only requires effective monitoring and switching between two languages, without necessarily requiring significant inhibition. This hypothesis is more likely, given that bilinguals' natural CS occurs spontaneously, effortlessly and efficiently, and it would not be so if inhibitory control was involved.

Verbal & non-verbal task-switching

In light of the inconsistent findings that argue for either domain-specific or domain-general mechanisms underlying CS and task-switching (verbal and non-verbal), there is a need to include both verbal and non-verbal task-switching measures to further examine the domain-specificity of the relationship between CS and task-switching. If CS and task-switching recruit similar general control processes, then a significant relationship between CS and both verbal and non-verbal switching tasks should be observed. However, if a significant CS-EF relationship exists, and if this is a domain-specific relationship, then CS performance should only be related to verbal task-switching. Finally, if CS does not engage EF –especially in a CS task that is internally generated and would intuitively appear to incur no language switching cost –, there should be no relationship between CS performance and performance on either verbal or non-verbal task-switching.

3.1.4. Motivation for novel CS task

In Chapter 2, questions were raised regarding the measurement of language switching in typical lab-based studies. Yim & Bialystok (2012) paved the way for introducing a measure of code-switching that is more reflective of CS in conversational discourse. However, using Yim & Bialystok's (2012) CS measure for children may be inappropriate. In their CS task, participants talked for as much as they wanted, and the CS score was calculated as number of switches for each participant divided by the total time spoken, multiplied by 60 to obtain the average number of switches per minute. Given that it might be more challenging for young children to talk about a topic over an extended period of time, this measure was not age-appropriate. Thus, a new CS measure was developed to trigger CS in an age-appropriate way for younger children.

Previous language switching studies have found large switch costs in bilingual participants that could be linked to the nature of the task – forcing bilinguals to switch by instructing them on which language to use across each trial (externally-generated). Consequently, in a lab situation using language-switching tasks that force bilinguals to switch languages based on external cues, bilinguals may adopt inefficient strategies that are hence costly and not representative of CS in their daily lives (Kleinman & Gollan, 2016). Thus, in the novel CS measure developed here, participants' responses were not externally induced. Participants were given the freedom to choose which language they wanted to respond in (internally-generated response). As described in Chapter 4 (Methods), the only instructions given by the experimenter was to answer the question as much as they can, and as fast as possible, making this CS measure more reflective of CS in natural discourse. In addition, the nature of the internally-generated CS might also eliminate language switch costs, thereby resulting in no significant relationship between CS and EF performance.

3.1.5. Motivation for measuring bilingual language proficiency

As described in Chapter Two, bilingual language proficiency influences EF performance. One source of inconsistency in the bilingual EF advantage involves variation in bilingual proficiency; thus, it is critical to consider and measure bilingual proficiency in this study. This thesis employed both direct and indirect measures to assess bilingual language proficiency. Lust et al. (2016) found that direct assessment of language proficiency revealed significant differences in terms of quantity and quality of bilingualism despite commonalities in caregiver reports. Thus, they suggested that caregiver reports (i.e., indirect measures) should be supplemented by direct child analyses in the estimation of child bilingualism. The term ‘bilingual language proficiency’ as used in this thesis adopts a broad concept. It is comprised of some scholastic measures (academic language proficiency), daily language use and exposure to both languages, as well as other language use patterns (i.e., parents’ estimates of child’s daily CS frequency). In a preliminary way, we included a direct measure of grammatical knowledge through an Elicited Imitation task.

3.2. Hypotheses

1. If a) the Singaporean population tested here is homogeneously highly proficient and engage frequently in CS, and/or b) the novel CS task developed in this thesis allows for internally-generated CS that is reflective of bilinguals’ everyday CS, then CS may not tax EF heavily, thus, resulting in a non-significant relationship between CS and EF.
2. On the other hand, the alternative hypothesis is: If there is a direct relationship between CS and EF, then performance on the CS task should significantly predict EF performance. Furthermore,

- a) If inhibitory control is required during CS, then CS performance should significantly predict Stroop.
 - b) If task-switching and CS share a domain-general mechanism, then CS performance should significantly predict both verbal and non-verbal task-switching.
 - c) If this is a domain-specific mechanism, then CS performance should only significantly predict verbal task-switching.
3. If proficiency is crucial in the relationship between CS and EF, then language proficiency will have an independent positive effect on EF performance, above and beyond CS performance (i.e., higher language proficiency predicting higher EF performance).

CHAPTER FOUR: METHOD

4.1 Participants

A total of 54 eight-year-old English-Chinese bilingual Chinese children from the same primary school participated in this study. They were all Primary Two students across seven different classes and all children were educated in English and Mandarin daily. As the language proficiency scores (e.g., school exam scores) had to be the same across all participants, children could only be recruited from one school. The principal distributed the consent forms to random students from each class in Primary Two, and approval was only obtained from 54 parents. Out of 54 children, 11 children were involved in the pilot study to test the CS measure in this particular age group. Based on the findings from the pilot study, the tasks were modified accordingly. The remaining 43 children (16 males; $M = 8.33$ years old, $SD = 3.32$ months) participated in the actual study. Forty-two parents completed the VLL Child Multilingualism Questionnaire (2016) to confirm that the sample spoke both English and Chinese at school, at home, and other places. Parents completed family and background questionnaires, while the participants completed a series of language assessments, one CS task (with two conditions), and three EF tasks. These tasks will be described in greater detail in the next section.

4.2. Tasks

4.2.1. Family & Language Background

Parents completed a family background questionnaire where they provided information on the following: average monthly household income (1: Less than S\$2,000, 2: S\$2,001 – S\$4,000, 3: S\$4,001 – S\$6,000, 4: S\$6,000 – S\$8,000, 5: S\$8,001 – S\$10,000, 6: More than S\$10,000) and highest educational qualification for each parent (on a scale of 1 to 8 based on Singapore's education system, 1: Primary School Leaving Examination, 2: GCE 'N' Level, 3:

GCE 'O' Level, 4: GCE 'A' Level/IB Diploma, 5: NITEC/Higher NITEC, 6: Polytechnic Diploma, 7: University Degree, 8: Graduate degree (post-university)).

For language background, parents completed part of the VLL Child Multilingualism Questionnaire (2016). They were asked to rate their child's overall language proficiency levels in both English and Chinese on a scale of 1 to 7 (1: very poor, 2: poor, 3: fair, 4: functional, 5: good, 6: very good, 7: native-like for his/her age). Parents were also asked to rate on a scale of 0 to 100 how bilingual/multilingual their child was (0: monolingual, 100: complete bilingual/multilingual). In addition, parents also reported estimates of their child's daily language exposure and use for their two languages. For each variable, the percentages add to 100% - that is, if a child is exposed to English 60%, then Chinese exposure would be 40%. Two ratios of daily exposure to and daily use of English and Chinese were computed (i.e., Daily Exposure/Use Ratio = $\frac{\text{Percentage exposure or use [English]}}{\text{Percentage exposure or use [Chinese]}}$). A score of 1 represents equal exposure/use to both languages, a score greater than 1 represents greater exposure/use to English and a score less than 1 represents greater exposure/use to Chinese.

Regarding CS, parents were first asked to rate the following statement as accurately as possible, on a scale of 1 to 7 – “In general, your child changes from one language to another during conversation (either inserting words from another language, or alternating between two or more languages)” where 1: not true at all, 4: somewhat true, 7: very true. Parents were also asked to rate on a scale of 1 to 7 (1: Hardly ever, 4: Frequently, 7: All the time) how frequently their child changes from one language to another during conversation with a) primary caregiver, b) secondary caregiver, c) siblings (if any) and d) friends.

One of the components used as a measure of broad bilingual language proficiency was the school exam scores. In the end-of-year examination scores for both English and Chinese

languages from the Singapore school, each language had an oral and written score. English and Chinese oral scores (16 and 30 points respectively; converted to 100%) included the following: i) Reading passage (e.g., student reads a prepared passage and is graded on vocabulary, pronunciation, articulation, fluency, rhythm and expressiveness), ii) Picture description (e.g., describe a picture presented), and iii) Conversation topic (e.g., teacher converses with student on a few topics. Each student is graded on clarity of expression (fluency, language use, pronunciation) and engagement in conversation)). The English Written exam (total of 40 points, converted to 100%) comprised grammar, vocabulary, sentence synthesis and transformation, and an open-ended comprehension test. The Chinese Written exam (total of 70 points, converted to 100%) comprised grammar, vocabulary, sentence formation, comprehension (multiple choice and open-ended). These academic literacy assessments were part of our broad bilingual proficiency estimates.

Finally, bilinguals were grouped into (1) Balanced (high- and low-proficient) and (2) Unbalanced bilinguals (English- and Chinese-dominant) (selection criteria based on Rosselli et al., 2002). Scores for the school language exam in English and Chinese were used as selection criteria. Participants with a difference between the Total English score (combined Oral and Written components) and Total Chinese score equal or lower than 11.50 (1 *SD* according to whole group scores) were represented as *Balanced Bilinguals*, and those with difference between two exam scores greater than 11.50 points were *Unbalanced Bilinguals*. Participants in the Balanced groups were further split up into high- and low-proficient balanced bilinguals. Those with a total exam score (English and Chinese) of 167 (group median) or higher were considered *high-proficient balanced bilinguals*, while those with scores below group median were *low-*

*proficient*¹ *balanced bilinguals*. Likewise, for the *Unbalanced Bilinguals*, 3 were categorized into *high-proficient unbalanced bilinguals* while 5 were *low-proficient unbalanced bilinguals*.

4.2.2. *Elicited Imitation (EI) Task*

To pursue converging evidence regarding children's language proficiency, and to initiate 'direct testing' of children's language competence (Lust et al., 2016) the Elicited Imitation (EI) task was used to assess a small set of various forms of complex sentences in both English and Chinese, controlled for length and vocabulary across languages (see Appendix C for examples). This task has been used in conjunction with experimental designs to assess grammatical knowledge in bilinguals and monolinguals (Gutierrez Ortiz, 2016; Lust, Flynn, & Foley, 1996). This small sample of sentences has been tested in full designs in larger studies of first and second language acquisition in both English and Chinese in both children and adults (e.g., Blume & Lust, 2016; Flynn, 1986; Lust & Chien, 1984).

An abridged version of this task from Flynn (1986) consisting of a battery of four stimuli sentences in each language was used to briefly assess knowledge of complex sentence formation using adverbial subordinate clauses with anaphora. Findings from previous research have shown that such direct production estimates may reveal significant differences in language proficiency over and above results from standardized tests. (e.g., Gutierrez Ortiz, 2016; Flynn, 1986). These sentence types varied in embedding direction and anaphora type and direction. Participants were required to repeat each sentence after the experimenter, under standardized conditions (Blume & Lust, 2016). After three practice trials, participants completed four experimental trials. Language order was counterbalanced. Percentage accuracy for 4 stimuli in each language was computed according to standardized scoring criteria for correctness (Blume & Lust, 2016). Because of the

¹ Low-proficiency here does not represent poor proficiency; just lower proficiency scores compared to the group median.

small number of sentences and the lack of a complete experimental design, parametric statistics were not applied.

4.2.3. Code-Switching (CS) tasks

There were two conditions in the CS task – inter-sentential (inter-CS) and intra-sentential CS (intra-CS) – with eight questions in each condition (See table 1 for examples). For both conditions, participants were told to answer the question as fast as possible and to say as much as they can. This ensured that they can choose which language they want to respond in (i.e., internally-generated response) for it to be more reflective of CS in natural discourse.

In the Inter-CS condition, the experimenter asked questions in alternating languages (e.g., Question 1 in English, Question 2 in Chinese, Question 3 in English etc. as exemplified in Table 1). For example, “Have you been to the zoo? Who did you go with and what did you do at the zoo?” and the child is given 20 seconds to respond. After 20 seconds, the experimenter interrupts the child (if the child is still speaking) and asks a related question in the other language (Chinese), like, “What were your favorite animals at the zoo? Why?” (see Table 1 Question 2). This paradigm measures discourse-level code-switching, since the child has to switch to the other language to comprehend the question and then to respond accordingly in the congruent language.

In the Intra-sentential condition (Intra-CS), questions included cross-language insertions (exemplified in Table 1). For example, “Can you describe 你的妈妈? What does she look like, and 最喜欢和妈妈做什么呢? Why?” (*English translation: Can you describe your mother? What does she look like and what do you like doing most with your mother? Why?*). There was only one order of questions in this condition. All participants completed this task in the same order. This condition combines internally-generated responses with external cues (e.g., the experimenter’s code-switched speech intended to trigger code-switching) and will be a means to

measure relatively spontaneous CS in a controlled situation that would hopefully guarantee sufficient CS frequency.

Table 1. *Examples of experimenter's questions in Inter- and Intra-CS. Italicized words are literal glosses.*

Inter-sentential CS (Inter-CS)		
Qn No.	Language	Questions
1	English	Have you been to the zoo? Who did you go with and what did you do at the zoo?
2	Chinese	在 动物园 里, 最 喜欢 什么 动物? <i>PROG zoo inside most like what animal</i> 为什么 呢? <i>Why DP</i> (What was/were your favorite animal/s at the zoo? Why?)
3	English	Other than the zoo, what other places do you go with your family or on school excursions? Why do you like these places?
Intra-sentential CS (Intra-CS)		
1	Mixed	Can you tell me all about yourself? For example, 你 的 名字, 年龄, and hobbies? <i>you GEN name, age</i> (Can you tell me all about yourself? For example, your name, age, and hobbies?)
2	Mixed	可以告诉 我 你 最 喜欢 吃 什么 食物, <i>can tell me you most like eat what food</i> and why do you like to eat 这 个 食物 呢? <i>this CLF food PRT</i> (Can you tell me what is your favorite food, and why you like to eat this food?)
3	Mixed	Can you describe 你 的 妈妈? <i>you GEN mother</i> What does she look like, and 最 喜欢 和 <i>most like with</i>

妈妈 做什么呢? Why?
mother do what PRT

(Can you describe your mother? What does she look like and
what is your favorite thing to do with your mother?)

Key: Qn No: Question number, PROG: progressive aspect, GEN: generative, CLF: classifier, PRT: particle.

The first CS measure was performance on **discourse-level CS** in the inter-CS condition. That is, when the experimenter switched into another language, did the participant also do so and respond in the congruent languages? Percentage of trials that were responded to in the language congruent with the question was computed. The other CS measure was **CS Fluency (RT)**, defined as the time taken for child to respond to each question (see Appendix A for how this measure was computed). For Inter-CS Fluency, RT for the response to the first question was excluded, since response to the first question did not involve any code-switching. Hence, Inter-CS Fluency only comprised 7 trials of RT data (instead of 8 like Intra-CS Fluency). The third CS measure was **CS Insertion Frequency** – broadly defined by the number of times a child inserts words, phrases or other constituents from another language in a sentence. Given the design of the CS task, CS Insertion Frequency should be higher in the Intra- than the Inter-CS condition, where experimenter’s questions model language insertions that are intended to trigger CS insertions. Examples of different types of CS produced by children in the Intra-CS condition and how CS Insertion Frequency is calculated is found in Table 2 in Results.

4.2.4. Semantic Fluency task

Semantic Fluency, one of two tasks (the other being phonemic fluency) in the Verbal Fluency test that measures executive function and linguistic skills (Baldo & Shimamura, 1998; Monsell, 2003) was used as a measure of verbal task-switching, as in Yim & Bialystok (2012).

In this task, participants were given 30 seconds² to list items that belong in a particular semantic category (e.g., types of sports). There were four conditions in this task – two blocked language and two mixed-language conditions. Four categories comprising animals, types of clothing, food and drinks, and body parts were tested. Participants were first asked to list items in each language (blocked language conditions). After this, they completed two mixed-language conditions, where items in each category had to be listed in alternate languages without repeating any item in both languages (e.g., for the category “Animals”, an example of how an individual should respond is, “dog, 蛇 (snake), horse, 熊猫 (panda), giraffe, 鱼 (fish), etc.”). For the mixed-language conditions, participants were told which language to begin with, followed by the respective category. All instructions were provided in English (unless otherwise stated). None of the categories were repeated and these were counterbalanced for language and order.

The first two conditions were always the blocked-language conditions, followed by the two mixed-language conditions. For both blocked- and mixed-language conditions, starting language was counterbalanced – either English or Chinese first. Incorrect or inaccurate responses comprised responses were coded in the incorrect category, as were language and repetition errors (e.g., if the item was listed in the wrong language, or had already been repeated either in the same or the other language). A switch cost for each participant was based on the difference between the number of accurate responses on the blocked-language condition and the mixed-language conditions. This resembles calculating a global switch cost in a task-switching paradigm, but since there were no non-switch trials in the mixed-language conditions, this estimate may not be as precise.

² Instead of the usual 60 seconds for the Semantic Fluency task, I reduced this to 30 seconds, since it is more challenging for children to come up with items for the entire 60 seconds.

4.2.5. Stroop task

A modified version of the Stroop task (Stroop, 1935) which has been used widely with monolinguals, bilinguals and trilinguals as a measure of verbal inhibitory control (Marian, Blumenfeld, Mizrahi, Kania & Cordes, 2013) was also administered to participants (see Appendix B for both English and Chinese Stroop tasks used here). In original versions of the Stroop task, participants are shown color words in different ink colors and are asked to read aloud the color of the ink, ignoring the word. On congruent trials, the written word matches the color of the ink (e.g., blue written in blue ink). On incongruent trials, there is a mismatch between the ink color and the word (e.g., word “blue” written in black ink). Incongruent trials are typically more difficult, resulting in slower RT, demonstrating the “Stroop effect”. This reflects competition between the automaticity in reading and the process of naming the color (MacLeod & MacDonald, 2000).

In this version of the Stroop, participants were shown 25 words (i.e., 5 words each in 5 rows) in different ink colors on a laptop screen, and asked to read aloud the color of the ink, ignoring the word, from left to right across each row from the top to the bottom. Participants completed the one English and one Chinese Stroop task; with the language order counterbalanced in which they completed the Stroop tasks. There were 25 words in each language, with 7 colors in total. There were 75% incongruent and 25% congruent trials in each block. The measures for Stroop were 1) Overall Accuracy (i.e., percentage of accurate trials over 25 words) and 2) Overall RT (i.e., total time taken to complete reading all 25 words) for each Stroop task. For accuracy, incorrect responses include incorrect colors read, as well as responses with self-corrections and hesitations. The critical dependent measure for the Stroop is the Stroop

Interference Effect for Accuracy, or the difference in accuracy between the congruent vs. incongruent trials. A smaller value represents less Stroop interference/better inhibitory control.

4.2.6. Hearts and Flowers task.

The Hearts and Flowers task (previously called the Dots task) (Davidson, Amso, Anderson & Diamond, 2006) combines elements of spatial Stroop and Simon task (Wright & Diamond, 2014). This task measures working memory, inhibitory control and cognitive flexibility (i.e., switching between two rule sets). It comprises three conditions – two blocked (Hearts, Flowers) and one mixed condition (Hearts and Flowers). The Hearts condition is a pure-congruent block where participants have to press the response button on the same side as the stimulus. The Flowers condition is a pure-incongruent block where participants have to press on the response button on the opposite side of the stimulus. The Hearts and Flowers condition is a mixed block where both the hearts and flowers stimulus appear together in the same block, and participants have to switch flexibly between the same-side and opposite-side rules.

The Hearts block comprised 12 congruent trials (responses on same side as heart), and this was followed by the Flowers block with 12 incongruent trials (responses on opposite side of the flower), and finally the Mixed Hearts and Flowers block where a total of 33 congruent and incongruent trials were randomly intermixed (17 incongruent, 16 congruent). Instructions and four practice trials each were given before each of the Hearts and Flowers blocks. For the Mixed block (Hearts and Flowers), only instructions were given before this block (e.g., “Remember, hearts same side; flowers opposite side”). Memory is required for all trials to remember the rules (e.g., respond on same or opposite side of the stimulus). Inhibition is also required for the Incongruent trials (Flowers condition) to inhibit the pre-potent response of pressing on the button on the same side as the visual stimulus.

For this task, the dependent measures were percentage of correct responses (accuracy) and speed (reaction time; RT). Following Davidson et al.'s (2006) criteria, a response time faster than 200ms was considered anticipatory (i.e., too fast to be responding to the stimulus); hence, these responses were excluded from analyses of accuracy or speed. Such anticipatory responses occurred when the participant did not wait for the stimulus on the current trial and pushed the buttons before the stimulus appeared, or failed to release the button from the previous trial. A trial was considered accurate if the first response after the stimulus was correct and the RT was greater than 200ms after stimulus onset. Percentage of accurate responses was calculated using the following formula: $\frac{\text{No. of correct responses}}{\text{Total (Correct + Incorrect responses)}}$. Anticipatory responses were excluded from this calculation. As for RT data, median RT for correct responses only were calculated for each participant, as the median value would reduce the effect of outlying RTs, compared to the mean value (Davidson et al., 2006).

The dependent measures for this task are accuracy and RT of Local Switch Cost and Mixing Cost. Local switch cost (accuracy and RT) refers to the difference in performance between switch and non-switch trials within the Mixed block (Davidson et al., 2006). Mixing cost (or 'global switch cost') (accuracy and RT) refers to the difference between the non-switch trials of Pure blocks (average of congruent and incongruent trials) and non-switch trials of the Mixed block (Davidson et al., 2006). For both these switch costs, a smaller value represents better performance.

4.3 Procedure

Parents completed the consent form and the Language and Family Background Questionnaires and returned these forms in sealed envelopes to the school. All participants were interviewed individually in a quiet room at the school. Final exam scores for both English and

Mandarin – both Written and Oral components were obtained from the school. Participants first completed the CS task, followed by three Executive Function tasks (Stroop, Semantic Fluency and the Hearts and Flowers task; order counterbalanced) and then the brief Elicited Imitation task assessing language production in both English and Chinese, with the language order counterbalanced. The entire study took approximately 30 to 40 minutes in one session. Participants were given a coloring set (worth \$10) each for their participation.

4.4. Data Analysis

Two trained coders transcribed data from the CS and the Semantic Fluency task with reliability checked across coders for accuracy. CS Fluency (RT data) was computed using Audacity. The coders evaluated the wavelength of the audio file and measured the time between the end of the experimenter’s question (where the wavelength ends on the experimenter’s last word) to the time of the participant’s first word (i.e., start of the new wavelength for first word; See Appendix A for example). Non-words (e.g., “uh”, “hmm”, etc.) were not considered as first words. As this was a production task, RT data was excluded only for trials in which participants did not know what to say (e.g., they told the experimenter that they did not have anything to say, stated that they did not understand the question, or required several prompts for a response). Based on this, 20/301 trials (6.64%) from the Inter-CS and 13/344 trials (3.78%) from the Intra-CS condition were excluded. Two coders reviewed the CS Fluency data to ensure reliability and consistency of coding, and the final CS Fluency data was the average of both coders’ RT data. The transcribed CS data are currently being entered in the Data Transcription and Analysis (DTA) tool (Blume, Flynn, & Lust, 2012), a web application created for language research, collecting both data and metadata in a structured database suitable for dissemination and ongoing collaborative analysis.

CS Insertion Frequency was computed as the number of times of other-language insertions, without differentiating between different types of CS insertions (e.g., lexical, phrasal or clausal). Names (e.g., if a child was speaking in Chinese and inserted the name of an English teacher like, “Miss X”), communicators or interjections that were ambiguous – for example, those that can be used either in English or Chinese utterances such as “uh”, “ah”, “oh”, or Singlish particles (e.g., “la”, “meh”; see Rubdy, 2007) and onomatopoeia were excluded from the CS Insertion Frequency counts.

To assess if CS and bilingualism predict EF performance, three multiple linear regression models were estimated, predicting EF performance for the Semantic Fluency and Stroop tasks (English and Chinese) from CS components and bilingual language proficiency scores. In addition, correlational analyses were conducted to further examine how the individual CS and bilingual language proficiency scores correlate with EF performance. All statistical analyses were performed using SPSS.

CHAPTER FIVE: RESULTS

5.1. Family & Language Background

Based on the family background questionnaire, participants ($n = 42$) were from families with an average monthly income of Level 4.96 (approx. S\$8,001 – S\$10,000) ($SD = 1.42$). Highest educational qualification (on a scale of 1 to 8) was 5.88 for mothers ($n = 42$; $SD = 1.92$) and 6.12 ($n = 41$; $SD = 1.89$) for fathers. This means that parents attained at least a Polytechnic diploma (one level below University degree). As the average median monthly household income in Singapore is S\$8666 and approximately 42.9% of its population aged 25 and above has attained at least a diploma (Department of Statistics Singapore, 2015), this sample can be considered average to high SES in Singapore.

For school exam scores, on the Written component, the average score for English was 90.00% ($SD = 5.68$), and 87.53 % for Chinese ($SD = 7.51$). Paired-samples t -test revealed that the Written English was significantly higher than Written Chinese, $t(41) = 2.10, p < .05$. For Oral exam scores, the average for English was 77.83% ($SD = 9.68$) and 82.54% for Chinese ($SD = 10.51$). Paired-samples t -test revealed that Oral Chinese was significantly higher than Oral English, $t(41) = 2.41, p < .05$. Based on the scoring criteria for bilingual group type, our sample comprised 34 *Balanced bilinguals*, out of which 19 were high-proficient (9 males) and 15 were low-proficient balanced bilinguals (4 males). The remaining were 8 *Unbalanced bilinguals* (3 males), of which 6 were English-dominant and 2 were Chinese-dominant bilinguals. As there were few unbalanced bilinguals, this group was analyzed together as “Unbalanced bilinguals”.

According to responses on the VLL Child Multilingual Questionnaire (2016), in general, all parents ($n = 41$) reported that their child was exposed to and used at least two languages on a daily basis, thus confirming that this sample is productively bilingual. Estimates of child’s

proficiency level for each language (out of 7: 7 being the highest), were significantly higher for English ($M = 5.38$, $SD = 0.80$) than Chinese ($M = 5.01$, $SD = 1.05$); $t(40) = 2.10$, $p < .05$.

Average ratings ($n = 38$) of how bilingual their child was (0 to 100, 0: Monolingual, 100: complete bilingual or multilingual) was 72.11 ($SD = 24.95$).

Parents' estimates for Daily Language Use Ratio was on average 3.34 ($SD = 3.41$) while Daily Language Exposure Ratio was on average 2.29 ($SD = 1.83$). This means that on a daily basis, most children were using English thrice more than Chinese, and exposed to English twice more than Chinese. Finally, parents' estimates of their child's overall CS Frequency ($n = 40$) was on average 4.04 out of 7 ($SD = 1.63$) (i.e., "somewhat true" that child changes from one language to another during conversation). The averages for how frequently the child switches between languages with different people (on a scale of 1 to 7, 1: Hardly ever, 4: Frequently, 7: All the time) were: 3.21 out of 7 with primary caregiver ($n = 39$; $SD = 1.67$), 2.97 out of 7 with secondary caregiver ($n = 31$; $SD = 1.82$), 3.03 out of 7 with siblings ($n = 30$; $SD = 2.11$) and 3.06 out of 7 with friends ($n = 36$; $SD = 1.93$). Thus, this sample code-switches frequently across different situations.

5.2. Elicited Imitation

All children completed the full set of 8 EI sentences – 4 in English and 4 in Chinese (see Appendix C for full set of sentences). For the scoring criteria, major changes in syntax or semantics were considered incorrect. (See Appendix D for scoring criteria). The average total score for English EI was 3.58 out of 4 ($SD = 0.63$) (89.53%) and for Chinese, 1.79 out of 4 ($SD = 0.94$) (44.77%). Since these sentences did not reflect a full factorial design, the average score for each sentence from best to worst performance for both languages were ranked in Table 3. For the English EI, participants performed best in the RB F Pron (Rightward branching forward pronoun)

with a score of 0.98, and worst in the LB F Null (Leftward Branching Forward Null subject). LB structures have been found to be more marked than RB structures for English. In addition, LB F Null is a topicalized sentence, ‘Daddy, when singing the song, washed the baby’.) with a score of 0.79. For Chinese, topicalization is unmarked, compared to English where this structure would be more marked. Thus, even without statistical factorial analysis from a full design, we see that the pattern of acquisition for English is a natural one for English language acquisition.

As for Chinese EI, where all sentences are Left Branching in keeping with the grammar for Chinese, best performance was in the LB F Null (Leftward branching Forward Null subject. This is a topicalized sentence in keeping with the unmarked Chinese grammar, and the null subject is also unmarked in Chinese, with a score of 0.84, and worst performance was in the LB B Pron (Leftward branching backward pronoun) with a score of 0.12, where lexical pronouns are marked.

Table 2. *English and Chinese EI performance ranked.*

Rank	English EI	M (out of 1)	Chinese EI	M (out of 1)
1	RB F Pron (S1)	0.98	LB F Null (S3)	0.84
2	LB B Pron (S2)	0.91	LB B Pron (S1)	0.60
3	RB F Null (S4)	0.91	LB B Null (S4)	0.23
4	LB F Null (S3)	0.79	LB B Pron (S2)	0.12

*S: *Sentence number. Sentence numbers correspond to the numbers in Table 1 in Appendix C.*

5.2.1. Comparison within English and Chinese EIs

For the English EI, comparing Left- vs. right-branching sentences, participants performed better for the right-branching sentences ($M = 0.94$, $SD = 0.24$) compared to the left-branching sentences ($M = 0.85$, $SD = 0.36$). Comparing Pronoun vs. Null subject sentences (English), participants performed better for Pronoun ($M = 0.94$, $SD = 0.24$) compared to Null-subject sentences ($M = 0.85$, $SD = 0.36$). In contrast, for the Chinese EI, Null subject sentences had a

higher average score ($M = 0.53$, $SD = 0.50$) compared to sentences with Pronouns ($M = 0.36$, $SD = 0.48$), in keeping with markedness in both languages.

5.2.2. Types of mistakes on the EI

Mistakes made on the English EI were mostly changes in tense and inflection (Stimulus: “Daddy, when singing the song, washed the baby”. Response: “Daddy when sing the song, washed the baby” – “sing” instead of “singing”) and topicalization omission (same stimulus sentence as before; Response: “When daddy sing a song, he washed the baby”) – where the child removes the antecedent (name ‘Daddy’) from topic position and inserts it in subject position in the subordinate clause (‘when singing the song’).

For Chinese EI, the most common mistakes were connective and tense/aspect changes – connective omissions (e.g., dropping the second part of the Chinese connective “的时候” (time-Rel.) in “当...的时候” (while...time-Rel.), since this comes as a pair and cannot be separated), or connective changes (e.g., changing the second part of the Chinese connective “的时候” (time-Rel.) to “之后” (after)). Frequent mistakes also included other tense/aspect changes. For example, participants often changed the clause, “当他看见小猫的时候” (when he saw cat time-Rel.) to “当他看到了小猫的时候” (adding the completed action marker “了” to the clause) This is an example of a grammatical mistake, where there is a mistaken use of “了” (le), which is a perfective, and is incompatible with the durative temporal clause, “当...的时候” (while...time-Rel.)). Another tense/aspect mistake was the dropping of the completed action marker (了) in the clause, e.g., “哥哥喝牛奶” (brother drink/is drinking milk) instead of “哥哥喝了牛奶” (*brother drink-ASP(Perf). Milk*; brother drank milk). Here, the stimulus denotes a perfective event (since there is the perfective “了”(le) used); however, the subject’s response denotes an imperfective

event. Thus, the mistake is in the change in aspect. Finally, another mistake involves either adding a pronoun in place of a null subject, or deleting the pronoun in place of a null subject. In Example 1 below, the participant added a lexical pronoun (她; she) in the first part of the sentence, when there was a null subject. In Example 2, the participant deleted the pronoun (他; he) in the first part of the sentence leaving a null subject.

Example 1

Stimulus:

当 给 书 涂 颜色 的时候, 姐姐 吃 了 苹果。

when give book paint color time-Rel., sister eat-ASP(Perf) apple

**Time-rel.: Time relative; ASP(Perf): Perfective aspect (completed action marker)*

Response:

当 她 在 擦 色, 姐姐 吃 了 苹果。

when he PROG paint color, sister eat-ASP(Perf) apple

**PROG: progressive aspect*

Example 2

Stimulus:

当 他 看见 小 猫 的时候, 哥哥 把 硬币 掉 了。

when he see little cat time-Rel., brother ba coin drop-ASP(Perf)

Response:

当 看到 了 小 猫 的时候, 哥哥 把 硬币 掉。

when see-ASP(Perf) little cat time-Rel., brother ba coin drop

Although performance on the Chinese EI was poorer than on the English EI, mistakes committed in the Chinese EI were not due to total absence of productivity but to the child dealing with several specific properties of Chinese syntax (e.g., connective structure, tense/aspect, pronominalization). In sum, EI performance, like parents' estimates of daily language use and exposure, confirmed that the sample, although highly productively bilingual, were English-dominant to some degree. While standard academic proficiency scores confirm this sample to be proficient bilinguals, more precise comparisons reveal a dominance of English over Chinese.

Summary of language background and proficiency in sample

Based on exam scores, parents' ratings and the bilingual group sorting criteria, this sample can be considered as productive bilinguals who are generally balanced but demonstrate an asymmetry in language control, generally favoring English – in terms of Written exams, Elicited Imitation, use and exposure estimates (although with dominance of Chinese on Oral language proficiency exam scores from school testing).

5.3. Code-Switching Task

There were two orders in the Inter-CS condition – 21 participants completed order 1 (first question in English) and 22 completed order 2 (first question in Chinese). Analyses revealed that these groups did not differ significantly on all components of the CS task, all p 's > .10.

5.3.1. Discourse-level Performance (Inter-CS)

In the Inter-CS condition, 93.90% of the trials (323/344) ($SD = 11.04$) were responded to in the congruent language. Almost all children switched to another language to match the experimenter's switch. Only one child did not switch at all across all 8 questions in the Inter-CS condition. This child responded to all the questions in Chinese (Note: for this participant, the experimenter asked the first question in Chinese). 6.10% (21/344) of incongruent language responses were produced by 34.88% (15/43) of the participants at least once. Of these 15 participants, 12 produced one incongruent language response. The remaining 3 produced 2, 3, and 4 incongruent responses out of 8 trials. English responses to Chinese questions occurred 52.38% of the time (11/21 trials), while the reverse occurred 47.62% of the time (10/21 trials).

5.3.2. CS Fluency

The average CS Fluency (average time taken to respond) for Inter- and Intra-CS was 1.47s ($SD = 0.77$) and 1.47s ($SD = 0.74$) respectively. A repeated-samples t -test revealed no

significant differences in CS Fluency across CS conditions, $p > .05$. Inter- and Intra-CS Fluency were highly correlated, $r = 0.79$, $p < .001$. Within each CS condition (Inter- and Intra-CS) there were no significant differences in CS Fluency between the languages participants chose to respond in – Inter-CS English: $M = 1.42s$ ($SD = 0.73$), Inter-CS Chinese: $M = 1.35$ ($SD = 0.77$), Intra-CS English: $M = 1.60$ ($SD = 1.17$), and Intra-CS Chinese: $M = 1.40$ ($SD = 0.60$); both p 's $> .05$. That is, participants responded just as quickly in English or Chinese. Regardless of the condition, the average time taken to respond was very fast (less than 1.5 seconds).

5.3.3. CS Insertion Frequency

In the Intra-CS condition, where the experimenter's question modeled CS insertions, 90.70% (39/43) of the participants code-switched by inserting words/phrases in their responses. In the Inter-CS condition, 37.21% (16/43) of the participants code-switched. The Intra-CS Insertion Frequency (i.e., number of times other-language words/phrases were inserted) was 4.00 ($SD = 3.10$) while Inter-CS Insertion Frequency was 0.67 ($SD = 1.06$). Intra-CS Insertion Frequency was significantly higher than Inter-CS Insertion Frequency, $t(42) = 6.87$, $p < .001$.

Examples of the types of code-switches participants produced in the Intra-CS condition are in Table 4. Most involved insertions of nouns (e.g., Responses E and F, Table 3), but there were also insertions of functional categories (e.g., connectives like 'but', 'and', 'then') as well as phrases (e.g., alternating between English and Chinese phrases as in Responses B and C in Table 3 and inserting of verb phrase; e.g., 'play chopsticks' in Response D).

Table 3. *Examples of children's CS insertions in the intra-CS condition.*

Questions & Responses	CS Frequency
<p><u>Question</u> 可以告诉我你最喜欢吃什么食物, <i>can tell I you most like eat what food</i></p> <p>and why do you like to eat 这个食物呢? <i>this CLF food PRT</i></p>	

(Can you tell me what is your favorite food, and why do you like it?)

Response A:

I like to eat 板 面 from the ‘kopitiam’ because I find them very nice.
board noodles coffee shop
(I like eating “ban mian” (noodles) from the coffee shop)

2:
1 Chinese
insertion,
1 Hokkien
insertion
(‘kopitiam’)

Question

See Question No. 3 in Table 1, under “Intra-sentential CS”.

Response B:

My mom has short hair and a very bad temper.

我最 喜欢 和 妈妈 看 故事书
I most like with mother see storybook
(My most favorite thing to do is read storybooks with my mother.)

1:
Switch from
English to
Chinese
sentence

Question

你 的 爸爸 呢? What do you like doing with your 爸爸?为什么呢?
You GEN father PRT father why PRT
(What about) your father? What do you like doing with your father?
Why?

Response C:

I like to play with my father too because sometime when my mother is
busy she doesn’t play with me at all.

我喜欢 和 我的 爸爸 聊天”
I like with my GEN father chat
(I like chatting with my father.)

1:
Switch from
English to
Chinese
sentence

Question

学校 recess 的时候,你 喜欢 和 你 的 朋友 play what games?
School time-Rel you like with you GEN friends

可以告诉我 the rules of the game? 怎么 玩?
Can tell me how to play

(During recess time at school, what games do you like playing with your
friends? Can you tell me the rules of the game? How do we play this
game?)

Response D:

我 和 我的 朋友 喜欢 play uh chopsticks. 那个 chopstick 我们,

5 English
insertions:

<i>Me and me GEN friends like</i>	<i>that CLF</i>	<i>we</i>	“play uh chopsticks”
我,是 那 个, like Addi(tion), like 加 扣 分			(Verb Phrase),
<i>I is that CLF</i>	<i>add deduct points</i>		“chopstick”,
那 个, 我 们 要 uh tap 那 个 finger 。 那 个 ...			“like Addition,
<i>that CLF we have</i>	<i>that CLF</i>	<i>that CLF</i>	like”, “tap”,
			“finger”

(My friends and I like playing “chopsticks”. That “chopsticks”, we, I, is that, it’s like Addition, like adding and deducting points. That (one), we have to tap that finger.)

Question

你 最 喜欢 哪 一 个 holiday 呢? Christmas, 农 历 新 年
you most like which one CLF PRT Lunar New Year

或者 other holidays? 为 什 么 呢?

or Why PRT

(Which is your favorite holiday? Christmas, Lunar New Year or other holidays? Why?)

Response E:

我 最 喜欢 的 holiday 是 Christmas.

My most like REL is

(My favorite holiday is Christmas)

2 English insertions:
 “Holiday”
 “Christmas”

Response F:

I like 新 年 because I will receive a lot of ang pows”

new year red packets

(I like (Chinese) new year because I will receive a lot of red packets.)

2 insertions:
 1 Chinese
 “新年”
 1 Hokkien:
 “ang pows”

Key: DP: discourse particle, CLF: classifier, GEN: generative; PROG: progressive aspect, PRT: particle.

Summary of CS Performance

For discourse-level CS performance (Inter-CS condition), most of the children switched to another language, and responded in the same language as the experimenter when the language of the question was switched. Participants were fast at responding across both CS conditions and responded as fast across both languages. As expected, productive CS occurred in the Intra-CS

condition (more than the Intra-CS condition), where 90.70% of the participants code-switched by inserting words/phrases in their responses.

Executive Function Tasks

5.4. Semantic Fluency

A paired-samples *t*-test revealed that participants produced more items in the blocked-language conditions ($M = 9.00$) than the mixed-language conditions ($M = 5.87$), $t(42) = 10.78$, $p < .01$, cohering with previous literature (e.g., Yim & Biaystok, 2012). In the mixed-language conditions, repeated samples *t*-test revealed no significant differences in performance whether the participant started the block with English or Chinese, $p > .05$. The average switch cost was 3.13 ($SD = 1.90$) – there were approximately 3 less items produced on the mixed-language compared to the blocked language condition. Finally, in the blocked-language condition, a repeated samples *t*-test showed that participants performed significantly better on the English than Chinese block, $t(42) = 3.15$, $p < .01$ (See Table 5).

Table 4. Average number of correct responses in the blocked- and mixed-language conditions of the Semantic Fluency Task.

Trial Type	Mean (<i>SD</i>)
Blocked-language condition	9.00 (1.67)
English items	10.35 (3.45)
Chinese items	7.65 (3.06)
Mixed-language condition	5.87 (1.25)
English first	5.98 (2.02)
English items	3.23 (1.00)
Chinese items	2.74 (1.16)
Chinese first	5.77 (1.49)
English items	2.72 (0.70)
Chinese items	3.05 (0.95)

5.5. Stroop Task

Participants performed better on the English compared to Chinese Stroop on all components of the Stroop task (see Table 6). English overall accuracy was higher (93.21%) than

Chinese overall accuracy (90.51%). Participants took less time overall to complete the English Stroop ($M = 38.03s$) than the Chinese Stroop ($M = 50.01s$). The Stroop Interference Effect (Accuracy) was smaller in the English (0.07) than Chinese Stroop (0.12). Furthermore, the difference in performance on congruent and incongruent trials was greater in the Chinese Stroop compared to English Stroop. Paired-samples t -tests revealed that English Overall Accuracy was significantly higher than Chinese, $t(42) = 2.06, p < .05$ (Cohen's $d = 0.29$), while English Overall RT was significantly faster than Chinese, $t(42) = -5.72, p < .01$ (Cohen's $d = 1.05$). Stroop Interference Effects were significantly smaller in the English than the Chinese Stroop, $t(42) = -2.11, p < .05$ (Cohen's $d = 0.45$). Stroop performance reflected English dominance, since participants performed significantly better on all components of the English Stroop.

Table 5. *Summary of components of English and Chinese Stroop task.*

Condition	English Mean (SD)	Chinese Mean (SD)
Overall Accuracy (%)	93.21 (8.92)	90.51 (8.51)
Overall RT (s)	38.03 (8.63)	50.01 (13.68)
Stroop Interference Effect (Acc)	0.07 (0.10)	0.12 (0.12)

Note: Overall Accuracy and RT: Total accuracy and total time taken across all Stroop trials, while Stroop Interference (Acc: Accuracy) refers to difference in accuracy between congruent and incongruent trials.

5.6. Hearts and Flowers Task.

Across all 3 conditions, participants' performance was best (in terms of accuracy and RT) in the Congruent, followed by Incongruent and Mixed condition (see Table 8 for summary of results). For comparison of performance with an age-matched sample, results from Davidson et al., (2006) were included in the table. In Davidson et al. (2006)'s study, the Dots task was used, which was an earlier version of the Hearts and Flowers, where participants saw two types of Dots (striped/solid) instead of hearts and flowers. Striped dots had vertical black and white stripes while Solid dots were completely in gray. All other features of the task were similar.

Participants were significantly more accurate on the Congruent compared to the Incongruent trials ($t(42) = 3.11, p < .01$) and Mixed trials ($t(42) = 9.33, p < .01$). Accuracy for Incongruent trials was also significantly higher than the Mixed trials, $t(42) = 8.20, p < .01$. Likewise for RT data, participants were significantly faster on the Congruent compared to Incongruent trials ($t(42) = -11.32, p < .01$) and Mixed trials ($t(42) = -20.72, p < .01$). RT for Incongruent trials was also significantly faster than the Mixed trials, $t(42) = -11.11, p < .01$.

Table 6. Accuracy and RT across 3 conditions of Hearts and Flowers task.

Condition	Accuracy (%) <i>M (SD)</i>	Accuracy (%) in age-matched sample ($n = 30$; Davidson et al., 2006)	RT (ms) <i>M (SD)</i>	RT (ms) in age- matched sample ($n = 30$; Davidson et al., 2006)
Congruent (Hearts)	97.37 (4.44)	99.65	588.38 (74.35)	395.05
Incongruent (Flowers)	93.53 (7.87)	90.46	722.86 (88.06)	501.63
Mixed (Hearts and Flowers)	82.35 (11.21)	73.70	871.88 (92.33)	725.98

Average Local switch cost was 14.93% ($SD = 20.52$) for accuracy and 77.11ms ($SD = 73.77$) for RT. Within the Mixed block, participants were 14.93% less accurate and 77.11 ms slower for switch trials compared to non-switch trials. Average Mixing Cost (global cost) was 6.35% for accuracy ($SD = 10.20$) and 195.23 ms ($SD = 87.34$) for RT. Participants were 6.35% less accurate and 195.23ms slower on the non-switch trials of the Mixed block compared to the non-switch trials (all trials) of the Pure blocks (e.g., average Congruent and Incongruent trials). Lastly, paired-samples t -tests were conducted to examine the differences between Local Switch Cost and Mixing Cost for Accuracy and RT separately. For Accuracy, Local Switch Cost was significantly higher than Mixing Cost, $t(42) = 2.03, p < .05$. On the other hand, for RT, Local Switch Cost was significantly less than Mixing Cost, $t(41) = -5.44, p < .01$.

Summary of EF performance across 3 bilingual groups

For Semantic Fluency, there were no significant differences across 3 bilingual groups for the pure English and Chinese conditions, although the balanced high-proficient bilinguals produced most items across all conditions. For the Mixed condition, both the balanced high-proficient and unbalanced bilinguals performed almost similarly, and both these groups produced significantly more items than the balanced low-proficient bilinguals. For Stroop, all 3 bilingual groups did not have significant differences in English and Chinese Stroop Interference. Finally, for Hearts and Flowers, all 3 bilingual groups again did not show significant differences for local and mixing costs (Accuracy and RT). Interestingly, balanced high-proficient bilinguals incurred the highest Local switch cost (Accuracy and RT) but lowest Mixing cost (Accuracy and RT).

5.8. How do CS and language proficiency predict EF performance?

Results above suggest generally high CS productivity and relatively high EF performance in a highly bilingual population. To examine how CS and language proficiency together predict EF performance, multiple regression models predicting individual EF performance (Semantic Fluency, Stroop, Hearts and Flowers) from CS and language proficiency (English and Chinese school exam scores) were estimated. The CS components included in the regression models were discourse-level CS, Average CS Fluency (since Inter- and Intra-CS Fluency were highly correlated, $r = 0.77$ ($p < .001$), and Intra-CS Insertion Frequency. Inter-CS Insertion Frequency was excluded from all the regression models, since only a small number of participants engaged in CS in the Inter-CS condition and the average Inter-CS Insertion Frequency was low ($M = 0.67$). For school exam scores, Written and Oral components for each language were combined into Average English and Average Chinese scores (since Written and Oral scores were

significantly correlated within each language – English: $r = .30$ ($p = .05$) and Chinese: $r = .40$ ($p < .01$)).

Following this, to further examine how CS and bilingual language proficiency individually relates to components of EF performance, separate correlational analyses were conducted – i) between CS components (this time including parents' estimates of child's CS frequency) and individual components of each EF task, ii) between more measures of bilingual language proficiency and each EF task. Results here are divided into three sections, one for each EF task – Semantic Fluency, Stroop and Hearts and Flowers. For each section, results first from the multiple regression models predicting EF performance from CS and school exam scores are first presented. Following this, results from correlational analyses – correlations between CS and EF performance, followed by correlations between bilingual language proficiency (school exam scores, Elicited Imitation performance and parents' estimates of daily language use and exposure) and EF performance are presented.

5.8.1. How do both CS and language proficiency predict Semantic Fluency performance?

A multiple regression model was estimated predicting Semantic Fluency switch cost (Model 1) from CS measures (i.e., discourse-level CS, Average CS Fluency, and Intra-CS Insertion Frequency) and school language proficiency scores (English and Chinese). The overall effects of CS performance and language proficiency on Semantic Fluency switch cost were marginally significant, $p = .054$ (Model 1). Most of the CS components did not significantly predict Semantic Fluency switch cost, all p 's $> .05$ (see Table 8). Only Average CS Fluency ($B = -0.91$, $SE = 0.39$) and Average Chinese score ($B = 0.09$, $SE = 0.04$) significantly predicted Semantic Fluency switch cost, both p 's $< .05$ (i.e., those with slower Average CS Fluency and

lower Chinese scores (Written and Oral combined) incurred lower switch cost on Semantic Fluency).

5.8.2. How do individual CS components correlate with Semantic Fluency?

Correlational analyses were conducted to further examine how each CS component – discourse-level CS, Inter- and Intra CS Fluency and Intra-CS Insertion Frequency – correlates with Semantic Fluency components (Average English, Average Chinese, Average Mixed, Semantic Fluency switch cost). The majority of correlations between CS and Semantic Fluency components were insignificant, p 's $> .05$. Correlation between Intra-CS Insertion Frequency and Semantic Fluency switch cost was negative, although this was not significant ($r = -0.10$), unlike in Yim & Bialystok (2012). In addition, correlational analyses between parents' estimates of children's CS Frequency with Semantic Fluency switch cost were also not significant $p > .10$. In general, CS measures (based on the CS task and parental estimates) did not correlate significantly with verbal task-switching. Only Intra-CS Fluency was significantly correlated with Semantic Fluency switch cost, $r = -0.33$, $p < .05$. Faster respondents on the Intra-CS condition incurred higher switch cost on Semantic Fluency.

To further explore if the relationship between the two variables would differ based on bilinguals' language proficiency levels, correlational analyses were conducted between Intra-CS Insertion Frequency and switch cost across the 3 bilingual groups. The results for the correlations between Intra-CS Insertion Frequency and switch cost across different groups of bilinguals are as follows for each group: a) high-proficiency balanced ($n = 19$): $r = -0.02$, b) low-proficiency balanced ($n = 15$): $r = -0.23$, and c) unbalanced (English- and Chinese-dominant combined, $n = 8$): $r = 0.24$. Although these correlations were not significant and the sample sizes for each group was small, these analyses may provide preliminary evidence for different CS-EF relationship

depending on proficiency and level of bilingualism. Semantic Fluency switch cost and Intra-CS Insertion Frequency were the least correlated for the high-proficiency balanced bilinguals.

5.8.3. How does language proficiency correlate with Semantic Fluency components?

Finally, direct and indirect measures of bilingual language proficiency (a) Written and Oral school exam scores, b) Elicited Imitation in English and Chinese, as well as c) daily language use and exposure ratios and d) parents' ratings of child's English and Chinese proficiency) are correlated with Semantic Fluency components – Pure English, Pure Chinese and Mixed Language blocks. For a), participants who scored higher on Oral Chinese also produced more items on the Pure Chinese block ($r = 0.35, p < .05$) and incurred lower switch cost ($r = 0.33, p < .05$). Next, those who scored higher on Written and Oral English also produced more items on Mixed Language blocks, $r = 0.34$ and $r = 0.36$ respectively, both p 's $< .05$. Both b) Elicited Imitation scores and c) daily language use and exposure ratios did not significantly correlate with any Semantic Fluency components, all p 's $> .05$. Finally, for d) higher parents' ratings of child's English proficiency was correlated with higher number of items produced on the Mixed Language blocks ($r = 0.43, p < .01$) and lower switch cost ($r = -0.36, p < .05$).

5.8.4. How do CS and language proficiency predict Stroop Interference Effect?

Next, two multiple regression models were estimated predicting English Stroop Interference Effect (Model 2) and Chinese Stroop Interference Effect (Model 3) from CS measures (i.e., discourse-level CS, Average CS Fluency and Intra-CS Insertion Frequency) and school language proficiency scores (English and Chinese). Overall, the effects of CS performance and language proficiency on English and Chinese Stroop Interference were also insignificant, both p 's $> .10$ (Model 2 & 3). None of the CS components significantly predicted English Stroop Interference, all p 's $> .10$. In Model 2, only Average English score was a

significant predictor of English Stroop Interference, $p < .01$. Those with higher Average English scores had lower English Stroop Interference (see Table 9 for summary).

Table 7. *Summary of Multiple Regression Analyses for Variables predicting Semantic Fluency Switch Cost and Stroop Interference Effect Accuracy (both languages).*

Variable	Model 1	Model 2	Model 3
	Semantic Fluency Switch Cost	Stroop Interference (English)	Stroop Interference (Chinese)
	<i>B, SE(B)</i>	<i>B, SE(B)</i>	<i>B, SE(B)</i>
Intercept	3.46 (4.77)	0.54 (0.26)	0.33 (0.34)
Discourse-level CS	0.51 (2.61)	0.05 (0.14)	-0.17 (0.19)
Average CS Fluency	-0.91 (0.39)*	-0.02 (0.02)	-0.02 (0.03)
Intra-CS Insertion Frequency	-0.06 (0.09)	-0.000 (0.01)	0.003 (0.01)
Average English	-0.08 (0.05)	-0.01 (0.003)**	0.003 (0.003)
Average Chinese	0.09 (0.04)*	0.001 (0.002)	-0.002 (0.003)
R^2	0.25 ($SE = 1.77$)	0.19 ($SE = 0.10$)	0.05 ($SE = 0.13$)
F	2.43	1.63	0.38

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

5.8.5. How do CS components correlate with Stroop Interference Effects?

Correlational analyses were conducted to further examine how each CS component – discourse-level CS, Inter- and Intra CS Fluency and Intra-CS Insertion Frequency – correlated with Stroop Interference (Accuracy) in both languages. CS components also did not significantly correlate with Stroop Interference Effect (Accuracy) in both languages. First, discourse-level CS did not significantly correlate with English and Chinese Stroop Interference, both p 's $> .10$, although these correlations were negative (e.g., more congruent-language responses on Inter-CS, smaller Stroop Interference). Second, Inter- and Intra-CS Fluency and Frequency with English and Chinese Stroop Interference Effect (Accuracy) also were not significant, all p 's $> .10$. In addition, correlational analyses between parents' estimates of children's CS Frequency with Stroop Interference (Accuracy) for both languages were also not significant, $p > .10$

To examine if the relationship between CS and inhibitory control differs across the 3 bilingual groups, CS Frequency was correlated with Stroop Interference Effects (both languages)

separately in these groups. As predicted, Intra-CS Insertion Frequency was not significantly correlated with Stroop Interference in both languages for the high- and low-proficiency balanced bilinguals (all p 's > .10). However, in the unbalanced bilingual group, Intra-CS Insertion Frequency was positively correlated with English Stroop Interference, $r = 0.78$, $p < .05$. Unbalanced bilinguals who produced more code-switches in the Intra-CS condition also performed worse on the English Stroop.

5.8.6. How does language proficiency correlate with Stroop Interference Effect?

Finally, correlational analyses were conducted to examine how direct and indirect measures of bilingual language proficiency (a) Written and Oral school exam scores, b) Elicited Imitation in English and Chinese, as well as c) daily language use and exposure ratios and d) parents' ratings of child's English and Chinese proficiency) correlate with English and Chinese Stroop Interference (Accuracy). For (a), those who scored higher on Written English also had lower English Stroop interference (Acc), $r = -0.46$, $p < .01$. For (b), those who scored higher on English EI had marginally lower English Stroop interference (Acc), $r = -0.30$, $p = 0.05$. All other correlations (c and d) did not significantly correlate with Stroop interference (Acc), all p 's > .05.

5.8.7. How do CS and language proficiency predict Hearts and Flowers performance?

Here, four multiple regression models (Models 4-7) predicting Hearts and Flowers components – Local Switch Cost (Accuracy and RT) and Mixing Cost (Accuracy and RT) from CS measures (i.e., discourse-level CS, Average CS Fluency and Intra-CS Insertion Frequency) and school language proficiency scores (English and Chinese) were estimated. All four regression models were not significant, all p 's > .10 (see Table 10). In addition, none of the CS predictors in Models 4 – 6 were significant. However, for Model 7, discourse-level CS significantly predicted Hearts and Flowers Mixing Cost (RT) ($B = 278.99$ $SE(B) = 112.11$, p

< .05). Participants who had more congruent-language responses in the Inter-CS condition also incurred higher mixing cost (RT) in Hearts and Flowers.

Table 8. Summary of Multiple Regression Analyses for Variables predicting critical components of Hearts and Flowers (HF) task.

Variable	Model 4	Model 5	Model 6	Model 7
	HF Local Switch Cost (Accuracy)	HF Local Switch Cost (RT)	HF Mixing Cost (Accuracy)	HF Mixing Cost (RT)
	<i>B, SE(B)</i>	<i>B, SE(B)</i>	<i>B, SE(B)</i>	<i>B, SE(B)</i>
Intercept	-17.72 (57.50)	431.82 (194.03)*	27.47 (28.71)	66.23 (205.67)
Discourse-level CS	18.52 (31.34)	-175.52 (107.28)	14.70 (15.65)	278.99 (112.11)*
Avg CS Fluency	-5.22 (5.35)	-16.84 (18.18)	-1.95 (2.67)	-38.79 (19.15)
Intra-CS Insertion Frequency	0.27 (1.07)	-5.32 (3.70)	-0.03 (0.54)	-0.62 (3.83)
Average English	-0.30 (0.58)	-0.61 (2.00)	-0.24 (0.29)	-0.26 (2.07)
Average Chinese	0.55 (0.47)	-1.09 (1.60)	-0.14 (0.24)	-0.68 (1.69)
<i>R</i> ²	0.07	0.17	0.07	0.21
	(<i>SE</i> = 21.35)	(<i>SE</i> = 71.82)	(<i>SE</i> = 10.66)	(<i>SE</i> = 76.36)
<i>F</i>	0.52	1.46	0.50	1.96

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

5.8.8. How do CS components correlate with Hearts and Flowers Performance?

Next, correlational analyses were performed to further examine correlations between CS–discourse-level CS, Inter- and Intra CS Fluency and Intra-CS Insertion Frequency – and Hearts and Flowers. Results revealed that only discourse-level CS was significantly correlated with both Local switch cost (RT) and Mixing cost (RT), $r = -0.31$ and 0.36 respectively, both p 's < .05. The higher the percentage of congruent-language response for Inter-CS, the lower the local switch cost incurred in terms of RT, and the higher the mixing cost (RT) incurred.

Correlational analyses were also conducted between parents' estimates of children's CS Frequency with Local switch cost and Mixing cost (Accuracy and RT). Only the correlation between parents' estimates of CS Frequency and Mixing Cost (Accuracy) was significant, $r = 0.34$, $p < .05$ – those who parents reported higher CS Frequency had higher mixing cost (i.e.,

performed worse on the non-switch trials of the Mixed block, compared to the non-switch trials of the Pure blocks).

5.8.9. How does language proficiency correlate with Hearts and Flowers Performance?

This section examines how direct and indirect measures of bilingual language proficiency (a) Written and Oral school exam scores, b) Elicited Imitation in English and Chinese, as well as c) daily language use and exposure ratios and d) parents' ratings of child's English and Chinese proficiency) correlate with Hearts and Flowers performance (Local Switch Cost, Mixing Cost – Accuracy and RT). None of these direct and indirect language proficiency measures were significantly correlated with Hearts and Flowers performance, all p 's > .05.

5.9. Summary of results

The Singaporean child population studied here were found to be proficient bilinguals and proficient code-switchers, as measured both by the indirect (i.e., parent reports) and direct measures (i.e., school language proficiency and elicited imitation scores). In the CS task, participants were fast and fluent at responding to questions across Inter- and Intra-CS conditions, whether they responded in English or Chinese. They were proficient at discourse-level CS performance, and could switch languages in less than 1.5 seconds whenever the experimenter switched. As for EF performance, Semantic Fluency switch cost was fairly low (approximately 3 less items produced in Mixed-language compared to pure-language conditions), which suggests that they were proficient at verbal task-switching. Stroop interference (accuracy) for both languages were also very low (0.07 for English and 0.12 for Chinese), which suggests high inhibitory control. Lastly, for Hearts and Flowers, age-matched comparisons showed superior performance in this sample in terms of Incongruent and Mixed blocks for Accuracy (they performed slightly worse for Congruent trials). This appeared to be compensated with their

higher RTs across all conditions compared to the age-matched counterparts (Davidson et al., 2006). Local switch cost (Accuracy) incurred was higher than Mixing (global switch) cost, while Local switch cost (RT) was lower than Mixing (global switch) cost. This suggests that participants took longer in order to ensure higher accuracy for the Mixing (global switch) cost.

The basic hypothesis of this thesis is: If CS is not directly related to EF, then there should not be a significant relationship between them. However, if other intervening factors such as bilingual proficiency interact in the CS-EF relationship, then one would expect to see language proficiency significantly predicting EF performance, above and beyond CS performance. Both hypotheses were proven true in this thesis. For the relationship between CS performance, bilingual language proficiency and EF performance, all regression analyses revealed that CS performance did not predict EF performance – for Semantic Fluency switch cost, English and Chinese Stroop Interference (Acc), and most components of the Hearts and Flowers (e.g., Local switch cost Accuracy and RT, Mixing Cost Accuracy). That is, CS performance did not predict verbal task-switching nor verbal inhibitory control, although it did predict Mixing Cost (RT) of non-verbal task-switching.

On the other hand, in these regression models, broad bilingual language proficiency (school exam scores) significantly predicted EF performance for some tasks. Chinese school exam scores significantly predicted Semantic Fluency switch cost. In addition, English exam scores significantly predicted Stroop English Interference, although school exam scores did not significantly predict Hearts and Flowers performance. Correlational analyses further provided descriptive results showing that both direct (school exam scores, EI task) and indirect measures (parents' ratings of proficiency) correlate with verbal EF performance. First, for individual components on the Semantic Fluency, higher Oral Chinese scores were correlated with more

items produced on Pure Chinese block. Higher scores on Written and Oral English also correlated with more items produced on the Mixed Language blocks. In addition, higher parents' ratings of child's English proficiency were also correlated with more number of items produced on Mixed Language blocks and lower switch cost. Second, for Stroop, higher Written English and English EI scores were correlated with lower English Stroop Interference. Finally, only Hearts and Flowers performance were not significantly correlated with direct and indirect language proficiency measures.

CHAPTER SIX: DISCUSSION

6.1. Critical results of this thesis

In general, results revealed a nonsignificant relationship between CS and EF, suggesting an indirect CS-EF relationship in this sample of highly proficient bilinguals who were prolific code-switchers. The majority of the results from the regression analyses revealed that most of the CS components did not predict EF performance for verbal task-switching (Semantic Fluency), non-verbal task-switching (Hearts and Flowers) and verbal inhibitory control (Stroop). For Semantic Fluency, both discourse-level CS and Intra-CS Insertion Frequency did not significantly predict Semantic Fluency switch cost. For Stroop, none of the CS components predicted Stroop performance in both languages. Like Soveri et al. (2011), results from this thesis reiterated that CS performance did not predict inhibitory control performance. This finding accords with previous research revealing the parallel activation of both languages during language production and comprehension in adults (e.g., Dijkstra, 2005; Kroll et al., 2006). Hence, CS may not necessitate inhibition of one language or the other, especially when switching between languages appears to occur seamlessly in natural situations.

As Soveri et al. (2011) suggested, the non-significant relationship between CS and inhibitory control shows that keeping both languages active and selecting between languages is more crucial for the bilingual EF advantage than the inhibition of the non-relevant language. Finally, for Hearts and Flowers, CS components also did not significantly predict 3 out of 4 measures of non-verbal task-switching (Hearts and Flowers) – Local Switch Cost (Accuracy and RT) and Mixing Cost (Accuracy). Thus, results revealed a general nonsignificant relationship between CS performance and 2 out of 3 EF components (of Miyake et al.'s (2000) EF model comprising Inhibitory Control, Cognitive Flexibility (or switching), and Working Memory).

Another critical result was the non-significant relationship between CS frequency and Semantic Fluency switch cost. Previous studies with adults showed that frequent language switching (either measured by self-reports or language-switching paradigms that are modeled after task-switching paradigms) correlates with smaller task switching costs (e.g., Prior & Gollan, 2011; Yim & Bialystok, 2012). However, this correlation was not significant in this sample. Even parents' estimates of children's daily CS Frequency did not significantly correlate with EF performance on Semantic Fluency and Stroop.

There are several possible explanations for the non-significant CS-EF relationship found. First, CS may not recruit EF to the same extent in prolific code-switchers who are regularly being exposed to and engage in CS. In Green & Abutalebi's (2013) adaptive control model, several components of cognitive control are recruited to perform particular language tasks. Variations in language use, context as well as levels of language proficiency and nature of language pairings may change the way control networks are engaged. As such, bilinguals may differ in their recruitment of these control networks from other bilinguals whose circumstances are different from theirs. Green (2011) also suggested that bilinguals in code-switching communities may recruit their language control networks differently. Thus, given that pervasive CS occurs in the broader sociolinguistic environment in Singapore, these habitual code-switchers may engage a different set of control mechanisms compared to non-habitual code-switchers who may engage in more effortful (or possibly different) control mechanisms when they engage in CS.

This is a likely possibility in this current sample, given the high prevalence of CS across multiple languages in Singapore (English, Singlish – a creole in Singapore, Malay and other dialects), even in children, resulting from the continual interactions of individuals across different ethnic groups. This was further confirmed in the language background questionnaires

where parents reported that their children engaged in CS at home, in school and with friends. Interviews with the children further confirmed parents' reports. When asked why they engaged in CS frequently, they explained it was "just a habit", or that the meanings of some words were better captured in a particular language, or simply that they did not know or remember the word in the other language. Hence, this further reiterates that the CS-EF relationship may differ depending on the broader sociolinguistic context. In a bilingual population where individuals engage less frequently in CS, CS may tax EF to a greater extent, or differently.

Second, the lack of a CS-EF relationship may also reflect, at least partially, the nature of the CS task. There is evidence showing that internally-generated or voluntary switching elicits significantly smaller switch costs than cued/involuntary switching (Arrington & Logan, 2005; Kleinman & Gollan, 2016). Thus, the CS task may have resulted in low (or no) switch costs incurred in terms of CS Fluency (RT). In this CS task, although it is the experimenter's language switching that triggers the speaker to code-switch, ultimately, the child decides whether to switch in response. Gullifer et al. (2013) argued that CS in a sentence context incurs no significant costs to lexical processing, in contrast to lexical switching across both languages. Thus, the sentence context in this CS task might have further reduced processing costs for the participants.

Third, it is unsurprising that most previous studies found that participants who perform better on the task-switching measures also perform better on their language-switching measures. This may be because the language-switching paradigm is modeled according to the task-switching paradigm. Thus, it makes sense that performance in both tasks would correlate highly. However, in this thesis, the CS task used is completely distinct from the task-switching paradigm. Instead of having external cues prompting participants to switch languages across trials of single digits (i.e., name digit in English when presented with American flag and in Spanish when

presented with Mexican flag), participants were engaged in a conversational discourse and were switching between languages across clauses/sentences, not just single words. In addition, they also had the freedom to choose to switch languages (or not) whenever the experimenter switched into another language (i.e., internally-generated CS). Thus, it could be due to the very different nature of how CS was measured in this thesis that might have contributed to the insignificant relationship between CS and task-switching.

Lastly, the non-significant CS-EF relationship can also be arguably attributed to the high performance for both CS and EF tasks, thereby reducing variability in the results. This could be due to the sample's average to high SES (see Section 5.1), or Singaporean children's general high academic performance, given that Singapore has been consistently rated as having the world's best education system according to the Organization for Economic Co-operation and Development's (OECD) latest global education survey in 2015 (OECD, Hanushek, & Woessmann, 2015). As such, there is a need for future studies to recruit children from different age groups across different SES levels to ensure that the insignificant CS-EF relationship is not necessarily due to the high SES background or the high academic achievement of this sample. However, previous work in low-SES Singaporean English-Malay bilinguals (in terms of parental education and monthly income) revealed that their EF performance remained high when compared to their high SES English-Chinese bilingual counterparts in Singapore (Kang, Thoemmes, & Lust, 2016). As such, it is unlikely that the above-average SES of this sample might have contributed to their high EF performance.

The next section discusses the other important results found in this thesis – the role of bilingual language proficiency in the CS-EF relationship. Again, we highlight the broad concept

of bilingual language proficiency adopted in this thesis, as it also includes scholastic measures (Oral and Written exam components).

6.1.1. Significant relationship between language proficiency and EF

In terms of the sample's language background, first, there was much evidence that revealed participants' English-dominance. Participants performed better on the English block of the Semantic Fluency, the English version of the Stroop, English Elicited Imitation and school exam scores. In addition, children performed more poorly on Chinese than in English on the EI task. As reported in the Results chapter, poorer performance on the Chinese EI (compared to English) did not reflect participants' total incompetence in Chinese language productivity. Rather, it did reflect that children were responding to markedness in Chinese grammar. (e.g., lexical pronouns vs nulls are marked and children made frequent changes of these proforms). There are several possible explanations for the lower Chinese EI scores. Mistakes on the Chinese EI mainly involved tense/aspect renditions of the sentence. The explanation for these difficulties remain to be studied by future research. A possible explanation for the low scores could be due to the influence of English, since participants made several grammatical mistakes that reflected an imperfect acquisition of Chinese. Participants changed certain aspect markers (e.g., when they dropped the perfective aspect “了” in some sentences). Moreover, some of the mistakes made on the Chinese EI could also be due to the possible influence of Singlish, which is a creole in Singapore, pervasively spoken across children and adults, that omits several tense/aspect markers. Lastly, another possible reason for the low Chinese EI performance could be due to the way in which the Chinese EI was scored. The use of the perfective “了(le)” aspect is complicated and linguistic analyses differ on whether this is obligatory or not. Perhaps a different scoring system for sentences that include this perfective aspect might result in higher performance on the

Chinese EI could be implemented in future studies that distinguishes between verb-final vs. sentence-final “了 (le)”.

Next, in the regression models, aspects of language proficiency as measured by school exam scores significantly predicted various components of EF performance. Preliminary analyses of the three types of bilingual groups revealed that the relationship between CS Insertion Frequency and Semantic Fluency switch cost differed across groups of high-proficiency balanced, low-proficiency balanced and unbalanced bilinguals. Although the sample sizes of these sub-groups were small and no correlations were significant, these results descriptively provide some insight into how language proficiency (in this case, as measured by school exam scores) may alter the direction of the relationship between CS Frequency and verbal switch cost. CS Frequency and switch cost was least correlated ($r = -0.02$) in the high-proficiency balanced group. A negative relationship between CS Frequency and switch cost was found in the low-proficiency balanced group ($r = -0.23$), as was seen previously in Yim & Bialystok (2012). For this group, the greater the CS, the lower the switch cost. However, for the unbalanced bilinguals, a positive relationship was found between the two ($r = 0.24$). For this group, the more CS they produced on the task, the greater the switch cost they incurred on Semantic Fluency. In sum, these results highlight the non-necessary CS-EF relationship (i.e., CS Frequency may not necessarily correlate with lower verbal task-switching switch cost) and the importance of considering language proficiency and types of code-switches (as well as the motivations underlying CS) when studying the CS-EF relationship.

Importantly, the role of bilingual language proficiency (that also encompassed scholastic oral and writing measures) was highlighted in the correlational analyses between language proficiency and individual verbal EF tasks/components (e.g., Semantic Fluency and Stroop). For

both Semantic Fluency and Stroop, participants who scored higher on some components of the school exam scores and EI scores also performed better on each task. These results underscore the role of bilingual language proficiency in examining the bilingual EF advantage. This may explain inconsistent findings in the field, where not all studies have found a bilingual EF advantage and issues have arisen as to what the underlying mechanisms are for the superior EF performance (e.g., Valian, 2015). These results suggest that even in a sample of highly proficient bilinguals, subtle nuances in language proficiency may influence EF performance. Future studies should distinguish between ‘language knowledge’ (i.e., general competence for a language) and language literacy (i.e., reading and writing skills) when defining language proficiency in order to more carefully examine the relationship between language proficiency and EF skills.

6.2. Anomalies in Results

There were some puzzling significant findings between certain CS components and EF performance. The first was the significant correlation between Inter-CS Fluency (RT) and Semantic Fluency switch cost ($r = -0.33$) – those who responded quicker on the Inter-CS questions (which reflects better CS performance) incurred greater switch cost on Semantic Fluency. However, we do not know if participants who incurred lower switch cost: i) took longer to respond (we did not collect RT data for Semantic Fluency), ii) performed poorly across blocked and mixed conditions, or iii) performed almost just as well across blocked and mixed conditions. Thus, it is difficult to interpret this counterintuitive significant correlation.

Next, in both regression and correlational analyses examining the relationship between Hearts and Flowers performance and CS components, discourse-level CS predicted Mixing Cost (RT) – participants more congruent-language responses (Inter-CS) incurred higher Mixing Cost (RT). This is somewhat similar to Soveri et al.’s (2011) results, where one aspect of CS (e.g.,

bilinguals' self-reports of daily CS frequency) significantly predicted Mixing cost (RT) but not Local switch cost (RT) in their task-switching measure. That is, only Mixing cost (RT) in the task-switching measure was sensitive to the bilingual experience of language-switching. The authors argued that mixing cost requires top-down management to manage competing task sets and this is similar to the decisions bilinguals must make when choosing between which language to use across conversations. Nonetheless, it is not clear why better performance on discourse-level CS (e.g., more congruent-language responses) was correlated with worse performance for Mixing Cost (RT).

Additionally, correlational analyses also showed that participants with more congruent-language responses (Inter-CS) also incurred higher Mixing Cost (RT), and lower switch cost (RT). It is also not clear as to why there were different directions of associations between discourse-level CS (i.e., proportion of congruent-language response) with local switch cost (RT) and mixing cost (RT). It has been suggested that local switch and mixing costs rely on different neural networks and/or relate to different stages of task processing (Hartanto & Yang, 2016). While local switch cost has been shown to reflect transient control mechanisms like associations of task cues to appropriate stimulus-response mappings (Braver et al., 2003), mixing cost is more demanding as it requires sustained control processes. This is because in the Mixed block, the individual needs to constantly keep the different task sets active to be able to react efficiently to task/rule changes, and this is similar to bilinguals' general language switching; for example, in a conversational context with other bilinguals, the bilingual has to keep both languages ("task sets") active in order to be able to react to any switches in their interlocutors' languages (Soveri et al., 2011).

The only significant correlation was that higher CS Frequency (as reported by parents) was correlated with higher Mixing Cost (Accuracy). This was a surprising finding, but when the results were analyzed separately for the 3 bilingual groups, it appeared to be the unbalanced bilinguals who were driving this positive correlation. Although correlational analyses of CS Frequency and Mixing Cost (Accuracy) were not significant across all 3 groups, the unbalanced bilinguals had the greatest positive correlation, $r = 0.64$, compared to the high-proficiency balanced ($r = 0.10$) and low-proficiency balanced ($r = 0.35$) bilinguals. This perhaps suggests that the unbalanced bilinguals might have been code-switching due to lack of proficiency in one of their languages, perhaps due to their English dominance. In light of this, it is not surprising to find that the unbalanced bilinguals who code-switched more incurred higher Mixing cost (Accuracy) on the non-verbal task-switching measure.

This anomalies further support the importance of considering types of code-switches and types of bilingual proficiency in future studies. High CS frequency can sometimes be attributed to lower proficiency in a bilingual's weaker language, thereby resulting in the bilingual having to insert words from the dominant language (i.e., intra-sentential CS). This might differ from high CS frequency in a high-proficiency balanced bilingual, who code-switches between clauses/phrases (i.e., inter-sentential CS), or does so because he/she has the language proficiency to do so effortlessly and frequently between languages.

6.3. Limitations & suggestions for future research

This thesis raises several issues which motivate future research. The first issue concerns complexity of the nature of bilingualism and its effect on EF. These results raise the question of whether totally balanced bilingualism exists (e.g., Cutler, Mehler, Norris & Segui, 1992). Methodologically, this study's results suggest it is crucial to consider assessments of the nature

of bilingualism in populations of “bilinguals” being studied and consideration of the language of testing when measuring bilinguals’ EF skills. On the Stroop task, inhibitory control performance differed significantly depending on the language of the task. This study’s results also provoke further research to more specifically differentiate between types of CS (e.g., Muysken’s (2000) CS types). For example, the Control Process Model of Code-switching (CPM; Green & Wei, 2014) argues that qualitatively different types of CS may recruit different cognitive control processes. Since our analyses did not go into detail about the grammatical complexity of the types of CS children produced, there is a need to analyze this in detail in future. For example, future studies could examine if different types of CS (e.g., intra-sentential CS vs. inter-sentential CS) might influence EF performance to a different extent.

As this was the first time our new CS task was used, it is difficult conclude if it is the developmental nature of this sample, the sample’s prolific CS habits and/or their high bilingual proficiency that may have resulted in the insignificant CS-EF relationship. Thus, future studies should employ the same CS and EF measures used in this thesis to test other developmental populations that vary in these characteristics (e.g., high/low bilingual proficiency, frequent/infrequent CS across different bilingual communities). Moreover, additional analyses could be conducted on the CS fluency within participants’ responses (i.e., RT taken for participants to code-switch within sentences) to examine if this other type of code-switching fluency within sentences might be correlated more significantly with EF performance. If so, this might reiterate that different types of CS tax EF to different extent. In addition, comparative studies of the CS-EF relationship in adults is also necessary to investigate similarities and differences in the CS-EF relationship across age groups using the new methodologies developed in this thesis.

Lastly, one drawback of using school exam scores (which included both reading and writing components) as a measurement of language proficiency is that these results do not accurately reflect language proficiency alone. Rather, school exam scores are often a measure of school academic outcomes/scholastic or academic skills (i.e., how good the child is at performing on standardized tests). Furthermore, reading and writing assessments are often considered to be tapping on metalinguistic knowledge. Thus, although they may be good measures of language skills required in the classroom, these measures are not necessarily critical to linguistic competence acquired under naturalistic conditions of language acquisition. In light of this, we need to be cautious in interpreting the results found in this dissertation with regard to bilingual proficiency. That is, the results obtained in this thesis may indicate that it is metalinguistic rather than naturalistic language skills that are predictive of children's EF performance. Hence, it is important for future work to distinguish between the two, since academic proficiency might be more representative of participants' metalinguistic skills rather than natural language proficiency per se.

However, it is often difficult to find a language proficiency measure that comprehensively and accurately captures all aspects of proficiency. Thus, we attempted to use these exam scores to capture one dimension of language proficiency using academic school assessments based on measures of grammar, vocabulary, comprehension and sentence formation. Furthermore, language production measures (Oral exam component as well as Elicited Imitation³) were also included as assessments of language proficiency, and we did not manage to obtain specific details on how the oral exam component was administered and/or scored. Thus, this thesis attempted as much as possible to accurately and comprehensively measure a broad concept

³ A more thorough analysis of the language production data (EI) should be carried out in the future, for more in-depth understanding of language proficiency.

of bilingual language proficiency in this thesis, which was one of the strengths of the current study. These issues confirm the need for using both direct and indirect assessments of proficiency in bilingual participants as well as for developing systematic assessments of child bilingualism to more accurately measure children's knowledge of both languages (Lust et al., 2016).

6.4. Importance of current thesis

First, this thesis demonstrated that bilingual children can code-switch effortlessly across both inter- and intra-sentential conditions. Unlike most previous adult studies, this thesis showed that cost-free switching can occur (given the low CS Fluency), and this is an important factor that motivates spontaneous switches in daily lives. The general conclusion regarding children's CS in this thesis is that CS need not be costly in terms of affecting fluency in language production, and that CS may not negatively influence EF performance in bilingual children.

Another important result pertains to the findings on language production, as seen in the Elicited Imitation results. In this task, results revealed patterned aspects of children's language which are important to the study of language acquisition in general, and this deserves follow-up in a more detailed and more extensive study. These results have important implications for the nature of language change, what happens to one language in the presence of another (i.e., influence of L1 on L2 and vice versa) and has implications for potential language attrition, even for Singlish formation and development in Singaporean bilingual children.

Next, a novel CS task was developed that more accurately captures the internally-generated nature of CS bilinguals engage in daily. In the Inter-CS condition, almost all the participants switched to another language to match the experimenter when she switched into another language across each question. Furthermore, in the intra-CS condition, participants were

also modeling the experimenter's CS (in the questions), and inserted other-language words and phrases in their responses. Previous language-switching measures are unnatural and inconsistent with natural CS, with the absence of grammatical encoding, connected speech and naturalistic cues to switching (Bullock & Toribio, 2009; Gollan, Schotter, Gomez, Murillo & Rayner, 2014; Li, Yang, Scherf & Li, 2013). Furthermore, these measures only involved single words and switching was prompted using externally-generated cues. This is unlike the CS task in this study in which the choice code-switch or not was based on the presence of trigger words (in intra-sentential condition) and whether or not the experimenter/'dialogue partner' switched (in inter-sentential condition). As Kootstra (2015) emphasized, it is important that participants' responses in language-switching tasks are internally-generated response (i.e., choice for them to switch). Although one may argue that the experimenter's questions may serve as external cue, the novel CS task developed here provided a way to study relatively natural and spontaneous CS in an experimental paradigm that would guarantee that a sufficient amount of code-switched responses in the intra-sentential condition was obtained.

In conclusion, this thesis revealed a general non-significant relationship between CS and EF, when CS was measured using the CS task that was developed here. This indirect relation holds in a developmental population where EF and bilingual language proficiency are still developing. Results here also suggest that the CS-EF relationship that has been previously found in adults may be more indirect and non-necessary than previously assumed. Lastly, results from this thesis underscore the importance of bilingual language proficiency in influencing EF performance in children, above and beyond CS ability.

REFERENCES

- Abutalebi, J., & Green, D.W. (2008). Control mechanisms in bilingual language production: Neural evidence from language switching studies. *Language and Cognitive Processes, 23*, 557-582.
- Abutalebi, J., Della Rosa, P.A., Green, D.W., Hernandez, M., Scifo, P., & Keim, R., Costa, A. (2012). Bilingualism tunes the anterior cingulate cortex for conflict monitoring. *Cerebral Cortex, 22*, 2076–2086.
- Adesope, O. O., Lavin, T., Thompson, T., & Ungerleider, C. (2010). A systematic review and meta-analysis of the cognitive correlates of bilingualism. *Review of Educational Research, 80* (2), 207–245.
- Adi-Japha, E., Berberich-Artzi, J., & Libnawi, A. (2010). Cognitive flexibility in drawings of bilingual children. *Child Development, 81*, 1356-1366.
- Alladi, S., Bak, T.H., Duggirala, V., Surampudi, B., Shailaja, M., Shukla, A.K., Chaudhuri, J.R., & Kaul, S. (2013). Bilingualism delays age of onset of dementia, independent of education and immigration status. *Neurology, 81*, 1938-1944.
- Aman, N., Appleyard, P., James, A., Bte Roslan, M., Tan, T. K., & Vaish, V. (2007). The linguistic ecology of Singapore students. Presentation to teachers of SSS 2006 participating schools. Singapore: CRPP.
- Appel, R., & Muysken, P. (1987). *Language contact and bilingualism*. London: Edward Arnold.
- Bao, Z. & Wee, L. (1999). The passive in Singapore English. *World Englishes, 18*, 1-11.
- Beauvillain, C., & Grainger, J. (1987). Accessing interlexical homographs: Some limitations of a language-selective access. *Journal of Memory and Language, 26*, 658-672.

- Best, J. R., & Miller, P. H. (2011). A developmental perspective on executive function. *Child Development, 81*, 1641-1660.
- Bhatia, T. K., & Ritchie, W. C. (1996). Bilingual language mixing, universal grammar, and second language acquisition. In *Handbook of Second Language Acquisition*, eds. W. C. Ritchie & T. K. Bhatia (San Diego: Academic Press), 627–688.
- Bialystok, E. (1999). Cognitive complexity and attentional control in the bilingual mind. *Child Development, 70*, 636-644.
- Bialystok, E., & Martin, M. M. (2004). Attention and inhibition in bilingual children: Evidence from the dimensional change card sort task. *Developmental Science, 7*, 325-339.
- Bialystok, E., Craik, F. I. M., & Ruocco, A. C. (2006). Dual-modality monitoring in a classification task: the effects of bilingualism and ageing. *The Quarterly Journal of Experimental Psychology, 59*, 1968–1983.
- Bialystok, E., Craik, F. I., & Freedman, M. (2007). Bilingualism as a protection against the onset of symptoms of dementia. *Neuropsychologia, 45*, 459–464.
- Bialystok, E., Craik, F. I. M. & Ryan, J. (2006). Executive control in a modified anti-saccade task: Effects of aging and bilingualism. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*, 1341–1354.
- Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false-belief understanding to emerging math and literacy ability in kindergarten. *Child Development, 78*, 647–663.
- Bokhorst-Heng, W. D., & Santos Caleon, I. (2008). The language attitudes of bilingual youth in multilingual Singapore. *Journal of Multilingual and Multicultural Development, 30*, 235-251.

- Braver, T. S., Reynolds, J. R., & Donaldson, D. I. (2003). Neural mechanisms of transient and sustained cognitive control during task-switching. *Neuron, 39*, 713–726.
- Bullock, B. E., & Toribio, A. J. (2009). Themes in the study of codeswitching. In B. E. Bullock & A. J. Toribio (Eds.), *The Cambridge handbook of linguistic code-switching* (pp. 1–18). Cambridge, England: Cambridge University Press.
- 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*, 399.
- Carlson, S. M., & Meltzoff, A. N. (2008). Bilingual experience and executive functioning in young children. *Developmental Science, 11*, 282–298.
- Cepeda, N. J., Kramer, A. F., & Gonzalez de Sather, J. C. M. (2001). Changes in executive control across the lifespan: Examination of task-switching performance. *Developmental Psychology, 37*, 715–730.
- Comeau, L., Genesee, F., & Lapaquette, L. (2003). The modeling hypothesis and child bilingual code-mixing. *International Journal of Bilingualism, 7*, 113–126.
- Costa, A., & Santesteban, M. (2004). Lexical access in bilingual speech production: Evidence from language switching in highly proficient bilinguals and L2 learners. *Journal of Memory and Language, 50*, 491–511.
- 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*, 59–86.

- Davidson M. C., Amso A., Anderson L. C., Diamond A. (2006). Development of cognitive control and executive functions from 4 to 13 year: Evidence from manipulations of memory, inhibition, and task-switching. *Neuropsychologia*, 44, 2037–2078.
- Eifring, H., & Theil, R. (2005). Language contact. In *Linguistics for Students of Asian and African Languages*.
- Fishman, J. A., & Cooper, R. L. (1969). Alternative measures of bilingualism. *Journal of Verbal Learning and Verbal Behavior*, 8, 276–282.
- Gade, M., & Koch, I. (2007). The influence of overlapping response sets on task inhibition. *Memory & Cognition*, 35, 603–609.
- Garbin, G., Sanjuan, A., Forn, C., Bustamante, J. C., Rodriguez-Pujadas, A., Belloch, V., & Avila, C. (2010). Bridging language and attention: Brain basis of the impact of bilingualism on cognitive control. *Neuroimage*, 53, 1272–1278.
- Gardner-Chloros, P. (ed.) (2009). *Code-switching*. Cambridge, New York: Cambridge University Press.
- Gerald, S. & Yakpo., K. (2015). Elusive or self-evident? Looking for common ground in approaches to code-switching. In Gerald Stell & Kofi Yakpo (eds.), *Code-switching between structural and sociolinguistic perspectives*, 1–16. (Linguae et Litterae 43). Berlin: De Gruyter.
- Gold, B. T., Kim, C., Johnson, N. F., Kryscio, R. J., & Smith, C. D. (2013). Lifelong bilingualism maintains neural efficiency for cognitive control in aging. *The Journal of Neuroscience*, 33, 387–396.

- Gollan, T. H., & Ferreira, V. S. (2009). Should I stay or should I switch? A cost-benefit analysis of voluntary language switching in young and aging bilinguals. *Journal of Experimental Psychology: Learning, Memory & Cognition*, *35*, 640–665.
- Gollan, T. H., Kleinman, D., & Wierenga, C. E. (2014). What's easier: Doing what you want, or being told what to do? Cued versus voluntary language and task switching. *Journal of Experimental Psychology: General*, *143*, 2167–2195.
- Gollan, T. H., Schotter, E. R., Gomez, J., Murillo, M., & Rayner, K. (2014). Multiple levels of bilingual language control: Evidence from language intrusions in reading aloud. *Psychological Science*, *25*, 585–595.
- Green, D. W. (1998). Mental control of the bilingual lexicosemantic system. *Bilingualism: Language and Cognition*, *1*, 67–81.
- Green, D. W. (2011) Language control in different contexts: The behavioral ecology of bilingual speakers. *Frontiers in Psychology*, *2*:103.
- Green, D. W. & Abutalebi, J. (2013). Language control in bilinguals: the adaptive control hypothesis. *Journal of Cognitive Psychology*, *25*, 515–30.
- Green, D.W., & Wei, L. (2014). A control process model of code-switching. *Language, Cognition & Neuroscience*, *29*, 499–511.
- Grosjean, F.(1982). *Life with two languages: An Introduction to Bilingualism*. Cambridge, MA: Harvard University Press.
- Grosjean, F. (1989). Neurolinguists, beware! The bilingual is not two monolinguals in one person. *Brain Language*, *36*, 3–15.
- Hakuta, K., Bialystok, E., & Wiley, E. (2003). Critical evidence: A test of the critical-period hypothesis for second-language acquisition. *Psychological Science*, *14*, 31–38.

- Hartanto, A., & Yang, H. (2016). Disparate bilingual experiences modulate task-switching advantages: A diffusion-model analysis of the effects of interactional context on switch costs. *Cognition, 150*, 10-19.
- Hernandez, A., Bates, E., & Avila L.X. (1996). Processing across the language boundary: A cross-modal priming study of Spanish-English bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*, 846-864.
- 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., 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.
- Hilchey, M. D., & Klein, R. M. (2011). Are there bilingual advantages on nonlinguistic interference tasks? Implications for plasticity of executive control processes. *Psychonomic Bulletin & Review, 18*, 625-658.
- Iluz-Cohen, P., & Armon-Lotem, S. (2013). Language proficiency and executive control in bilingual children. *Bilingualism: Language and Cognition, 16*, 884-899.
- Kang, C., Thoemmes, F., & Lust, B. (2015). An Assessment of the Effects of SES on the Development of Executive Attention: 4 to 6-year-old English-Malay Bilinguals in Singapore. *Bilingualism: Language and Cognition, 19*, 1042–1056.
- Kang, C., Yow, W.Q., Li, N., & Lust, B. (2015). Code-switching in Singaporean English-Mandarin 5-6 year-olds reveals grammatical interaction. Paper presented at the 10th International Symposium on Bilingualism, Rutgers, NJ.

- Kim, A., Park, A., & Lust, B. (2016). Simultaneous vs. successive bilingualism among preschool-aged children: A study of four-year-old Korean-English bilinguals in the USA. *International Journal of Bilingual Education and Bilingualism*, 1-15.
- Kleinman, D., & Gollan, T. H. (2016). Speaking two languages for the price of one: Bypassing language control mechanisms via accessibility-driven switches. *Psychological Science*, 27, 700-714.
- Kootstra, G. J. (2015). A psycholinguistic perspective on code-switching: Lexical, structural, and socio-interactive processes. In G. Stell & K. Yakpo (Eds.), *Code-switching between structural and sociolinguistic perspectives*. (pp. 39-64). Berlin: De Gruyter.
- Kovács, A., & Mehler, J. (2009). Flexible Learning of Multiple Speech Structures in Bilingual Infants. *Science*, 325, 611-612.
- Kroll, J. F., & De Groot, A. M. B. (1997). *Lexical and conceptual memory in the bilingual: Mapping Form to Meaning in Two Languages*. In A.M.B. De Groot & J. F. Kroll (Eds.), *Tutorials in bilingualism: Psycholinguistic perspectives* (pp. 169-199). Mahwah, NJ: Lawrence Erlbaum Publishers.
- Kroll, J. F., S. C. Bobb, & Z. Wodniecka. (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., Dussias, P. E., Bogulski, C. A. & Valdes Kroff, J. R. (2012). Juggling two languages in one mind: What bilinguals tell us about language processing and its consequences for cognition. *Psychology of Learning and Motivation: Advances in Research and Theory*, 56, 229– 262.
- Kroll, J. F., & Bialystok, E. (2013). Understanding the consequences of bilingualism for

- language processing and cognition. *Journal of Cognitive Psychology*, 25, 497–514.
- Kroll, J. F., Dussias, P. E., Bice, K., & Perrotti, L. (2015). Bilingualism, mind, and brain. In M. Liberman, & B. H. Partee (Eds.), *Annual Review of Linguistics*, 1, 377–394.
- Linck, J., Schwieter, J., & Sunderman, G. L. (2012). Inhibitory control predicts language switching performance in trilingual speech production. *Bilingualism: Language and Cognition*, 15(3), 651-662.
- Luk, G., Bialystok E., Craik F. I. M., & Grady C. L. (2011). Lifelong bilingualism maintains white matter integrity in older adults. *Journal of Neuroscience*, 31, 16808–16813.
- 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, 588-595.
- Luk, G., Green, D. W., Abutalebi, J., & Grady, C. L. (2012). Cognitive control for language switching in bilinguals: A quantitative meta-analysis of functional neuroimaging studies. *Language and Cognitive Processes*, 27, 1479–1488.
- Luk, G., & Bialystok, E. (2013). Bilingualism is not a categorical variable: Interaction between language proficiency and usage. *Journal of Cognitive Psychology*, 25, 605–621.
- Luria, A. R. (1966). *Higher cortical functions in man*. New York: Basic Books.
- Marian, V., Spivey, M. & Hirsch, J. (2003). Shared and separate systems in bilingual language processing: Converging evidence from eye-tracking and brain imaging. *Brain and Language*, 86, 70–82.
- 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, 1–13.

- McClelland, M. M., Cameron, C. E., McDonald Connor, C., Farris, C. L., Jewkes, A. M., & Morrison, F. J. (2007). Links between early self-regulation and preschoolers' literacy, vocabulary, and math skills. *Developmental Psychology, 33*, 947–959.
- Meiran, N. (2000). Reconfiguration of stimulus task sets and response task sets during task switching. In S. Monsell & J. Driver (Eds.), *Attention and performance XVIII: Control of cognitive processes* (pp. 377–400). Cambridge, MA: MIT Press.
- Meiran, N., Chorev, Z., & Sapir, A. (2000). Component processes in task switching. *Cognitive Psychology, 41*, 211–253.
- Meuter, R. (2005). Language selection in bilinguals: Mechanisms and processes. In J.F. Kroll & A.M.B. De Groot (Eds.), *Handbook of bilingualism: Psycholinguistic approaches* (pp. 349–370). New York, NY: Oxford University Press.
- 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.
- Miccio, A. W. , Hammer, C. S. , Rodríguez, B. L. (2009). Code-switching and language disorders in young bilingual children. In *Handbook on Linguistic Code-Switching*, ed. J. Toribio, B. Bullock, pp. 241–52. New York: Cambridge Univ. Press.
- 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*, 49–100.
- Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences, 7*, 134–140.
- Muysken, P. (2000). *Bilingual Speech: A Typology of Code-Mixing*. Cambridge: Cambridge University Press.
- Myers-Scotton, S. (1993). Common and uncommon ground: Social and structural factors in

- codeswitching. *Language in Society*, 22, 475–503.
- Myers-Scotton, S. (1997). Structural uniformities vs. community difference in codeswitching. In R. Jacobson (Ed.), *Codeswitching worldwide* (pp. 91–108). Berlin: Mouton de Gruyter.
- OECD, Hanushek, E., Woessmann, L. (2015). *Universal Basic Skills: What Countries Stand to Gain*, OECD Publishing, Paris.
- Paap, K. R., & Sawi, O. (2014). Bilingual advantages in executive functioning: Problems in convergent validity, discriminant validity, and the identification of the theoretical constructs. *Frontiers in Psychology*, 5.
- Paap, K. R., Johnson, H. A., & Sawi, O. (2014). Are bilingual advantages dependent upon specific tasks or specific bilingual experiences?, *Journal of Cognitive Psychology*, 26, 615–639.
- Paap, K. R., & Greenberg, Z. I. (2013). There is no coherent evidence for a bilingual advantage in executive processing. *Cognitive Psychology*, 66, 232–258.
- Philipp, A.M., & Koch, I. (2009). Inhibition in language switching: What is inhibited when switching between languages in naming tasks? *Journal of Experimental Psychology: Learning, Memory & Cognition*, 35, 1187–1195.
- Posner, M. I. & Fan, J. (2004). Attention as an Organ System. James R. Pomerantz and Michael C. Crair, Eds. *Topics in Integrative Neuroscience: From Cells to Cognition*. Cambridge UK: Cambridge University Press.
- Posner, M. I., & Petersen, S. E. (1990). The attention systems of the human brain. *Annual Review of Neuroscience*, 13, 25–42.
- Posner, M. I., & Rothbart, M. K. (2000). Developing mechanisms of self-regulation. *Developmental Psychopathology*, 12, 427–441.

- Price, C. J., Green, D. W., & Studnitz, R. V. (1999). A functional imaging study of translation and language switching. *Brain*, *122*, 2221–2235.
- Prior, A., & Gollan, T.H. (2011). Good Language-Switchers are Good Task-Switchers: Evidence from Spanish–English and Mandarin–English Bilinguals. *Journal of the International Neuropsychological Society*, *17*, 682–691.
- Prior, A., & Gollan, T. H. (2013). The elusive link between language control and executive control: A case of limited transfer. *Journal of Cognitive Psychology*, *25*, 622–645.
- Prior, A., & MacWhinney, B. (2010). A bilingual advantage in task switching. *Bilingualism: Language and Cognition*, *13*, 253–262.
- 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*, 422–433.
- Rodriguez-Fornells, A., Krämer, U. M., Lorenzo-Seva, U., Festman, J., & Münte, T. F. (2012). Self-assessment of individual differences in language switching. *Frontiers in Psychology*, *2*, 1-15.
- Rubin, O., & Meiran, N. (2005). On the origins of the task mixing cost in the cued task switching paradigm. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *31*, 1477–1491.
- Soveri, A., Rodriguez-Fornells, A., & Laine, M. (2011). Is there a relationship between language switching and executive functions in bilingualism? Introducing a within-group analysis approach. *Frontiers in Psychology*, *2*, 1-8.

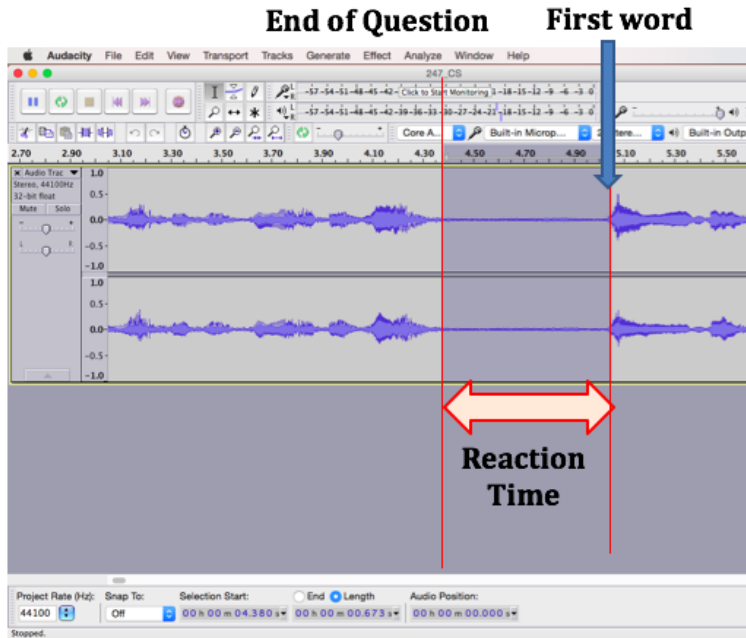
- Sebastian-Galles, N., Albareda-Castellot, B., Weikum, W. M., & Werker, J. F. (2012). A bilingual advantage in visual language discrimination in infancy. *Psychological Science*, 23, 994-999.
- Scaltritti, M., Peressotti, F., & Miozzo, M. (2015). Bilingual advantage and language switch: What's the linkage?, *Bilingualism: Language and Cognition, FirstView Article*, 1–18.
- Valian, V. (2015). Bilingualism and Cognition. *Bilingualism: Language and Cognition*, 18, 3–24.
- Verhoef, K., Roelofs, A., & Chwilla, D.J. (2009). Role of inhibition in language switching: Evidence from event-related brain potentials in overt picture naming. *Cognition*, 110, 84–99.
- Videsott, G., Rosa, P., Wiater, W., Franceschini, R., and Abutalebi, J. (2012). How does linguistic competence enhance cognitive functions in children? A study in multilingual children with different linguistic competences. *Bilingualism: Language and Cognition*, 15, 884–895.
- Wang, H., and Fan, J. (2007). Human attentional networks: a connectionist model. *Journal of Cognitive Neuroscience*, 19, 1678–1689.
- Wang, Y., Kuhl, P. K., Chen, C., & Dong, Q. (2009). Sustained and transient language control in the bilingual brain. *Neuroimage*, 47, 414–422.
- Wang, Y., Xue, G., Chen, C., Xue, F., & Dong, Q. (2007). Neural basis of asymmetric language switching in second-language learners: An ER-fMRI study. *Neuroimage*, 35, 862–870.
- Weikum, W. M., Vouloumanos, A., Navarra, J., Soto-Faraco, S., Sebastian-Galles, N., & Werker, J.F. (2007). Visual Language Discrimination in Infancy. *Science*, 316, 1159.
- Wiseheart, M., Viswanathan, M., & Bialystok, E. (2016). Flexibility in task switching by monolinguals and bilinguals. *Bilingualism: Language & Cognition*, 1-6.

- Wu, Y. J., & Thierry, G. (2010). Chinese-English bilinguals reading English hear Chinese. *Journal of Neuroscience*, *2*, 7646-7651.
- Xu, D., Chew, C. H., & Chen, S. (1998). Language use and language attitudes in the Singapore Chinese community. In S. Gopinathan, A. Pakir, W. K. Ho, & V. Saravanan (Eds.), *Language, society and education in Singapore* (2nd ed., pp. 133–154). Singapore: Eastern Universities Press
- Yakpo, K. (2015). Codeswitching and social change: Convergent language mixing in a multilingual society. In Gerald Stell & Kofi Yakpo (eds.), *Codeswitching between structural and sociolinguistic perspectives*, 259–287. (Linguae et Litterae 43). Berlin: De Gruyter.
- Yeung, N., & Monsell, S. (2003). The effects of recent practice on task switching. *Journal of Experimental Psychology: Human Perception and Performance*, *29*, 919–936.
- Yim, O. & Bialystok, E. (2012). Degree of conversational code-switching enhances verbal task switching in Cantonese–English bilinguals. *Bilingualism: Language and Cognition*, *15*, 873-883.

Appendix

Appendix A: Analysis of CS Fluency data

Fig. 1. How CS Fluency data was computed in Audacity.



Appendix B: Modified English and Chinese Stroop tasks

Fig. 1. English Stroop.

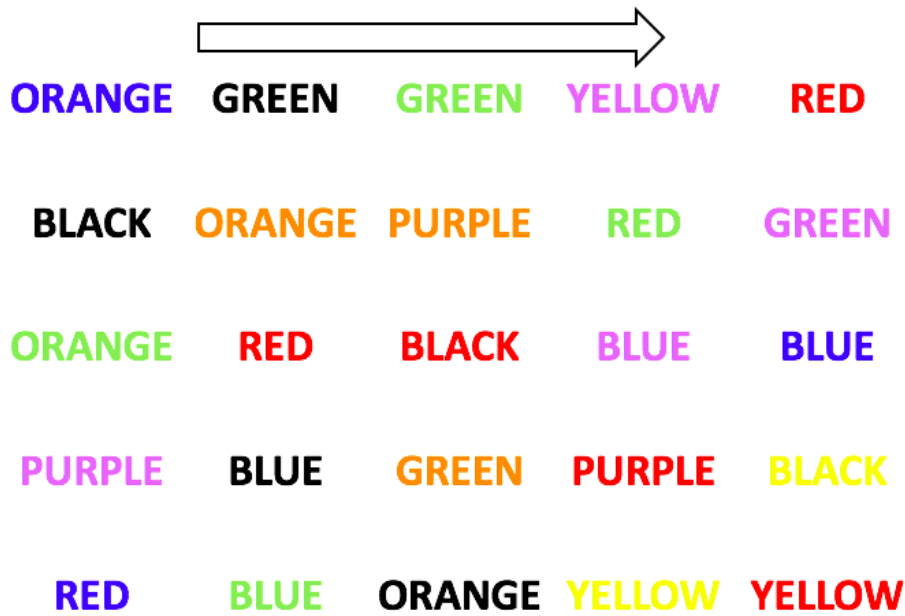
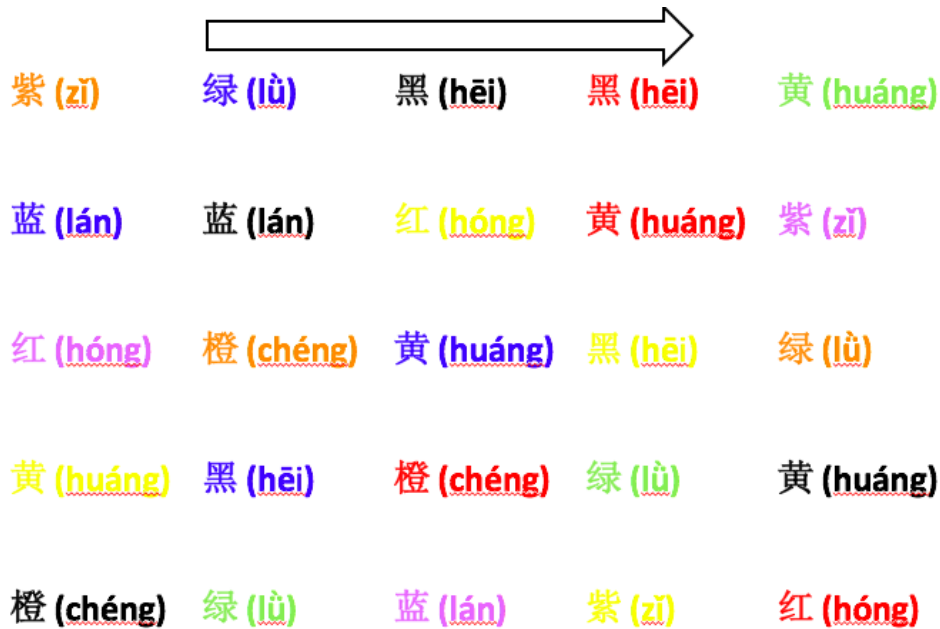


Fig. 2. Chinese Stroop.



Appendix C: English and Chinese Elicited Imitation Sentences

English Elicited Imitation Sentences

1. Billy dropped the penny, when he saw the cat. [RB F Pron]
2. When he colored the books, Alex drank the milk. [LB B Pron]
3. Daddy, when singing the song, washed the baby. [LB F Null]
4. Bill ate the apple when coloring the book. [RB F Null]

Chinese Elicited Imitation Sentences

1. 当 他 看 见 小 猫 的 时 候, 哥 哥 把 硬 币 掉 了。 [LB B Pron 1]
when he see little cat time-Rel., brother ba penny drop-ASP(Perf).
(When he saw the cat, brother dropped the penny.)
2. 当 他 给 书 涂 颜 色 的 时 候, 哥 哥 喝 了 牛 奶。 [LB B Pron 2]
When he give book paint color time-Rel., brother drink-ASP(Perf) milk.
(When he was coloring the book, brother drank milk.)
3. 爸 爸 当 唱 歌 的 时 候, 洗 洗 娃 娃。 [LB F Null]
Dad, when sing song time-Rel., wash baby.
(Dad, when singing the song, washed the baby.)
4. 当 给 书 涂 颜 色 的 时 候, 姐 姐 吃 了 苹 果。 [LB B Null]
When give book apply color time-Rel., sister eat-ASP(Perf) apple.
(When coloring the book, sister ate the apple.)

*Key: ASP(Perf): Perfective aspect, time-Rel.: Relative time, RB: Right-branching, LB: Left-branching, F: forward, B: backward, Pron: pronoun.

Appendix D: Scoring Criteria for Elicited Imitation Task

English and Chinese EI

1. Alteration of original sentence structure is scored as incorrect in the following instances:

a. Clause Reversal

Stimulus: Billy dropped the penny when he saw the cat.

Response: When he saw the cat, Billy dropped the penny.

b. Omission of a clause

Stimulus:

当他给书涂颜色的时候,哥哥喝了牛奶。

When he give book apply color time-Rel., brother drink-ASP(Perf) milk.

Response:

当他...在...他在喝牛奶。

when he V he V drink milk.

c. Topicalization omission

Stimulus: Daddy, when singing the song, washed the baby

Response: When Daddy sing the song, washed the baby

Stimulus:

爸爸当唱歌的时候,洗洗娃娃。

Dad, when sing song time-Rel., wash baby.

Response:

当爸爸唱歌的时候,洗洗娃娃

when father sing song time-Rel., wash baby.

d. Incorrect verb form (tense): ‘saw’ for ‘seen’ or ‘drinking’ for ‘drank’

Stimulus: When he colored the books, Alex drank the milk.

Response 1: When he colors the book, Alex drank the milk.

Response 2: When he colored the books, Alex drinks the milk.

Stimulus:

当他看见小猫的时候,哥哥把硬币掉了。

when he see little cat time-Rel., brother V penny drop-ASP(Perf).

Response:

当哥哥看到猫的时候,又把硬币掉了。

when brother see cat time-Rel., again V coin drop-ASP(Perf).

Stimulus:

当 给 书 涂 颜 色 的 时 候, 姐 姐 吃 了 苹 果。
when give book paint color time-Rel., sister eat-ASP(Perf) apple.

Response:

当 给 书 涂 了 颜 色 的 时 候, 姐 姐 吃 了 水 果。
when give book paint ASP(Perf) color time-Rel., sister eat-ASP(Perf) fruit.

e. All pronominalization errors were scored as incorrect. Subcategories are:

i. Adding Pronoun

Stimulus: Bill ate the apple when coloring the book.

Response: Bill ate the apple, when he coloring the book.

Stimulus:

当 给 书 涂 颜 色 的 时 候, 姐 姐 吃 了 苹 果。
when give book paint color time-Rel., sister eat-ASP(Perf) apple.

Response:

当 她 在 擦 色, 姐 姐 吃 了 苹 果。
when she PROG paint color, sister eat-ASP(Perf) apple.

ii. Deleting Pronoun

Stimulus:

当 他 给 书 涂 颜 色 的 时 候, 哥 哥 喝 了 牛 奶。
When he give book apply color time-Rel., brother drink-ASP(Perf) milk.

Response:

当 把 书 涂 颜 色 的 时 候, 哥 哥 喝 了 奶。
when ba book apply color time-Rel., brother drink-ASP(Perf) milk.

iii. Changing a NP to a Pronoun

Stimulus: Daddy, when singing the song, washed the baby.

Response: When daddy was singing the song, he washed the baby.

iv. Adding NP

Stimulus: Daddy, when singing the song, washed the baby.

Response: When Daddy sing a song, Daddy washed the baby.

v. Deleting determiner

Stimulus: Daddy, when singing the song, washed the baby.

Response: Daddy, when singing the song, washed baby.

vi. Deleting/Changing connective

Stimulus: Daddy, when singing the song, washed the baby.

Response: Daddy, singing a song, washed the baby.

Stimulus:

当他给书涂颜色的时候,哥哥喝了牛奶。
When he give book apply color time-Rel., brother drink ASP(Perf) milk.

Response 1: [Connective Change]

当他给书涂了颜色后,当哥哥喝了牛奶。
when he give book apply-ASP color after, when brother drink-ASP(Perf). milk.

Response 2: [Connective Omissions and change]

他给书涂了颜色后,哥哥喝了牛奶。
he give book paint-ASP color after brother drink-ASP(Perf) milk.

2. Major changes in constituents of sentence were scored as incorrect

Stimulus: Bill ate the apple when coloring the book.

Response: Bill ate the color when coloring the book.

3. The following changes were scored as correct:

- a. Article changes: 'a' to 'the' or 0 to 'the' to 'a' or 0
- b. Changes in conjunction: 'when' to 'while'
- c. Additions to original sentences which do not produce a change in meaning or essential structure (i.e., addition of adverbs, particles, etc.)
- d. False starts and self-corrections were scored as correct as long as the sentence did not completely consist of self-corrections.

4. Other mistakes:

a. Reduction of complex Verb Phrase

Stimulus:

当给书涂颜色的时候,姐姐吃了苹果。
when give book paint color time-Rel. sister eat-ASP(Perf) apple.

Response:

当给书涂了时候,姐姐吃了苹果。
when give book paint-ASP(Perf) time sister eat-ASP(Perf) apple.