Effects of Bilingualism on Cognitive Control:
Considering the Age of Immersion and Different Linguistic Environments

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Thesis submitted to the
Faculty of Arts
in partial fulfillment of the requirements
for the Doctorate in Philosophy degree in Linguistics

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Tuksnesis slēpj sevī kādu aku, un tas padara to skaistu.
What makes the desert beautiful is that somewhere it hides a well.
砂漠が美しいのは、どこかに井戸を隠しているからだよ.
Ce qui embellit le désert, c'est qu'il cache un puits quelque part.

Antoine de Saint-Exupéry
The Little Prince

Acknowledgements

While research and writing can be lonely work, I have been truly lucky to have amazing support and encouragement throughout this process from family, friends, and colleagues on three continents. I would like to thank everyone who, whether they know it or not, has had an impact on this work!

A sincere thank you to my *super*visor Dr. Laura Sabourin, who introduced me to the field of psycholinguistics in 2007, and who has been a wonderful teacher, mentor, and friend ever since. Thank you for inspiring me, motivating me, accepting my quirks, and giving me a chance to be an ERPLing.

Thank you also to all of the professors in the Department of Linguistics at the University of Ottawa. A special thank you to Dr. Tania Zamuner, who had an indescribable influence on my decision to pursue grad school.

Thank you to Dr. Nigel Duffield at Konan University and to Dr. Ayumi Matsuo at Kobe College for making the work on Japanese-English bilinguals possible, and for letting me borrow their students and their dog.

Research in Japan would also not have been possible without the Watanabe family and the Kano family.お世話になりましたことを深く感謝いたします。心よりありがとうございます。

I have been fortunate to be part of a fantastic research team, and none of this would have been possible without my fellow ERPLings. Thank you to Dr. Christie Brien, Michèle Burkholder, Joy Yu Ying Li, and Dr. Yoriko Aizu for all the academic discussions, random chats, sushi, and continued friendship. Thank you also to all the ERPLing Lab members, and especially to Chantal Farhat, Natalie Ho, Sameer Ratti, and Cooper Rigg for their assistance with data collection in Canada. For their assistance with data collection in Japan, I would like to thank Natsuno Aoki and Takuya Inui.

Thank you also to friends in Latvia, Canada, and Japan, with special thanks to Kim Allenby, Julia Bassili, Toms Bergs, Jessie Daly, Kanako Endo, Kristy Kirkup, Yoko Maeda, Elīna Sedleniece, Lori Sops, Patrique Tardif, and Stephanie White.

The biggest thank you of all goes to my parents Mileta and Inārs and to my sister Linda. A whole book would not suffice to tell you how grateful I am! Es jūs ļoti, ļoti mīlu!!! ♥♥♥

Abstract

Cognitive control-e.g. the abilities to pay attention, to ignore irrelevant input, and to switch between tasks- has received much attention in recent literature. Since both of their languages are activated in parallel, bilinguals have been suggested to have improved cognitive control skills in both the linguistic and non-linguistic domain (e.g., Bialystok, 2017), but inconsistent results (e.g., Hilchey, Saint-Aubin, & Klein, 2015) have lead to a heated debate in the field. However, when found, the effects of bilingualism on cognitive control appear to be generally positive (Valian, 2015). Furthermore, earlier bilingualism has been linked to greater cognitive benefits (Yow & Li, 2015), and Green and Abutalebi's (2013) Adaptive Control Hypothesis (ACH) suggests that the bilingual environment also plays a role. The aim of the current study is to investigate the role of the Age of Acquisition (AoA) of the second language on cognitive control in young adult bilinguals in two different linguistic environments, as well as to examine the underlying processes of cognitive control via event-related brain potentials (ERPs). Two research questions are focused on: 1) Which, if any, cognitive control abilities are enhanced by bilingualism? and 2) Does the type of bilingual experience modulate observed effects?

The present study uses the non-linguistic Attention Network Test (ANT; Fan et al., 2002), in which sets of arrows appear with a central target arrow in either a congruent (e.g. ← ← ←) or incongruent (e.g. ← → ←) condition, to examine Alerting, Orienting, and Executive Control networks, and a linguistic Stroop task (Stroop, 1935), in which colour terms appear in congruent (i.e. the word "red" presented in red font) and incongruent (i.e. the word "red" presented in green font) conditions, to examine language processing of English-French bilinguals in Canada and in Japanese-English bilinguals in Japan. In addition, Canadian participants also completed an ERP version of the Stroop task to examine possible underlying differences.

The results of this series of experiments revealed a complex, yet interesting picture of bilingual cognitive control: although bilingual advantages were not consistent, there was support for earlier bilingualism being more beneficial to cognitive control. Particularly, results show Executive Control advantages for Simultaneous bilinguals, and significant differences between Simultaneous and Early Sequential bilinguals (typically grouped together as "early") in the Stroop task, demonstrating that balanced, proficient bilingualism enhances both linguistic and non-linguistic control. Interestingly, these effects only become apparent when both languages are mixed in the task, in line with suggestions that young adults' cognitive resources need to be maximally taxed before advantages become apparent. Indeed, ERP results confirmed a greater engagement of cognitive resources in the more difficult version of the task. Although AoA and environment turned out to be confounded, there were still differences between Canadian and Japanese participants. Most notably, Canadian participants appeared to have better Executive Control.

Taken together, the current work concludes that despite increased processing load, bilingual cognition does not suffer. Instead, cognition may receive a boost from dual language experience in some cases. Several rarely-explored factors were examined, and the complex results suggest possible areas that would benefit from further exploration, as well as raise interesting questions for future research.

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List of Abbreviations

ACH	Adaptive Control Hypothesis
ACC	Anterior Cingulate Cortex
AoA	Age of Acquisition
AoI	Age of Immersion
ANT	Attention Network Test
BEPA	Bilingual Executive Processing Advantage
BIA	Bilingual Interactive Activation (model)
BICA	Bilingual Inhibitory Control Advantage
CMA	Conflict Monitoring Advantage
GCA	Generalized Cognitive Advantage
EEG	Electroencephalography
EF	English-French
ERP	Event-related brain potentials
FE	French-English
ICM	Inhibitory Control Model
JE	Japanese-English
L1	First language
L2	Second language
pre-SMA	pre-supplementary motor area
RITL	Rapid Instructed Task Learning
RT	Reaction Time
SA	Switching Advantage

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Chapter 1. Introduction: Bilingual Lexical Access and the Need for Cognitive Control

According to the European Commission, 65.7% of European Union citizens speak at least one additional language (Eurostat, 2015), while Statistics Canada reports that 63.5% of Canadians speak two languages in general (2011)[1] and 54.5% of people with a native language other than English or French speak their native language and an official language in the home (2017). Although no data exist for the world at large, it is has been estimated that about half of the world's population is bilingual (Grosjean, 2010). Given the prevalence of bilingualism, researchers from a number of fields, including psycholinguistics, have become increasingly interested in the effects of knowing two (or more) languages on not only language processing, but also on general cognition (Kroll & Bialystok, 2013). The former line of research has been concerned with the representation of both languages in the mental lexicon, the nature of lexical access, and modelling bilingualism, while for the latter, of particular interest has been the link between bilingualism and cognitive control − a set of processes that include, but are not limited to, inhibition, attention, conflict monitoring and resolution, selection, and task switching.[2] Although speaking two languages has clear communicative, social, and professional advantages, whether bilingualism also confers cognitive control advantages is the subject of intense ongoing debate (e.g. Della Sala & Grafman, 2015).

[1] Data from the 2016 Census does not provide an overall percentage of bilinguals in Canada.
[2] These processes are also sometimes referred to as "executive control". It is important to note that while the terms "cognitive control" and "executive control" tend to be used interchangeably, they do not necessarily carry the same meaning in every instance. For the purpose of the current paper, "cognitive control" is used as a broad definition for the multitude of processes used by the cognitive system for information processing and management. "Executive control" is used for the specific attentional network in the ANT, as defined by Fan et al., (2002).

This dissertation explores the effects of bilingualism on both linguistic and general cognitive control processes through the use of a linguistic Stroop task (Stroop, 1935) and a non-linguistic Attention Network Test (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002) in samples of age- and education- matched non-immigrant young adult bilinguals. It takes into consideration the highly heterogeneous nature of bilingualism, and rather than being separated based on monolingual or bilingual status, the bilingual sample is divided into Age of Acquisition (AoA) groups. Importantly, AoA grouping also include a separate group for simultaneous bilinguals- a distinction that is often not made in the existing literature, where simultaneous and early sequential bilinguals are often grouped together and classified as a single "early" group. This dissertation aims to examine the conditions, if any, under which bilingualism has an effect on linguistic and non-linguistic cognitive control, and to link these effects to different types of bilingual experiences.

1.1 Overview of the Chapters

The remainder of Chapter 1 will briefly discuss bilingual language processing, focusing on the non-selective nature of bilingual lexical access and resulting cross-activation of two languages. It will then define the concept of "cognitive control". This will be followed by an overview of the experiments used in this dissertation.

Chapter 2 will provide the background to the current studies by examining previous bilingual cognitive control literature in detail. It will look at both the proposed bilingual advantage view, as well as the controversy surrounding it. Furthermore, it will look at some of the factors, including group characteristics and methodological considerations, that may affect the mixed results in this field. Both behavioural and neural aspects of bilingual cognitive control will be discussed. Although code-switching behaviours may affect cognitive control, a discussion of the literature in this field of research is beyond the scope of the current dissertation.

Chapter 3 will present an examination of non-linguistic cognitive control via the ANT task, while Chapter 4 will present the methodology and results of an examination of linguistic cognitive control via the Stroop task. Data from two populations- Canadian and Japanese- will be discussed for both experiments. This will be followed by Chapter 5, which will present a pilot study examining the neurophysiological consequences of bilingualism in the linguistic Stroop task.

Finally, Chapter 6 will summarize the findings of all three experiments and discuss them with respect to the heterogeneous nature of bilingualism and the bilingual environment. Implications for bilingualism research and the field of psycholinguistics, as well as education, will be discussed, and future directions will be suggested.

1.2 Bilingual Lexical Access and Cross-Activation of Two Languages

A body of literature has shown that a bilingual's languages are accessed in a parallel, non-selective manner, and as a result, there is cross-activation of the two (see Kroll & Dussias, 2013). As Kroll and Dussias (2013) note, this cross-activation is seen even in the most proficient bilinguals, and is not just restricted to learners, who have yet to master their second language (L2) and might therefore be expected to have interference from their first language (L1). Much work has investigated the nature of this cross-activation, showing that it exists at many levels and in different contexts (e.g., Libben & Titone, 2009; Kroll, Dussias, Bogulski, & Valdes Kroff, 2012; Kroll & Dussias, 2013), and that the degree of activation can be influenced by factors including proficiency (Blumenfeld & Marian, 2007; 2013) and the bilingual setting (e.g. Grosjean, 2001; 2013). Although a thorough examination of bilingual lexical access is beyond the scope of the current work, a few illustrative examples are discussed in this section to demonstrate the need for the cognitive control mechanisms discussed in the following section. Because the current experiments are concerned with visual word recognition and comprehension processes, these will be the focus, and production processes will be discussed only briefly.

Current models of the bilingual mental lexicon differ in details regarding the organization of the bilingual mental lexicon and the exact pathways involved in bilingual lexical access, but whether these models look at comprehension of spoken or of written language, or production of spoken language, a common element in all is that a bilingual's languages are linked to some degree. The Bilingual Model of Lexical Access (Léwy &Grosjean, 2008) for speech perception, consisting of three nodes- Features, Phonemes, and Words, posits that while the Phoneme and Word nodes store each language separately, the initial Features node is shared by both. In other words, both languages are active at the initial stages of processing.

Similarly, the Bilingual Interactive Activation model (BIA; Dijkstra & Van Heuven, 1998), a model concerned with visual word recognition, includes Features and Letters nodes shared by the two languages. Its updated theoretical version, Bilingual Interactive Activation Plus (BIA+; Dijkstra & Van Heuven, 2002), adds connections not only between orthographic, but also between phonological and semantic nodes. Both phonological and semantic representations, say the authors, are also activated for both languages, though due to factors such as frequency, the L2 is activated slightly after the L1, resulting in cross-linguistic effects (e.g., priming, lexical decision) being larger in the L1 to L2 direction.

For language production, too, there are connections between the two languages. De Bot's (2004) Multilingual Processing Model shows that at the lemma level, both languages are activated by conceptual information. This in turn can activate words and phonemes in both languages. However, this model also posits that the intent to speak the target language constrains the activation of the non-target language. For an excellent overview of this production model and others, see Hall (2011). Regardless of the model, there appears to be consensus that both languages are active simultaneously, at least in the initial stages, during both speech comprehension and speech production.

Experimental evidence also supports activation of both of a bilingual's languages. Some of this evidence for cross-activation comes from cognates and interlingual homographs (e.g. Dijkstra, Grainger, & van Heuven, 1999; Hoshino & Thierry, 2012), where there is a clear overlap between the two languages in terms of sound and/or written form (e.g., English word COIN, and French word COIN, meaning "corner"). These effects are even found when the written form is presented using vastly different writing systems, as demonstrated by Hoshino and Kroll (2008). The authors found facilitation for both Spanish-English cognate pairs (e.g., GUITARRA and GUITAR), as well as for Japanese-English cognate pairs, where Japanese words were presented in the katakana syllabary (e.g., GUITAR and ギター[gitaa]). Given the phonological and orthographic similarity, cross-language activation may be expected in the case of cognates and interlingual homographs. However, suggesting that bilingual lexical access is truly non-selective, there is also evidence for simultaneous activation from non-cognates, and even if the bilingual is using only one language.

Looking at comprehension processes, Marian and Spivy (2003) tested English-Russian bilinguals using eye-tracking to examine whether there is phonological interference in the first language (L1), the second language (L2), and importantly, between languages. In the within-language condition of this study, participants were presented with a display of 4 objects- a target, a distracter with an overlapping sound, and two unrelated control items (e.g. for the target SHOVEL, a SHARK was also given, along with control items such as CARD). Critically, in the between-language condition, one of the control items was replaced with a distracter in the non-target language that overlapped with the target (e.g. for the target SHOVEL, a SHARK and a BALLOON -*sharik* in Russian- were also given, along with a control such as CARD). Participants were asked to pick up the target object, while their eye movements were tracked and the proportion of fixations to each object in the display was measured.

As expected, participants showed within-language interference. When asked for a shovel, a significant proportion of the participants' fixations also fell on the shark (compared to the non-overlapping control item). Supporting activation of the both languages, in the between-language condition, a larger proportion of the fixation fell on the balloon (*sharik*) than on the control item. This was the case even when the participant was tested in an English environment, by an English-speaking researcher, using English-only instructions; there was still interference from the Russian distracter. The authors conclude that while a number of factors, including L2 proficiency and language dominance, can affect the degree of interference, both languages are active even when only one is used.

This cross-language activation is not limited to phonology and comprehension of spoken words, but also extends to the written modality (e.g. Hoshino, Midgley, Holcomb, & Grainger, 2010; Hoshino & Thierry, 2012; Sabourin, Brien, and Burkholder,2014). For example, Sabourin et al., (2014) used a masked priming lexical decision paradigm with English-French bilinguals to examine whether cross-language activation exists at other levels. In this task, participants identified whether a word displayed on a screen was a real word or not, but prior to presentation of the target word, a subliminal prime word that was either semantically-related or a translation equivalent was presented (e.g., the target word APPLE could be preceded by the semantically-related *pie* or the French translation equivalent *pomme*). In addition, an unrelated prime (e.g., *web*) was presented as a control. Reaction times (RTs) and accuracy were measured. The authors found that there was within-language semantic priming and importantly, also translation priming, although the latter was limited to simultaneous bilinguals and bilinguals with an early Age of Acquisition (AoA). However, importantly, the presence of non-cognate translation priming between English and French once again demonstrates that the bilingual's two languages are connected.

In a visual task such as lexical decision, which relies on the activation of language through reading, even languages that do not share a writing system demonstrate simultaneous activation. Ando, Matsuki, Sheridan, and Jared (2015) used a masked priming lexical decision task with English targets and Japanese phonological primes to test Japanese-English bilinguals in an English environment. This task combined English words written in alphabet with Japanese words written in the Japanese katakana syllabary, and found that even though the primes were presented in a different language *and* a different script, there were still facilitation effects. Thus, it appears that regardless of the language and the modality, there is cross-activation of a bilingual's two languages during comprehension.

Similarly, both languages appear to be active during production. However, this field of study is far more complex than that of comprehension, as in some cases, production processes can be confounded with comprehension processes. For example, bilinguals may be asked to read aloud one word in the presence of another (e.g., Costa, Miozzo, & Caramazza, 1999), thereby adding an element of written word recognition (along with comprehension processes involved in reading) to the task. Still, even studies with confounds can demonstrate the simultaneous activation of both languages.

Kaushanskaya and Marian (2007) used a picture-word interference task, in which a picture must be named in the presence of distracting information, and eye-tracking with Russian-English bilinguals to examine whether words presented in the non-target language could affect naming times and eye movements when asked to name a picture in the target language. Longer naming times of the picture and significant fixations to the non-target language word compared to control items did suggest that even in a naming task, both languages are activated. Despite the confound introduced by the written word, this production task does show the interference of the non-target language, and therefore cross-activation of the two.

Using picture-naming only, thereby eliminating the confound created by written word recognition, Colomé and Miozzo (2010) showed Spanish-Catalan bilinguals overlapping pictures, each in a different colour, and asked participants to name the one indicated by a specific colour. Experiment 1 involved Spanish-Catalan cognates, while Experiment 2 used Catalan items with phonologically-similar Spanish distracters. Demonstrating clear cross-language activation, Experiment 2 found that phonologically-similar distracters in the non-target language were able to facilitate naming of the stimulus in the target language, suggesting activation of the target's non-target counterparts. The field of bilingual production research is complex, with several factors affecting the degree of cross-language activation; still, when viewed overall, the argument appears to be in favour of the production system as a whole, like the comprehension system, being non-selective (see the excellent overview by Kroll, Bobb, & Wodniecka, 2006 for more information).

1.3 Managing Two Languages: A Need for Cognitive Control Processes

It is now widely accepted that lexical representations of both languages are active simultaneously, and as seen in the previous section, evidence suggests that there is cross-activation during both comprehension and production. This activation of both languages is believed to result in competition between the two (e.g., Kroll, Bobb, & Hoshino, 2014), although the exact nature of competition is still debated (Hall, 2011). Roelofs, Piai, Garrido Rodriguez, and Chwilla (2016) summarize three main views from the literature. The first, between-language competition, views both languages as active and competing for selection, and bilinguals can either selectively boost the activation of one or inhibit the other (e.g., Hermans, 2004), while according to the second view, within-language activation, both languages are active, but only the target language competes for selection (e.g., Hall, 2011). Slightly diverging is the third, no competition, view, which holds that despite both languages being simultaneously active, there is no competition between the two because the target language is activated beyond a necessary threshold and therefore selected (e.g., Finkbeiner, Gollan,& Camarazza, 2006).

In light of the studies presented in the previous section, the current work follows a between-language competition perspective (although see Roelofs et al., 2016 for arguments in favour of within-language competition), and therefore, the remainder of this discussion, while briefly mentioning the other views, will accept that both languages are active and competing for selection at all steps along the processing pathway. Despite this language competition, it is rare for bilinguals to unintentionally lapse into the non-target language (Sandoval, Gollan, Ferreira, & Salmon, 2010; Gollan, Sandoval, & Salmon, 2011). When speaking with monolinguals, bilinguals have no trouble staying in a single language, without intrusion from the other, yet bilinguals are also able to freely switch between their two languages with bilinguals of similar language backgrounds. This ability has been attributed to inhibiting one language while selecting another, and to a host of other processes collectively termed "cognitive control".

In the cognitive psychology literature, cognitive control, or "executive functions", is defined as a set of top-down mental processes that are applied when automatic processing is insufficient or inappropriate (Diamond, 2013), and it functions across a number of domains, including language processing, to regulate and support flexibility in behaviour (Crysikou, Novick, Trueswell, & Thompson-Schill, 2011). As Morton, Ezekiel, and Wilk (2011) note, that such cognitive control processes operate is self-evident (i.e., humans can adapt to situations), but the exact nature of cognitive control is more difficult to define. Although Cooper (2011) raises the question of whether cognitive control can be sub-divided into components or should be taken as a product of other mental processes such as learning, he concludes that the prevailing views seem to favour components (although see Abrahamse, Braem, Notebaert, & Varguts, 2016 for a review of cognitive control as associative learning). Diamond (2013) identifies the three "core" components as being inhibition (also called inhibitory/interference control or selective attention), working memory, and cognitive flexibility (also set shifting or mental flexibility), and says that these basic processes form higher order ones such as reasoning, problem solving, and planning. Although defining cognitive control is difficult, work in this area agrees that "cognitive control" is a broad term for a set of interconnected processes that allow flexible adaptation to a given situation.

The linguistic literature, too, has examined some of these cognitive control processes, particularly inhibition, with respect to language processing. de Groot (2011) lists four theoretical dimensions along which language control can operate, identifying the *scope, direction, locus,* and *source* of control (p.208). The scope, based on de Groot and Christoffels (2006), divides processes into *local* and *global*. Local control processes refer to regulating specific elements of the language, such as lexical representations in one language or the other, while global control processes refer to regulating an entire subsystem (i.e., one language or the other). The direction of control can be *proactive* or *reactive*. Proactive, or early, control refers to pre-emptively preparing the language system in anticipation of speaking one language or the other (e.g., upregulating activation of the target language or downregulating the non-target one), while reactive, or late, control acts at the later stage to possibly prevent the incorrect lexical item from being produced. The third dimension, the locus, refers to whether the control is applied to the language system as a whole or just to the output, while the fourth dimension, source, describes whether the control is internal (e.g., the intention to speak the L1 or the L2) or external (e.g. a stimulus in the linguistic environment).

As de Groot (2011) discusses, these different dimensions can be examined in combination or separately, and different dimensions of control can work together to achieve a specific communication goal. In the case of the bilingual, this goal is communicating in one or the other language, or switching between the two, all the while managing the competition between his or her simultaneously-active languages. The goal of the current work is to examine how this bilingual experience impacts cognitive control with respect to both language and domain-general information.

1.4 Overview of Experiments

In this dissertation, I present five experiments (four behavioural and one electrophysiological) that examine the nature of cognitive control in age- and education-matched non-immigrant young adult bilingual populations. In the behavioural experiments, two separate bilingual populations are examined: The first population is English-French bilinguals living and tested in Ottawa, Canada (Experiments 1 and 3) and the second population is Japanese-English bilinguals living and tested in Kobe, Japan (Experiments 2 and 4) using identical tasks and procedures. In the electrophysiological experiment (Experiment 5), only the English-French bilingual population of Ottawa is tested. These groups allow for an examination of cognitive control in groups with different language pairings, as well as of different bilingual environments. In addition, the use of identical tasks and procedures allows comparisons between populations.

In Experiments 1 and 3, I use the ANT task in which participants respond to directional arrows while ignoring distracting misleading arrows. This non-linguistic task allows for an examination of domain-general cognitive control abilities. Reaction times (RTs) and accuracy from manual button presses are measured, and differences between groups of bilinguals defined by the age at which they became immersed in their second language, the Age of Immersion (AoI), are examined. Functional monolinguals, defined as individuals with low proficiency who have been exposed to the L2 but have never been immersed, are included as the comparison group. Differences in three attentional networks- Alerting, Orienting, and Executive Control- are calculated and compared across groups. In addition, to examine the impact of different linguistic environments on attentional abilities, the Canadian and Japanese groups are compared.

As bilinguals are experts particularly in controlling language, in Experiments 2 and 4, I use a bilingual Stroop task in which participants respond to colour stimuli while ignoring distracting written words to examine linguistic control and processing in the L1 and L2. Furthermore, to examine possible differences due to differential processing of scripts in reading-based tasks, I compare RT and accuracy results from two bilingual Stroop tasks that are identical in design except for the language combination used. An English-French task (where both languages use alphabetic script) is compared to an English-Japanese task (where one language uses an alphabetic and the other a logographic script). Although as will be seen throughout this dissertation, no two cognitive control tasks are equivalents, the Stroop shares many features with the ANT task. Therefore, while the two tasks will not be directly compared, the Stroop task is used as a linguistic counterpart to the ANT.

Finally, Experiment 5 serves as a pilot study to examine the neural processes involved in the linguistic Stroop task. English-French bilinguals in Canada perform the English-French bilingual Stroop task from Experiment 3 while, simultaneously, I collect electrophysiological data in the form of Event-Related (brain) Potentials (ERPs). This electrophysiological methodology allows for the examination of RTs and accuracy as in Experiment 3, but also of real-time brain activity which indicates not only the end-state of processing given by button presses, but also the continuous time-course of processes leading up to the response.

Chapter 2. Bilingualism and Cognitive Control: A Literature Review

As discussed in Chapter 1, a bilingual's two languages are both activated in a variety of situations. To resolve the resulting linguistic competition with two simultaneously-active languages, bilinguals must use cognitive control processes to pay attention to their environment, select the target language, inhibit the non-target one, or rapidly switch between the two. Whether such mental exertion has positive or negative consequences has been a topic of discussion for over a century. Early views were largely negative, and in 1905, Epstein even referred to bilingualism as a social plague (in Hakuta & Diaz, 1985). Hakuta and Diaz (1985) observe that bilingualism continued to be viewed as an unfavourable trait until Peal and Lambert (1962) showed benefits in their study of bilingual children in Montreal.

In a sample of 75 monolingual English and 89 English-French bilingual 10-year-olds, Peal and Lambert (1962) showed that the bilingual group performed better on tasks requiring manipulation and reorganization of visual stimuli in general intelligence tests such as Raven's Progressive Matrices Test. Contrary to the authors' initial hypothesis, bilinguals did better in both the non-verbal and the verbal components. This study became a turning point in the bilingual literature, and suggested that rather than being a hindrance, bilingualism may, in fact, have a positive effect on cognition. Since then, an increasing amount of research has been dedicated to examining bilingualism and its many aspects.

In addition to showing the simultaneous activation of both languages as discussed in Chapter 1, research has also supported a more positive view of bilingualism, particularly with respect to its effects on general cognition. Although the interaction between language and cognition is complex and multifaceted (see Kroll & Bialystok, 2013), the skills gained from managing two languages are proposed to transfer to domain-general cognitive processes, leading to enhanced overall cognitive control for bilinguals relative to monolinguals (e.g., Bialystok, Craik, & Luk, 2012). Termed the "bilingual advantage hypothesis", it suggests that bilinguals have an advantage in performing both linguistic and non-linguistic tasks, and a number of studies have shown these positive effects (e.g., Bialystok, Craik, Klein & Viswanathan, 2004; Stocco & Prat, 2014; Marton, Goral, Campanelli, Yoon, & Obler, 2017).

The current work focuses on the young adult population, who are at the peak of their cognitive control abilities (Costa, Hernández, & Sebastián-Gallés, 2008), but positive effects of bilingualism have been shown across the lifespan. Kovács and Mehler (2009) used eye-tracking to demonstrate 7-month-old bilingual infants' superior ability to attend to cues, while Poarch and van Hell (2012) showed that 5-8 year old bilingual children have improved conflict resolution in comparison to monolingual children. In young adults, these attentional and inhibitory benefits have been shown by Bialystok, Craik, and Luk (2008), and Pelham and Abrams (2014). Furthermore, Bialystok and colleagues have shown cognitive advantages for middle age adults (Bialystok et al., 2004) and older adults (Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok et al., 2008; see also review by Baum & Titone, 2014), even demonstrating that bilingualism has neuroprotective effects as one ages (Bialystok, Craik, & Freedman, 2007). However, the bilingual advantage hypothesis is not universally accepted, and experimental results have been inconsistent across studies. While some studies show cognitive benefits of bilingualism, others have noted that these effects, if they are even present, are difficult to generalize and may only be found under certain conditions (e.g., Costa et al., 2008;

Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Hilchey & Klein, 2011; Paap & Greenberg, 2013; Hilchey, Saint-Aubin, & Klein, 2015).

Over the past ten years, published results have included a variety of experimental outcomes, including studies that support, challenge, or are ambiguous regarding bilingual benefits (Sanchez-Azanza, Lópes-Penadés, Buil-Legaz, Aguilar-Mediavilla, & Adrover-Roig, 2017). Recognizing the complexity of the bilingual experience, in addition to simple yes-or-no questions regarding the presence or absence of a bilingual advantage, researchers are focusing more on when and where bilingualism makes a difference through the use of a variety of tasks that examine differences not only between monolinguals and bilinguals, but also within the highly heterogeneous bilingual group itself. This chapter reviews the cognitive control literature with specific focus on the young adult population, where findings have been the least robust and inconsistency is the greatest (Hilchey et al., 2015). It examines some of the theoretical and neurobiological underpinnings of the proposed bilingual advantage, experimental evidence in favour of and against such a claim, and some of the factors that are suggested to modulate any observed effects or lack-thereof.

2.1 Linking Language Processing to Cognitive Control

It is now well accepted that two languages are linked in the bilingual mind, and the theories underlying this link have been empirically tested. Some theories have gained support, while others have been refuted by the data, and this in turn has helped theories evolve. However, with respect to theories linking language with cognitive control and how such a link impacts general cognitive abilities, some have pointed out that there is a distinct *lack* of a theoretical foundation, and that much of the work in this field is driven by task results (e.g., Jared, 2015). Furthermore, despite much empirical work, there is still no clear understanding of the mechanism(s) responsible for the bilingual advantage. Still, the link between language and cognitive control processes has been examined theoretically as well as experimentally, and although concrete theories are limited, they propose plausible links between bilingualism and general cognition, and how the former may improve the latter.

2.1.1 Theoretical Underpinnings

The mechanisms of cognitive control have been examined from various perspectives. Looking at cognitive control mechanisms from a psychological perspective, Miyake, Friedman, Emerson, Witzki, Howerter, and Wagner's (2000) influential framework includes Updating, Inhibition, and Set Shifting as the three major processes that allow flexible adaptation of behaviour (i.e., cognitive control). Miyake et al. (2000) define Updating as actively monitoring incoming information and manipulating representations in working memory based on relevant input. Shifting refers to not only the switching of attention from one task or mental set to another, and the engagement and disengagement of this attention, but also to focusing on tasks despite interference. Finally, the authors discuss Inhibition, which requires further specification, caution Friedman and Miyake (2004).

Friedman and Miyake (2004) note that there are three types of Inhibition: The first is what the authors call "prepotent response inhibition", or the deliberate suppression of an automatic or dominant response, where this suppression is intentional; the second is "resistance to distractor", where one ignores interference from distractions that detract from a given task; while the third is "resistance to proactive interference", where one must prevent distraction from previously task-relevant information that is no longer relevant for the task at hand (e.g., having to name shapes in one task, but then having to name the colour of the shape in the subsequent task; interference from the instructions to name shapes must be suppressed). The deliberate suppression of automatic responses and resisting external distractions are highly related (see Miyake & Friedman, 2012); however, Friedman and Miyake (2004) find that resistance to proactive interference is unrelated to the first two, and is instead related to working memory. Luk, Anderson, Craik, Grady, and Bialystok (2010) also differentiate between "response inhibition", which matches Friedman and Miyake's (2004) prepotent response inhibition, and contrast it with "interference suppression", where the conflict between stimulus and response location has to be resolved before the response. In this work, inhibition is defined broadly as preventing interference from irrelevant information (i.e., as both the ability to deliberately suppress automatic responses and resist external distraction; although see footnote 1 of Hilchey, et al., 2015, for discussion of the some implications of the different types).

The processes of this framework have been popular among many researchers investigating bilingual cognitive control, and all have been examined as the underlying mechanism of the bilingual advantage, although no particular mechanism has been identified as *the* mechanism responsible. While the much-studied inhibition may be a prime candidate, Bialystok and colleagues (see Bialystok, 2017) argue in favour of a different process altogether-attention, which allows an individual to direct cognitive resources toward relevant details in their surroundings or away from irrelevant ones. As Bialystok (2017) explains, this type of "executive attention" may be developed throughout the lifespan, and particularly trained by language. This role of attention and inhibition was particularly prevalent in an early, yet still highly influential, theory linking language and cognition.

The Inhibitory Control Model (ICM; Green, 1998) of language production shown in Figure 2.1 links language and general cognitive skills from a theoretical perspective. This model assumes that representations of both languages are active, and a number of different subsystems act together to allow the bilingual to use the target language while preventing interference from the non-target language. At the core of the model are the conceptualizer, the bilingual lexico-semantic system, language task schemas, and the supervisory attention system. Each plays a different role and works in concert with the other subsystems to manage the bilingual's two languages based on a communication goal.

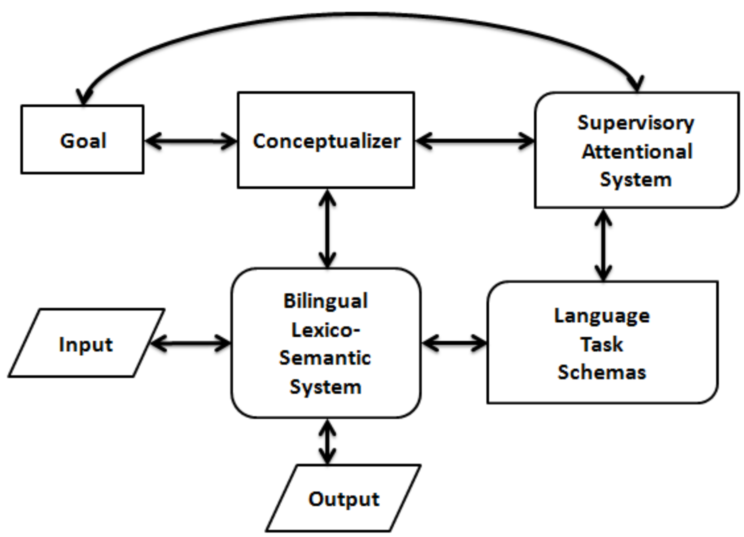

Figure 2.1. The Inhibitory Control Model (Green, 1998). A model of bilingual language control. Arrows indicate interaction between components. Image recreated based on Green (1998).

The bilingual lexico-semantic system in the model is the main language system that stores information about words in both languages (form and meaning). Importantly, at the lemma level, each word contains a tag specifying that word's language membership. Activation of words in the system is partially driven by the conceptualizer, which uses information from long-term memory to build conceptual representation based on a specific goal. The ICM also contains language task schemas and the supervisory attentional system. Language task schemas are essentially a set of actions, based on previous experience, that run routine behaviours. As Green (1998) points out, the language task schemas in the ICM are not just static pre-programmed actions in long-term memory, but can be adapted on the spot for use with a similar task, or new ones can be created in novel situations. Activation of language task schemas, modification of existing schemas, or creation of new ones is overseen by the supervisory attentional system, which plans, regulates, and checks the running of the language task schemas, but is itself a limited-resource control system. The supervisory attentional system alters the activation levels of the running schemas to meet a goal, whether that goal be maintaining a conversation in one language, or switching back and forth between two.

Inhibition in this model works at both the lemma level in the lexico-semantic system to locally manage activation of specific representations and at the level of the supervisory attentional system to globally manage one or the other language system, and both work together for a specific language task. When a particular language task schema is run (e.g. speaking the L1), at the level of the lexico-semantic system, activation of L2 lexical items is altered (in this case, decreased), and L2 output from the system as a whole is inhibited. This inhibition happens at the lemma level, where the language tags on lexical items allow the system to identify these items, and at the supervisory attentional system, which can activate the L1 or the L2 language task schemas in general by regulating the relative activation levels of each. As Green (1998) explains, a language task schema regulates input and output from the lexico-semantic system, and continues to do so until a particular goal is achieved, it is inhibited by a different task schema, or the supervisory attentional system changes the particular goal. The supervisory attentional system itself does not act on the input and output directly; it works toward a specific goal through the language task schemas.

The ICM makes several important assumptions that are particularly relevant for the current work: first, a bilingual's two languages are connected and active in the mental lexicon, and therefore, control mechanisms are needed to manage potential interference. Second, bilingual language control is achieved by interconnected systems. While the linguistic system contains representations of the two languages, their overall management is overseen by the supervisory attentional system, and the two systems interact to achieve specific language goals. Third, the supervisory attentional system is a language-external general control system (Green, 1998; Abutalebi & Green, 2008).

As seen in the ICM, inhibition and attention are important processes in regulating bilingual language output. However, such processes are also needed by monolinguals to control a single language (e.g., select the correct lexical item, such as in the within-language competition and no-competition situations briefly mentioned in Section 1.3 of Chapter 1). With respect to the bilingual advantage hypothesis, for bilinguals these limited resources are required to manage twice the information (i.e., not only the L1, but also the L2). In other words, bilinguals must manage not only within-language interference, but also interference between the two languages, and it is this language management that may give them a general cognitive control advantage.

2.1.2 Neurobiological Underpinnings

As McFarland (2017) states, because human behaviour stems from our complex brains, any theory of cognition should be consistent with what is known in neuroscience. In addition to the connection between language and cognitive control in theory, this connection has also been shown in the brain. Looking at brain regions involved in cognitive control, Abutalebi and Green (2007) and Abutalebi (2008) review earlier neuroimaging work, and conclude that the evidence supports overlapping representations of a bilingual's languages in the brain, and management of the two is carried out by a single network that integrates the L1, the L2, and dynamic cognitive control processes. Abutalebi and Green (2007; 2008) summarize the neural network involved in language and cognitive control as follows: the prefrontal cortex (i.e., the regions in the front of the brain) is involved in general executive functions (i.e., cognitive control) such as decision making, response selection and inhibition, and working memory, and it forms a loop with the anterior cingulate cortex (ACC), which is involved in attention, and conflict monitoring and detection. These interact with the inferior parietal lobule, which is involved in maintaining and implementing language representations, as well as working memory. These three regions can interact either through a direct link from the prefrontal cortex to the parietal lobule, or through an indirect link via the subcortical basal ganglia network, particularly the caudate nucleus, which is important for planning and selection of information (whether language or in general).

Based on more recent neuroimaging data, Green and Abutalebi (2013) and Abutalebi and Green (2016) further specify that both the left and right inferior frontal cortices are involved in cognitive control, attributing response selection and response inhibition to the left and the right, respectively. Looking at language switching, they note that in addition to the ACC, the pre-supplementary motor area (pre-SMA) is involved in conflict monitoring and also in switching between languages, and that the thalamus may be involved in selecting lexical and semantic representations in the L1 and the L2. Although previously thought to be involved in motor control only, the cerebellum is added to this updated model as it is linked to all of the aforementioned structures, and may play a role in the network. Specifically, the right cerebellum is suggested to modulate the activity of the left prefrontal cortex. This network of language and cognitive control structures is shown in Figure 2.2.

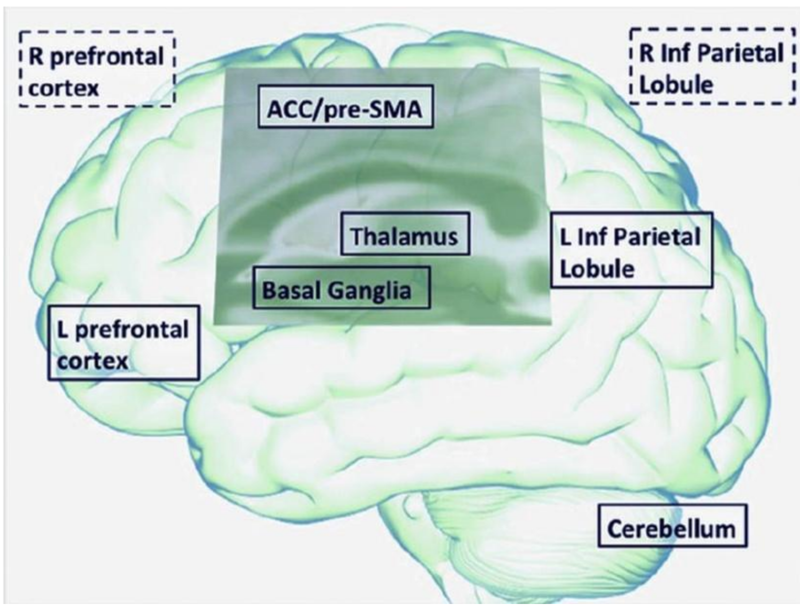

Figure 2.2 Language and cognitive control regions in the brain. Image from Abutalebi & Green, 2016. The prefrontal cortex, anterior cingulate cortex (ACC), and parietal lobule/cortex interact either through a direct link from the prefrontal to partietal cortices, or through an indirect link involving the thalamus and basal ganglia network (shaded area).

These same brain areas are activated by both monolinguals and bilinguals, but what is crucial with respect to the bilingual advantage hypothesis is the question of what happens in a brain that must process two languages compared to the monolingual's single language. An important functional difference between monolingual and bilingual brains is clearly shown by Coderre, Smith, Van Heuven, and Horwitz (2016), who hypothesize that since, as a result of the simultaneous activation of both languages, bilinguals must use these cognitive control processes more frequently than monolinguals, language and cognitive control would evolve interdependently; this would result in greater co-activation of language and cognitive control areas in bilinguals than monolinguals. Using functional magnetic resonance imaging (fMRI; a technique with high spatial resolution that allows active brain areas to be seen), and a flanker task with a combination of linguistic and non-linguistic distractors (e.g., the word "right" presented before a set of left-facing arrows), as well as a semantic categorization task, the authors analysed the conjunction of the three tasks to determine the common areas that are recruited, and how these differ between the groups. While the monolinguals showed no activation overlap between the tasks, suggesting to the authors that different areas of the brain were employed for each task, the simultaneous and early bilinguals who participated in the study showed significant overlap in the left inferior frontal gyrus (a part of the left prefrontal cortex). This study thus demonstrates the functional overlap between the neural areas involved in language processing and those used for language and general cognitive control, and shows that while these areas are separate for monolinguals, they are networked in bilinguals.

Since cognitive control processes are the product of interacting brain networks (McFarland, 2017), it is particularly relevant to examine how the various brain areas interact and how this may lead to changes in cognitive control for bilinguals. Stocco, Yamasaki, Natalenko, and Prat (2014) put forth a model of the possible neurocognitive mechanism behind the bilingual advantage called “Conditional Routing”. This model highlights how bilingual "brain training" may strengthen specifically the basal ganglia network, a collection of cells located in the middle of the brain that uses excitatory and inhibitory[3] signals to control input to the frontal lobe. Conditional routing, Stocco et al. (2014) explain, allows one signal to be prioritized over another via a circuit that selectively relays signals to the prefrontal cortex. In essence, the basal ganglia manage the flow of signals to the cognitive control regions in the brain based on task demands, and flexibly adjust this information flow to maintain task-appropriate responses.

Without conditional routing, signal transfer is based on the relative strength of connections in the brain (i.e., Abutalebi and Green's, 2007; 2008, direct link), and the strength of these connections is based on previous experience. The stronger the connection, the more likely a certain cognitive pathway is to be activated. In other words, the stronger the pathway, the more automatic it is. In some cases, however, the automatic cognitive pathways of these connections are insufficient to achieve the desired output (e.g., the signal coming from a particular connection does not lead to activation of a desired region of the prefrontal cortex, which may result in, for example, the individual not inhibiting the non-target language), and this is where the basal ganglia network comes in. Through the excitatory and inhibitory connections, the basal ganglia can modify the strength of the competing signals coming from different regions of the brain. In doing so, they may downregulate a stronger signal that does not result in the activation of the desired network or region of the prefrontal cortex in favour of a weaker signal that does. As the authors explain, engaging this basal ganglia network frequently or increasing the demands placed upon it shapes the neural circuit, and this circuit is affected by bilingual language experience (Yamasaki, Stocco, & Prat, 2018). In terms of

[3] "Inhibition", as used here, does not refer to the cognitive control process, but to the process of preventing the transmission of a chemical or electrical signal between neurons.

language use, it may allow the bilingual individual to not only control their two languages (e.g., more efficiently inhibit the more dominant L1 in favour of the weaker L2), but also to strengthen general control pathways. This type of signal management is similar to Green and Abutalebi's (2007; 2008) indirect link. By modifying the strength of signals to the prefrontal cortex and selectively amplifying the signal that will activate the pathway leading to the desired output, conditional routing in the basal ganglia can mediate competition from various sources, bypass automatic pathways, and control the flow of information via neural signals.

As seen in both the Stocco research group's and the work of Green and Abutablebi and colleagues, the same pathway is responsible for language selection, as well as general cognitive processes. In the case of bilinguals, information and context can be shared between the two languages, yet the representation of each language needs to be functionally separate (i.e., bilinguals need to use a word in one or the other language, even when they are switching between the two). Stocco et al. (2014) particularly discuss bilingual morphological rules, giving the example of pluralisation, where the rules between two languages may differ greatly. The rule that needs to be applied depends on the language being spoken (the input) to produce the correct plural word (the output). Linguistic rules, say the authors, are highly complex, and need to be flexibly applied under specific conditions, and thus the basal ganglia system is recruited to conditionally activate competing rules to map, for example, the correct plural rule to the correct language. Because of this practice in managing language rules, Stocco et al. (2014) propose that the basal ganglia pathways are strengthened, resulting in a network that is more efficient in controlling established cortical connections, thereby being more capable of flexibly rerouting signals to the prefrontal cortex, which, as shown by Coderre et al. (2016), is the point of functional overlap between language and domain-general cognitive control. Thus, the conditional routing model takes into consideration specifically the networks involved in language and general control.

In addition to proposing the basal ganglia as an underlying mechanism, Stocco et al.'s (2014) model makes predictions about which aspects of cognitive control should benefit from this practice in rerouting information. In particular, bilinguals are predicted to have enhanced selection abilities, overriding habitual responses (i.e., inhibition, although to avoid confusion with inhibition in the neurobiological sense, the authors prefer "overriding"), shifting between task sets, and maintaining top-down goals despite distractors. Flexible linguistic rule application is also hypothesized to result in a better ability to adapt behaviour to novel or changing rules (Stocco & Prat, 2014). Furthermore, this model predicts areas where bilinguals should be at a disadvantage: due to less practice in retrieving one language as a result of having to constantly manage two, and because of the interference caused by the non-target language, bilinguals are expected to have decreased lexical retrieval and verbal fluency abilities. Additionally, as a trade-off to their superior top-down processing skills, bilinguals are expected to underperform in cases where sudden changes that require immediate behaviour modifications (i.e., bilinguals are better multitaskers, but less reactive to a sudden change). Thus, this conditional routing model, which connects language processing with general information processing, provides a neurocognitive theory for the basis of the bilingual cognitive control advantage.

A second theory linking bilingual language use to cognitive control is Green and Abutalebi's (2013) Adaptive Control Hypothesis (ACH). Unlike Stocco et al.'s (2014) proposal that focuses on the basal ganglia in bilingual language processing, the ACH looks at all the brain areas implicated (see Figure 2.2), and proposes that control processes associated with these areas adapt to specific demands placed on them by language processing in specific linguistic, or "interactional", contexts. The authors identify three such interactional contexts (the single-language context, the dual-language context, and the dense code-switching context) and propose that each places different demands on eight cognitive control mechanisms (goal maintenance, conflict monitoring, interference suppression, salient cue detection, selective response inhibition, task disengagement, task engagement, and opportunistic planning).

In a single-language context, each of the bilingual's languages is used in distinct settings, e.g., using one language exclusively at school, and the other everywhere else. As the authors explain, in such a context, the language task schemas (see the IC model in the previous section) are in direct competition, as each language must be kept separate from the other. Therefore, this context is predicted to train goal maintenance (i.e., speaking in one language or the other), and interference suppression (i.e., inhibiting the nontarget language). Such processes are associated with the left inferior frontal gyrus, and the single-language context may therefore strengthen this area and the processes associated with it. In direct contrast is the dense code-switching context, where both languages are used in the course of a single utterance, e.g., an English-French bilingual may switch languages halfway through a sentence, or switch back and forth between the languages throughout the sentence. Here, the language task schemas act cooperatively, and speakers can use alternate forms (i.e., the other language) to express themselves. Such an interactional context is proposed to affect only opportunistic planning, which involves only the link between the prefrontal cortex and the cerebellum. Such a context does not require goal maintenance or interference suppression, as both languages can be used freely.

The dual-language context is expected to be the most challenging for a bilingual, as in this context, each language is typically used with different people, but in the same environment e.g., both languages may be used in the same classroom, but one with teachers and the other with friends. Just as in the single-language context, the language task schemas are in competition, but this competition is increased by the presence of both languages in the same environment, making global suppression of either language challenging, if not impossible. Thus, greater control must be exercised to maintain separation of the two. This context is proposed to involve all aforementioned processes, with the exception of opportunistic planning. Strong goal maintenance and interference suppression are particularly important in such a context. However, as Green and Abutalebi (2013) point out, this is a situation that creates a control dilemma: the strong interference suppression results in a trade-off in the speed of salient cue detection, which is necessary for noticing language switches. To prevent associated problems, task engagement and task disengagement processes are also used, as are conflict monitoring and selective response inhibition. Thus, this interactional context involves connections between various areas, most notably the prefrontal cortex, the parietal cortex, and the basal ganglia network. In this sense, the dual-language situation closely resembles that of the bilingual situation described by Stocco et al. (2014), where bilingual benefits are attributed to the ability to prioritize one language over another based on the situation.

These interactional contexts strengthen their associated brain areas and pathways, and the ACH predicts different patterns of activation in each context. It also makes predictions at a behavioural level. For speakers from dense code-switching contexts, better performance is expected in tasks where they can switch between languages at will, but no advantages are expected if they are required to stay in a single language. However, it is the opposite case for speakers from single-language and dual-language contexts. In addition, these latter two populations will also be more aware of language switching cues, but cues are expected to benefit bilinguals from a dual-language context, as the set of cognitive processes is more efficient for this population. Essentially, the cognitive control abilities strengthened will closely mirror those that are used in each specific context (as an example, Abutalebi and Green predict better interference suppression for bilinguals in dual-language contexts). It is important to note that these are predictions for language-based tasks, but the authors acknowledge that these interactional contexts affect performance on domain-general tasks as well.

Specifically comparing monolingual and bilingual performance, Green and Abutalebi (2013) predict that when the task demands match the environmental demands, bilinguals will outperform monolinguals. Looking at the different interactional contexts, the ACH predicts better performance by bilinguals in dual-language contexts, as this setting trains a variety of cognitive control processes. They do acknowledge that the question of which specific mechanism is responsible is an open one, and that it is the pattern of results on a range of tests that will demonstrate bilinguals' abilities. The ACH thus provides a language usage-based theory for the bilingual advantage hypothesis.

Although the theoretical foundations of the bilingual advantage hypothesis are not as clear and defined, it is not necessarily the case that it is only a task-driven field as has sometimes been suggested (see Paap, Johnson, & Sawi, 2015 and Jared, 2015). The three theories discussed in this section, while differing in their mechanisms, all assume simultaneous activation of the two languages, link language processing and general cognitive processing, and propose that monolingual and bilingual processing are different. The two neurobiologically-based models are relatively new and their predictions have not yet been tested extensively, but Green's (1998) IC model has had great influence and has served as a theoretical foundation for many of the studies discussed in the following sections.

2.2 Testing the Bilingual Advantage Hypothesis

Numerous studies have sought to examine the bilingual advantage, focusing on between-group differences and on which cognitive abilities are enhanced in bilinguals relative to monolinguals in non-linguistic tasks. Given that the term "bilingual advantages" is such a broad one, Hilchey and Klein (2011) and von Bastian, Souza, and Gade (2016) break the concept down into more concrete possibilities, or hypotheses, each of which attempts to specify the domain-general cognitive mechanisms enhanced by bilingualism. Each hypothesis makes specific predictions with respect to how the bilingual advantage will manifest in different types of general (non language-based) tasks. This subsection will review the different hypotheses that associated with bilingual advantages.

Hilchey and Klein (2011) propose the Bilingual Inhibitory Control Advantage (BICA) and the Bilingual Executive Processing Advantage (BEPA) hypotheses, each of which proposes a different cognitive mechanism for the bilingual advantage. The BICA hypothesis states that because of their experience in managing language interference, bilinguals will have better inhibitory abilities relative to monolinguals. The BEPA hypothesis states that bilinguals have an overall general cognitive control advantage, and this advantage will be apparent beyond inhibition. Based on the current literature, von Bastian et al. (2016) break BEPA down into three additional hypotheses to account for the bilingual advantage. In addition to the BICA, they suggest the Conflict Monitoring Advantage (CMA), the Shifting Advantage (SA), and the Generalized Cognitive Advantage (GCA). The CMA is suggested to be the result of bilinguals' constant need to monitor for and resolve linguistic conflict in the environment, and this is proposed to lead to better cognitive control in tasks involving conflict. Interestingly, bilinguals' heightened monitoring in conflict situations is suggested to "spill over" to non-conflict situations (see work by Costa and colleagues in the following subsection). Because bilinguals are proficient in switching back and forth between their two languages, a Shifting Advantage (SA) has also been proposed. According to this hypothesis, such language switching results in faster and more efficient shifting between mental sets. von Bastian et al. (2016) also list the General Cognitive Advantage (GCA), according to which, the experience of being bilingual rewires general cognitive processing, making it more flexible (i.e., Kroll & Bialystok's proposal), and this is what leads to improved cognitive control skills in general.[4] These hypotheses have been tested using various paradigms, and although a complete review of the multitude of tasks is not possible in the current work, there are three basic task types commonly used.

To examine participants' ability to control interference, many of the tasks used include some variation of congruent trials, where information from two dimensions matches and incongruent trials, where there is an information mismatch (e.g., Bialystok, et al. 2008; Costa et al., 2008; Pelham & Abrams, 2014, Verreyt, Woumans, Vandelanotte, Szmalec, & Duyck, 2016).

[4]von Bastian et al. (2016) equate BEPA with the CMA. However, BEPA also shares characteristics with the GCA (e.g., similar definition and predictions). Because of slightly different nuances, I will keep them as separate entities.

The latter type creates a conflict, since the irrelevant information from the distractor interferes with the target. For example, in the Stroop task (discussed in detail in Chapter 4), the congruent condition is created by matching colour words with the colour of the font they are written in (e.g., RED written in red font) and the incongruent is created by a mismatch (e.g., RED written in green font); in a flanker task, distractor arrows point in the same direction as target in the congruent direction, or in the opposite direction of the target in the incongruent condition (the ANT, a type of flanker task, is discussed in detail in Chapter 3); and in the Simon task, the stimulus appears on the same side as the response key in the congruent condition and on the opposite in the incongruent one. By looking at the differences between the two types of trials (or, in some cases, a neutral trial), researchers are able to assess how well interference is suppressed, or "inhibited". While these types of tasks are the focus of this work, it is important to also be aware of switching and n-back tasks, as these are becoming increasingly used in the field.

Participants' ability to shift between information sets can be examined through the use of switching tasks (e.g., Prior & Gollan, 2011; Wisehart, Visvanathan, & Bialystok, 2016; Marton et al., 2017). Such tasks consist of switch trials, where a correct response requires shifting from information of one type to another in subsequent trials, and no-switch trials, where the same information is required as in the previous trial. For example, in the Colour-Shape task, shapes appear in different colours. For each trial, participants are prompted to either identify the colour (paying no attention to the shape) or the shape (paying no attention to the colour). In a non-switch trial, for example, a colour must be named when the previous trial also required colour naming, while in a switch trial, a "shape" prompt follows a "colour" prompt, or vice versa.

A linguistic version of this task, such as picture-naming, may further require participants to perform the task in their L1 and L2, maintaining a single language throughout the task in the within-language version, while either staying in the same language in a no-switch trial or changing from one language to another in a switch trial of the between-language version. N-back tasks, on the other hand, have been used to investigate updating (e.g., Soveri, Rodriguez-Fornells, & Laine, 2011). In such a task, participants are shown a series of images, letters, or numbers one after another, and are then asked to decide whether the item they are seeing in the current trial is the same as that presented n trials previously. In such a task, increasing the n (i.e., the number of trials between the two stimuli) increases the difficulty of the task. Soveri et al. (2011) also included a spatial aspect, requiring participants to state whether a square 1 or 2 trials previously appears in the same positions as the current trial. Through the use of this type of task, a participant's updating, as well as working memory, capacity may be tested.

Using a variety of these tasks, Miyake and Freidman (2012) observe that there are correlations between tasks, which demonstrate that to a degree, the three processes are a common underlying factor in all the tasks, yet also that they can also be dissociated, and call this the "unity and diversity" of cognitive control. When looking at bilinguals, Kroll and Bialystok (2013) note that equating a single task to a single component is not sufficient to capture the complex relationships among not only processes needed for executing the task, but also the complex characteristics of the groups performing these tasks. They suggest that the effects of bilingualism may only become apparent when looking at effects in a broader context (e.g., across different tasks and considering all effects together). This is echoed by Morales, Gómez-Ariza, and Bajo (2016), who argue against single-component analyses, and advocate a multi-component approach to sufficiently capture complex interactions. Although some researchers are moving in this direction (e.g., Stocco & Prat, 2014, who use a Rapid Instructed Task Learning paradigm), the majority of studies still take a component approach.

With respect to these task types, each of the aforementioned hypotheses makes different predictions. Focusing on inhibition, BICA predicts that bilinguals will show smaller interference (i.e., faster responses) in incongruent trials (Hilchey & Klein, 2011), while BEPA predicts an RT advantage across all trial types (congruent, incongruent, and neutral). The CMA predicts that in paradigms with mixed trial types, bilinguals will show faster reaction times (RTs) across all conditions (e.g., Costa, et al., 2008). Focusing on shifting, the SA predicts that bilinguals will show smaller switch costs and faster RTs in trials that require switching from one task set to another. Finally, taking a broad focus, the GCA predicts a bilingual advantage across various tasks of cognitive control (e.g., including ones that measure working memory and updating, in addition to the aforementioned inhibition and shifting), regardless of the specific task conditions or requirements (von Bastian et al., 2016). The proposed possibilities are summarized in Table 2.1, where each of these hypotheses and their associated predictions for bilingual improvements are listed, along with representative tasks and process that these tasks are proposed to engage. While often not specifically addressing these hypotheses as such, studies in the field have both supported and challenged them, as well as the view that bilingualism confers cognitive control advantages. The following section will review a number of such studies, focusing on broader comparisons, but going into detail when the methods or participant samples are comparable to the studies presented in this dissertation.

Table 2.1. Five Bilingual Advantage Hypotheses

Hypothesis	Predictions	Mechanisms tested	Select representative tasks
Bilingual Inhibitory Control Advantage (BICA)	Faster RTs in incongruent trials, resulting in less interference (improved inhibition)	Inhibition	Flanker; Simon; Stroop
Bilingual Executive Processing Advantage (BEPA)	Similar performance across all task types (neutral, congruent, incongruent)	General mechanisms	Non-linguistic flanker
Conflict Monitoring Advantage (CMA)	When conflict present (incongruent trials), faster RTs in congruent and neutral trials	Conflict resolution and monitoring	Flanker; Simon; Stroop
Shifting Advantage (SA)	Faster RTs in switch trials, leading to smaller switch costs	Task shifting	Colour-shape switching; Animacy-Size
Generalized Cognitive Advantage (GCA)	Regardless of task, better performance compared to monolinguals	General mechanisms (incl. working memory and reasoning)	N-back; Complex digit span

2.2.1 The Benefits of Bilingualism

Although little work has specifically addressed the hypotheses discussed in the previous section, many studies have shown that the ability to manage interference from irrelevant information at the behavioural level has been shown to benefit from bilingualism. The work of Bialystok and colleagues has been highly influential for research on bilingual cognitive control, with Bialystok being a particular advocate of the bilingual advantage view (see Bialystok, Craik, Green, & Gollan, 2009; Bialystok & Craik, 2010; Bialystok, et al. 2012; Kroll & Bialystok, 2013; Bialystok, 2017). Using a Simon task, Bialystok et al. (2004) found that relative to monolinguals, bilinguals show better interference suppression, and while this argued for an inhibitory control advantage, the RT data showed that these benefits were broader in nature. In addition to faster RTs in the incongruent condition, bilinguals also showed faster RTs in the congruent condition, where there was no interference. These effects were largest in older bilinguals (aged 60-88), but were also present for middle age adults (aged 30-54). In a follow-up study using magnetoencephalography, again using the Simon task, Bialystok, Martin, and Viswanathan (2005) supported their previous findings, extending them to children (age 5). This 2005 study, however, noted that although bilingual effects were strong for children and older adults, these benefits were not apparent for the young adult population, who were typically undergraduate students between the ages of 20 and 30. However, subsequent work showed that even young adults receive a boost from bilingualism (e.g., the flanker task of Costa et al., 2008). Examining the younger adult population, Bialystok et al.'s (2008) work supported their previous findings, leading Bialystok et al. (2004; 2008) to suggest that rather than bilingualism improving inhibition, it improves the bilingual's ability to manage attention when faced with complex and changing tasks.

A positive impact on attention has been supported by the Bialystok group's more recent work. For example, Friesen, Latman, Calvo, and Bialystok (2015) show that young adult bilinguals are better able to find a target among distractors in a visual search, particularly when the visual display is complex. In this study, participants were required to search based on a single feature (e.g., the colour green, with the target being a green triangle in a field of yellow triangles) or a combination of two features (e.g., a turquoise circle had to be found among a field of turquoise squares and pink circles), ignoring interference from irrelevant stimuli characteristics. Both groups performed faster in the single-feature task compared to the task that required searching based on combined features, but bilinguals performed significantly better than monolinguals in the more complex task that required searching for a combination of features. Friesen et al. (2015) thus concluded that selective attention, and particularly the engagement of attention processes, benefitted from bilingualism even in the young adult population. In addition, bilingual young adults may be better able to disengage attention, as shown by Grundy, Chung-Fat-Yim, Friesen, Mak, and Bialystok (2017). Although there were no group differences in flanker task performance nor in the size of the flanker effect, when the sequences of trials was taken into account, bilinguals showed smaller sequential congruency effects (i.e., a smaller influence from the previous trial on the following trial), suggesting to Grundy et al. (2017) that the bilingual group is better able to redirect attention. This was supported by electrophysiological data (N2 and P3 waves, discussed in Chapter 5), leading Grundy et al. (2017) to conclude that bilinguals show superior ability in directing attention.[5] This selective attention, in turn, allows bilinguals to better inhibit interference. Such findings appear to best support the BEPA or GCA hypotheses, in which the bilingual advantage is general in nature and applies across a broad set of domains.

Further supporting interference control advantages is work by Costa and colleagues. Testing young adults, Costa et al.'s (2008) results revealed differences between the monolingual and bilingual groups in a flanker task. Specifically, bilinguals showed less interference in incongruent conditions, and just as in the Bialystok et al. (2008) study, had faster global RTs. Similar results were found by Costa, Hernández, Costa-Faidella, and Sebastián-Gallés (2009), who varied the proportion of congruent and incongruent trials, and by Hernández, Costa, Fuentes, Vivas, and Sebastián-Gallés (2010), whose participants showed a trend (*p*=.061) toward faster global RTs, in addition to reduced interference in the non-linguistic

[5] However, see Goldsmith and Morton (2018) for counterargument regarding this interpretation.

Stroop task. Explaining the observed advantage across different trial types, Costa et al. (2008) propose that when the monitoring system faces high demands such as created by the incongruent condition, individuals with superior monitoring and resolution are unaffected by this increased difficulty; thus, their response speed remains high even for congruent trials.

Costa and colleagues' studies, which may be classified as testing the aforementioned CMA, attribute the bilingual advantage to superior conflict monitoring and resolution, i.e., the ability of the attentional system to detect a conflict (such as in incongruent conditions of tasks), assess the degree of conflict, and adjust behaviour accordingly (Costa, 2009). Costa et al. (2009) specifically demonstrated the role of conflict monitoring and resolution by varying the proportion of congruent and incongruent trials in their study of young adult monolinguals and bilinguals. In the two low conflict monitoring versions of the task (8% incongruent and 92% congruent, and vice versa), where the need for monitoring was low because most of the trials were of the same type, the groups were fairly evenly matched. However, in the higher conflict monitoring versions, where both types of trials were more in proportion (50% of each, or a 25-75% distribution) thus creating a situation where the need for monitoring was high, the bilingual group surpassed the monolingual one. This suggests that engaging the conflict monitoring and resolution system is particularly beneficial for bilinguals.

Although offering different explanations, the work of Bialystok and colleagues and Costa and colleagues suggests that, while not as robust as in children and older adults (see Bialystok, 2017), even young adults benefit from bilingualism, particularly when task demands are high. The only known exception to this is Salvatierra and Rosselli's (2011) work, which shows that it may not always be necessary to tax the control system to see bilingual advantages. Using a

Simon task in a simple (two different colour squares) and complex form (four colour squares), the authors noted that bilinguals outperformed monolinguals only in the simple condition. This was attributed to improved selective attention when working memory demands are low. Interestingly, although these differences were significant only for older bilinguals, in young adults, the Simon effect was also reduced for the bilingual group compared to the monolingual group. This suggests that while observed behavioural effects may not be as strong in young adults, young adult bilinguals nonetheless show some differences from their monolingual peers.

Much of the research has focused on improved domain-general cognitive control using non-linguistic stimuli, but it is important to keep in mind that bilinguals are masters of controlling *language*. Although they have been reported to have smaller vocabulary sizes in any of their languages compared to monolinguals (Bialystok & Luk, 2012) and slower linguistic processing (e.g., Poarch & van Hell, 2012; Pelham & Abrams, 2014), leading them to underperform in vocabulary and lexical retrieval tasks compared to monolinguals, when looking purely at the control, bilinguals appear to outperform monolinguals (Pelham & Abrams, 2014). A number of studies have used the linguistic, also known as the colour-word, Stroop task to investigate this bilingual cognitive control advantage hypothesis. Perhaps the best-known among these is Bialystok and colleagues' (2008) investigation, which used the Stroop task and English-only stimuli, and found that bilinguals show a smaller Stroop effect relative to monolinguals. For the bilingual group, the overall RTs in this task were also faster, particularly in the incongruent condition. Although these effects were larger for older than younger adult bilinguals, they were nonetheless apparent for the younger group. Study 1 of Bialystok, Poarch, Luo, and Craik (2014) supported this earlier work, showing that word interference on colour naming is greater for monolinguals compared to bilinguals, and while these advantages were clearly larger in older bilinguals, the younger group benefitted as well. Similar findings with respect to Stroop interference for older vs. younger bilinguals are reported by Kousaie, Sheppard, Lemieux, Monetta, and Taler (2014).

Heidlmayr, Moutier, Hemforth, Courtin, Tanzmeister, and Isel (2014) support these findings, and using an L1 and L2 Stroop task, the researchers also found that the Stroop effect was larger for monolinguals; although their study did not reveal group differences for specific conditions of the Stroop task (i.e. the congruent, incongruent, and neutral trials). Additionally, looking at bilinguals' L2 results, Heidlymayr et al. (2014) found that in line with previous research, the Stroop effect was greater in participants' L1 French than L2 German. This latter finding demonstrates the relatively greater automaticity of L1 processing compared to the L2. The results of Stroop studies, however, are not always as clear-cut.

Looking at groups of young adult bilinguals with an L2 AoA of approximately 10 years of age, Coderre and colleagues (Coderre, Van Heuven, & Conklin, 2013; Coderre & Van Heuven, 2014) found that the situation is more complex than simple differences in Stroop effect magnitude between monolinguals and bilinguals. Comparing English monolinguals to English-Chinese bilinguals (overall self rated L2 proficiency ranging from 6.5/10, SD=1.3), no group differences were found overall. However, when the magnitude of the Stroop effect of monolinguals in their L1 English was compared to the magnitude of the Stroop effect of Chinese-English bilinguals (self rated proficiency ranging from 6.6/10, SD=1.2) in their L1 Chinese and L2 English, the analysis revealed smaller interference for the Chinese-English bilinguals in both their L1 and the L2 compared to the interference of the monolinguals in their

L1. Again, for the bilinguals, the interference was smaller in the L2 compared to the L1. Coderre et al.'s 2013 study reveals an advantage for the Chinese-English bilinguals, but as this did not extend to the English-Chinese bilinguals, the authors did not interpret their findings as a conclusive bilingual inhibitory advantage. To account for these differences between the groups, the authors reason that it may be the former group's lower relative proficiency in the L2, and therefore less interference, from the weaker language that results in the apparent advantages. However, they propose another interesting possibility: it is plausible that the differences in task performance actually reflect an effect of script, and it is the difference between processing English alphabet and Chinese logographs that leads to the observed results. This latter possibility will be discussed in more detail later in the current work, where differences between the alphabetic and logographic writing systems will be examined.

The team's later findings provided clearer support for a bilingual advantage view. Using behavioural and electrophysiological methods with the Stroop task, Coderre et al. (2014) found that rather than a reduced Stroop effect, which would signal better inhibitory skills, bilinguals showed faster RTs and higher accuracy in control trials. A similar finding was reported by Kousaie and Phillips (2012), who did not find inhibitory control improvements in young adult bilinguals, but although these findings were not statistically significant, the bilingual group showed shorter overall RTs in a linguistics Stroop task than young adult monolinguals.

Although tasks such as the Stroop have not been discussed in reviews such as Hilchey and Klein's (2011) (indeed, the authors specifically do not include the linguistic Stroop task in their review due to its relationship with language), the hypotheses outlined by Hilchey and Klein (2011) and von Bastian et al. (2016) may also be applied to language-based tasks such as the

Stroop task, as first done by Coderre et al. (2014), who note that BICA would predict smaller Stroop effects and faster response in the incongruent condition of the task, while BEPA would predict faster overall RTs in all conditions. The results of Coderre et al. (2014) and Kousaie and Phillips (2012) favour the BEPA hypothesis, while Heidlmayr et al. (2014) favours BICA. Bialystok et al. (2008) find both an interference suppression advantage and an RT advantage, while only Coderre et al.'s (2013) Chinese-English bilinguals demonstrate an interference suppression advantage, suggesting that there may be broader, more general cognitive mechanisms at work, as suggested by the GCA, but that they may become apparent under different conditions. It appears that while the relationship between bilingualism and cognitive control as shown in the Stroop task is complex, the Stroop task in these studies does reveal differences between bilingual and monolingual groups, and these differences seem to favour bilinguals.

Interestingly, just as with non-linguistic tasks such as the ANT (e.g., Costa et al., 2008), better conflict monitoring and resolution may modulate the bilingual advantage in linguistic tasks as well. Goldfarb and Henik (2007) manipulated the proportion of congruent and incongruent trials in a Stroop task and showed that performance varied with the degree of task conflict. Also using the Stroop task and varying the SOA of word and colour presentation, Coderre et al. (2013) observed that bilingual performance was best at an SOA of 0ms, which represented the most challenging condition as words and colours were presented simultaneously. These findings seem to support previous results of better control in higher conflict situations (e.g., Costa et al., 2009; Friesen et al., 2015.)

As evident by the studies discussed so far, much work on bilingual cognitive control has focused on bilinguals' ability to suppress interference from irrelevant information; however, researchers are also increasingly considering the role of other mechanisms. One mechanisms that has been investigated has been Miyake and Friedman's (2012) shifting, and this has led to the Shifting Advantage hypothesis described in Table 1, which proposes that bilingualism trains the ability to switch between information sets. Evidence for the SA has come largely from a variety of switch tasks. For example, using a colour-shape task with single-task blocks (where participants saw either the colour or the shape) and mixed-task blocks (where colours and shapes where intermixed), Prior and MacWhinney (2010) showed that young adult bilinguals experience smaller switch costs (defined as the difference between the switch and non-switch trials in the mixed-task block) compared to monolinguals. Although, the two groups performed similarly in the single-task blocks and there were no differences for mixing costs (the difference between non-switch trials in the mixed-task block and the single-task block). Wiseheart et al. (2016), however, noted smaller mixing costs for the bilingual group compared to the monolingual one. Such results support a Switching Advantage for bilinguals, suggesting that due to the experience of using multiple languages, bilinguals enjoy greater mental flexibility. Although such switching studies are being increasingly performed, a thorough discussion of these is beyond the scope of this work.

It is possible that the bilingual advantage cannot be broken down into just a few improved cognitive mechanisms. As Kroll and Bialystok (2013) and Morales et al. (2016) reason, bilingualism is a composite experience made up of many factors, and therefore to best show the advantages conferred by bilingualism (the GCA, as labelled by von Bastian, et al., 2016), more multi-component tasks and analyses should be used. Although these are far more uncommon in the existing literature, one example is the Rapid Instructed Task Learning (RITL) paradigms used by Stocco and Prat (2014) to test young adult bilinguals with an early AoA and high proficiency in their L2. RITL paradigms can take many forms, but all involve giving participants a new set of instructions at the beginning of the trial (vs. typical tasks where instructions are given at the beginning for the whole experiment), thereby requiring the participant to adapt behaviour to what is essential a novel situation in every trial. In their study, Stocco and Prat (2014) use a basic set of arithmetic operations (e.g., add, subtract, multiply) and simple numbers, combining them in novel ways at the beginning of each trial, to examine participants' flexible rule application. Because bilinguals must flexibly adapt rules from two languages, the authors predicted this ability to transfer to the non-linguistic task. Indeed, their results indicated that bilinguals were faster than monolinguals at behavioural adaptation, as measured by the speed of trial completion. Such studies are still not common in the literature, and given that task designs vary greatly from study to study, difficult to replicate. The lack of replicability of studies in particular is an issue in bilingual cognitive control research, however, and has led some to question the existence of bilingual advantages.

2.2.2 Does the Bilingual Advantage Really Exist?

Although bilingual advantages have been reported for children, young adults, and older adults, in light of failures to replicate previous studies and an absence of observable advantages, particularly in the young adult population, the bilingual advantage hypothesis has been challenged. It has also been pointed out that not only are advantages not universal, but that they are inconsistent (see Hilchey & Klein, 2011; updated in Hilchey et al. 2015). Such inconsistent effects are seen not only when looking at language status, however, but also when looking at other activities suggested to improve cognitive control such as, for example, exercise, action video games, and socioeconomic status (Valian, 2015). With respect to bilingualism, de Bruin, Treccani, and Della Salla (2015) report a publication bias in favour of positive results, and the authors suggest that the specific focus on bilingualism and the bilingual advantage view may partially stem from a lack of published evidence to the contrary.

Showing this inconsistency across tasks is a series of experiments using flanker, Simon, colour-shape switching, and antisaccade tasks, by Paap and Greenberg (2013). Testing a large number of young adult participants in 3 studies (90, 86, and 110 in Studies 1, 2, and 3, respectively), the authors were unable to find consistent cognitive advantages for the bilingual group. Furthermore, the results showed little correlation in abilities across tasks. In other words, although tasks such as the flanker and Simon are both considered as measures of interference suppression, both did not necessarily show bilingual advantages. Such lack of between-task correlation was also reported by Kousaie and Phillips (2012a), who examined younger and older bilinguals and also failed to find an advantage in the Stroop task for either group, and no differences between monolinguals and bilinguals in Stroop and flanker tasks (2012b). Kousaie et al. (2014) also fail to find any between-group differences in a Simon task, although they report a "weak" advantage for bilinguals in the Stroop task.

A subsequent study by the Paap research group (Paap & Sawi, 2014) used the same battery of tests with a new group of young adult participants divided, based on self-ratings, into monolinguals and bilinguals. Similarly to their previous study, no consistent bilingual advantages are found in any of the tasks, and in fact, Paap and Sawi (2014) report a weak *monolingual* advantage in the Simon task; however, this does not correlate with the flanker task, in which there are no significant differences between the two groups. The combined dataset from Paap and Greenberg (2013) and Paap and Sawi (2014) of 168 bilinguals and 216 monolinguals are further explored in Paap, et al.'s (2015) examination, and as expected, yield similar results. von Bastian et al. (2016), testing a group of 118 bilinguals on 21 cognitive control tasks, support these findings. It therefore appears that although some studies offer strong support for the bilingual advantage hypothesis, others show mixed results, and caution that the link between bilingualism and enhanced cognitive control may be far more unreliable. This inconsistency is particularly noticeable when looking across studies, and it was evident early on that not all studies of bilinguals report cognitive advantages.

Reviewing 10 behavioural studies that compare non-linguistic control in bilinguals and monolinguals, Costa, et al. (2009) found that across 37 experiments included in the 10 studies, only 9 experiments suggest a bilingual advantage for interference suppression, and 14 show faster global RTs for the bilingual group compared to the monolingual one. Of that set of studies, when looking at those that use a mixed design (i.e., where congruent and incongruent trials are intermixed vs. a blocked design, where all trials in a single block are the same), they find that in the 25 experiments, 6 showed bilingual advantages with respect to effect size, and 12 showed global RT effects. No significant between-group differences were seen in the remainder of the experiments.

In an empirical review of the behavioural literature aimed at testing specifically the BICA and the BEPA hypotheses, Hilchey and Klein (2011) examined 31 experiments from 13 separate studies, including ones with older adult, middle-aged adult, young adult, and child participants. With older adults, of the 4 experiments included, all supported BICA and all but one supported

BEPA. This pattern was the same for the 4 experiments with middle-aged adults, except that here all supported BEPA and all but one supported BICA. For the young adults, however, the 17 experiments showed irregular advantages. While BEPA was (in some cases, weakly) supported for most studies, the BICA indicators were highly inconsistent, hovering around the 0 difference mark. The pattern was similar in the 6 child studies. The authors therefore concluded that the evidence favoured the BEPA hypothesis and general processing advantages for bilinguals. Furthermore, they noted that for young adults, these advantages are the most inconsistent, and when inhibitory advantages are found, "they appear only briefly, early on, and dissipate very rapidly" (p.654). When conducting a similar empirical analysis and including studies published since their initial review, however, Hilchey et al. (2015) note that the experimental results across this timeframe are far too varied among all groups (child, young adult, and older adult) to support any clear cognitive control advantages for bilinguals. The authors consider the possibility that overall enthusiasm for the bilingual advantage hypothesis, combined with a publication bias as suggested by de Bruin et al. (2014), may contribute to the differences between the outcomes of the two empirical reviews, but caution that further investigation is needed into this issue.

To examine the current state of the literature, Sanchez-Aranza et al. (2017) conducted a bibliometric study of research published within the last ten years. Following de Bruin et al.'s (2014) criteria, the authors identified 139 studies which report results of behavioural cognitive control studies, and categorized them as supporting the bilingual advantage, being ambiguous toward an advantage (this category included articles reporting several experiments, some of which supported and some of which did not support an advantage), challenging the bilingual advantage hypothesis, or not mentioning an advantage. The latter category included studies that did not compare monolinguals and bilinguals, but rather, looked at bilingual groups only (e.g., bilingual participants only, grouped by AoA or proficiency), as well as studies that examined switch costs, regardless of whether a monolingual group was included or not. Citations and impact were considered in the analysis. Of the 139 studies, 43 supported, 42 were ambiguous, 25 made no mention of, and 29 challenged the bilingual advantage hypothesis. Furthermore, results revealed that the majority of supporting evidence was published before 2013, with 2014 seeing a marked increase in the publication of evidence to the contrary. Being the most cited paper challenging the bilingual advantage, Paap & Greenberg's (2013) study is particularly identified as a turning point. Thus, Sanchez-Aranza et al. (2017) conclude that a shift in publishing trends has taken place, and the available literature includes evidence pointing in both directions. Furthermore, they conclude that the publication of a spectrum of experimental outcomes does not necessarily refute the bilingual advantage hypothesis. Although challenges have increased, supporting evidence continues to be published. They thus advise caution and advocate for the reporting of all results based on well-designed, controlled, replicable studies. de Bruin et al. (2015) agree, concluding that, "All data, not just selected data that supports a particular theory, should be shared, and this is especially true when it comes to data regarding issues that have enormous societal relevance and implications, such as bilingualism" (p.106).

Given the state of the literature, researchers have tried to identify factors contributing to the mixed findings. Valian (2015) also points out that when looking at factors that enhance cognitive control, bilingualism is not the only one to show mixed results, and suggests three possible reasons for the inconsistency. She first discusses the broad definition of "cognitive control" and the lack of understanding of the mechanisms involved. She focuses on the definitions provided by Miyake and Friedman's (2012) model, but acknowledges that although detailed and structured, it is likely not a complete account. As previously discussed, the definition of cognitive control is indeed broad (see Chapter 1; see discussion by Cooper, 2011; Diamond, 2013), and lacking clear identifiers for the concept of cognitive control, it is certainly a difficult task to identify the underlying mechanisms. Although various mechanisms have been proposed, as also seen throughout this chapter, there is still no clear mechanism(s) identified for the bilingual advantage. Further complicating this issue is the lack of a single, unified, generally accepted theory of the components of cognitive control, their link with language processing, and how this provides advantages for bilinguals (see Paap & Sawi, 2014; Treccani & Mulatti, 2015).

Valian (2015) next discusses the task impurity problem (Miyake et al., 2000; Miyake & Friedman, 2012), which can be summarized as systematic variance from other cognitive processes introduced necessarily by the nature of the task itself. In other words, a cognitive control component has to be embedded within a task that may require other cognitive skills (e.g., visual or auditory processing), which can lead to measurement error, noise, and difficulty in measuring the cognitive control component of interest itself. Kroll and Bialystok (2013) also discuss this issue, noting that certain tasks themselves have become linked with the proposed process most needed to complete it, and have thus acquired labels such as "measure of inhibition" for the Stroop task, "measure of working memory" for the n-back task, and "measure of shifting" for switching tasks. They do not, however, agree with this type of labelling, and point out that there is no one-to-one mapping between bilingualism and specific component processes. The various tasks do contain components such as inhibition and shifting, but they are not exclusive measurements of each. Valian (2015) concludes that because there is no clear analysis of the tasks, researchers may not really know what they are measuring. Moreover, as shown by Costa et al. (2008), even the level of difficulty of the task may lead to different outcomes. This may lead to what Paap and Sawi (2014) describe as a problem in convergent validity, or the lack of correlations between tasks and lack of replicability of studies.

Valian's (2015) final suggestion for the inconsistency is the possibility of other rich cognitive experiences such as musical training, video game playing, and exercise that may have similar benefits to those of bilingualism. She particularly points out that for children and young adults, whose lives are already full of experiences that boost their cognitive skills (for example, attending school and actively learning), bilingualism competes with these other experiences. As a result, any possible benefits of bilingualism are obscured. Such logic is in line with Costa et al. (2009), who discuss the lack of strong effects for the young adult population, and attribute this partly to young adults being at the peak of cognitive control. If cognitive function is already at its peak for this group, the additional benefit of bilingualism may be very small. This is also considered by Paap & Greenberg (2013). Although not specifically considered among the enriching experiences, it is also possible that not only the experiences themselves, but also the environment in which these experiences occur can lead to inconsistencies in observed benefits. This possibility is addressed in the current work, which uses identical tasks but hypothesized that different bilingual environments will lead to different outcomes.

In addition to the above, as well as identified publication biases (see de Bruin et al., 2015), Paap et al. (2015) also highlight methodological issues. With respect to data collection, they say that small group sizes can greatly inflate Type 1 errors, leading to false positive results that are then interpreted as bilingual advantages. It is indeed often the case that psychological (and psycholinguistic) studies have small group or overall n's, and the current work is no exception, with group sizes ranging between 14 and 23 participants. Furthermore, with data analysis and reporting, Paap et al. (2015) point out that in cases where significant effects for only one component out of many are found, it is that component effect that is reported. Bakker (2015) agrees, giving evidence that many small underpowered studies lead to statistically-significant differences faster than a single large study with a large sample size.

Baum and Titone (2014) and van Heuven and Coderre (2015) also suggest reconsidering current statistical approaches. Although broadly used, analysis of variance allows for the comparison of means of several groups (Howell, 2011), but such statistical methods necessarily limit analysis to group means of a few categorical variables, making it impossible to account for all the variability of a bilingual sample. Paap et al. (2015) discuss that factors other than bilingualism may be responsible for cognitive control advantages, and highlight some possible confounds, including socio-economic status, immigrant status, and cultural differences that may create confounds, but statistical methods such as ANOVAs are unable to capture these. Thus, Baum and Titone (2014) observe, researchers are moving more towards regression analyses and mixed effects modelling- approaches that are more complicated to carry out, but allow item-level and participant-level variability to be included. Although this is likely a superior statistical approach, many fields are still transitioning from the use of ANOVAs, and it is therefore common to see a mix of approaches in the literature.

Given the aforementioned concerns and uncertainties, in recent years questions of whether the search for bilingual advantages should continue have been raised (e.g., Goldsmith & Morton, 2018). There have been heated debates in discussion forums, e.g., in volumes 73 (2015) and 74 (2016) of Cortex, with supporters of each side of the argument refusing to back down, and accusing each other of failing to consider the evidence. Others, however take a more open-minded approach, suggesting that in light of mixed results, it is time to move away from a yes/no debate (e.g., Bak, 2015), and instead, to examine when and where bilingualism makes a difference. Even with the mixed results in current literature, as Valian (2015a) observes, when bilingual effects are found for tasks of cognitive control, they are generally in the positive direction. Although bilinguals face increased processing demands that slow lexical retrieval (e.g. Pelham & Abrams, 2014), they rarely appear to have significant *dis*advantages in cognitive control (e.g., de Bruin et al.'s, 2014 analysis shows 4/104 studies with a bilingual disadvantage. And in cases where there is no apparent processing advantage, they perform similarly to monolinguals (e.g., Paap & Liu, 2014), despite handling the cognitive challenges of two languages. While it may not be the only force driving cognitive improvements, it is difficult to dismiss bilingualism as being completely inconsequential.

Although tasks themselves can impact performance (see Qu, Low, Zhang, Li, & Zelazo, 2016 for discussion) and simple tasks may be unable to sufficiently capture bilingual differences, on a larger scale, it may be that behavioural tasks are altogether not sensitive enough. Some researchers have thus called for more use of neuroimaging techniques (e.g., van Heuven &

Coderre, 2015). For example, event-related brain potentials (ERPs; discussed in detail in Chapter 5), which have a high temporal resolution, can show the precise timing of cognitive processes, while functional magnetic resonance imaging (fMRI), which has high spatial resolution, can show the activation of brain areas associated with cognitive control (see Section 2.1.2.), as well as diffusion tensor imaging (DTI), which can show the connections between areas of the brain via white matter tracts.

Even when there are no behavioural differences, the underlying processing may not be the same for monolinguals and bilinguals. This was demonstrated by Kousaie and Philips (2012b), whose bilingual participants showed no clear RT or accuracy advantages in behavioural Stroop, Simon, and flanker tasks, but did differ from monolinguals when looking at the amplitude and latency of ERP components such as the N2, P3, and ERN. However, as in previous behavioural studies, these differences were inconsistent and differed across the three tasks, and therefore no clear conclusions of a bilingual advantage could be made.

Despite such findings, as shown by Coderre et al. (2016), bilingual brains do differ from monolingual ones. In their study, the authors found a functional overlap between language and general cognitive control areas in bilinguals. Using fMRI, Rodrígues-Pujadas, Sanjuán, Ventura-Campos, Román, Martin, Barceló, Costa, and Ávila (2013) also observed that brain areas involved in language control were more activated for non-linguistic tasks in early bilingual participants than in monolinguals, and Pliatsikas et al. (2017) show that continuous use of an L2 can significantly expand subcortical structures such as the thalamus, demonstrating that bilingualism does alter the brain. Even Paap, Johnston, and Sawi (2016) agree that neurophysiological methods can reveal differences that behavioural ones cannot and that bilingualism can change subcortical structures, but the authors challenge the bilingual advantage hypothesis by asking whether neurophysiological change without accompanying behavioural change can really be considered an *advantage*.

Requiring correlations between neural processes and behaviours, however, misses the essence of the bilingual advantage hypothesis: the complex experience of bilingualism leads to positive consequences for cognition. These are not necessarily restricted to tasks in a laboratory, but are likely broad and span one's lifetime (see Bialystok, 2017). Baum and Titone (2014) also suggest reframing the question of the bilingual advantage as one of life-long neuroplasticity, while the Stocco research group (e.g. Stocco et al., 2017) place the emphasis on cognitive flexibility brought about by training the basal ganglia network through bilingualism. Testing the indirect pathway through use of a Simon task and a selection task, Stocco et al.'s (2017) study finds a negative correlation between indirect pathway activation and behavioural results (i.e., the greater the activation, the smaller the behavioural cost), demonstrating a more efficient allocation of cognitive resources at both the behavioural and neural levels.

Furthermore, does an *advantage* necessarily have to manifest in behaviour in order for it to be considered an advantage? Berroir, Gazi-Saidi, Dash, Adrover-Roig, Benali, and Ansaldo (2017) examined the brain regions activated during a Simon task using fMRI, and focused specifically on the regions and connections within and between them. Results revealed that bilinguals had greater functional connectivitiy in a single region (the inferior temporal sulcus), while for monolinguals, multiple regions including ones involved in motor, visual, and interference control were recruited to carry out the same task. Despite both groups performing similarly at a behavioural level, bilinguals required *less* neural resources. The authors conclude that it is not a case of task-specific advantages, but that for any task, bilinguals allocate fewer resources more strategically. Such findings demonstrate that the bilingual brain is not only organized differently from a monolingual one, but that it is also more efficient. And from a neuroscientific perspective, efficiency *is* an advantage.

Testing the bilingual advantage hypothesis has proven to be a challenging task, particularly given the lack of a concrete definition of cognitive control and task issues, leading to difficulty in determining which cognitive processes participants are using in behavioural tasks. Furthermore, considering methodological aspects including statistical analyses, it becomes clear that there remains much work to be done in designing and implementing different tasks in cognitive control studies. Identifying the specific processes required for specific tasks, the locus of each process, and how these processes interact continues to be an ongoing challenge for the field of bilingualism and cognitive control. Neurophysiological studies are instrumental in helping to resolving these issues, and the studies such as Abutalebi and Green (e.g. 2008) and Coderre et al. (2016), as well as meta-analyses such as Luk, Green, Abutalebi, and Grady (2012) have been able to shed light on some processes of cognitive control. However, the findings at a behavioural level also should not be ignored, and thus, challenges remain.

2.3 Exploring Contributing Factors

While we may not be able to control which processes participants use in tasks, we can identify certain characteristics of participants we examine. This too, however, has been raised as an issue in studies of bilingual cognitive control (see Kroll & Bialystok, 2013), particularly because bilinguals themselves are a highly heterogeneous group (Luk & Bialystok, 2013).

Specifically, a topic of discussion has been how do we define "bilingual"? And as Luk (2015) asks, who are our monolinguals? Bilingual groups have been defined in many ways. Costa et al. (2008) used the language of the surrounding community. Participants in the bilingual group came from Barcelona or Catalonia, where both Spanish and Catalan are spoken, while monolinguals came from Tenerife, where only Spanish is spoken by the community. The authors acknowledge that there may be confounds such as intelligence, motivation, socioeconomic status, and education, but reason that since the sample was large and all participants were university students in the same educational system, differing only in the language characteristics of the region in which they lived (e.g., bilinguals were bilingual not because they were more intelligent or motivated, but because they grew up exposed to two languages), these other factors would not impact their performance in the ANT. In Bialystok et al.'s (2008) study, bilinguals were defined as ones who used English and another language (which could be French, Polish, Cantonese, Spanish, Albanian, Arabic, Croatian, German, Greek, Hebrew, Indonesian, Korean, Latvian, Macedonian, Mandarin, Persian, Filipino, Portuguese, Punjabi, Somali, Tamil, Thai, Serbo-Croatian, and Ukrainian) daily. Many participants had immigrated to Canada, but all were proficient in English and had similar degrees of formal education. Furthermore, the bilingual groups were separated by age at the time of testing. Similar to Bialystok et al.'s (2008) participants, Paap and Greenberg's (2013) bilingual group also consisted of a mix of native and non-native speakers of English, with various L2's, reflecting the multilingual environment of San Francisco. Once again, the bilingual population also included a mix of individuals who had emigrated from their countries of origin.

While these approaches allowed for a good categorical division of participants into monolinguals and bilinguals, they did not consider the heterogeneous nature of the bilingual group itself. Participants are not only differentiated by their status as "bilingual" and "monolingual"; both groups also vary in a host of other characteristics that should be taken into account (Luk, 2015; Hernandez, 2015). Baum and Titone (2014), calling the lack of consideration for within-group variability in language learning and proficiency, "the single most important concern that plagues the vast majority of studies of bilingual speakers, weather younger or older" (p.875), call for more attention to factors such as degree of fluency, the age of L2 acquisition, the L1 of the speakers as well as their country of origin, and the daily usage of the L1 and L2, in addition to community norms of language switching. As the authors explain, such characteristics are confounded in studies that only distinguish between monolinguals and bilinguals.

These differences in bilingual experience may affect the development of cognitive control abilities and therefore affect the outcomes of tasks, such as is shown by the very different results across studies. Indeed, Baum and Titone (2014) say that the heterogeneity in groups across studies makes it difficult to make precise conclusions, and to make use of variability when looking at cognitive control outcomes in studies. Although it is difficult to control and match for every possible variable, taking heterogeneity into consideration, studies have examined not only the differences between monolinguals and bilinguals, but also the differences within the bilingual groups themselves.[6] Factors such as age, L2 proficiency, balance

[6] It must be mentioned that studies such as Paap et al. (2015) and von Bastian et al. (2016) have included a variety of within-group factors and, finding no effects, conclude that specific experiences are not related to cognitive control. This will be addressed further in the Discussion chapter.

of language use, and frequency of language switching have been examined. The following two sections will focus specifically on the age of acquisition and the bilingual language environment, which are hypothesized to affect cognitive control outcomes in the current work.

2.3.1 Age of Second Language Acquisition

One commonly examined within-group factor that reflects the amount of bilingual experience is the age of acquisition (AoA) of the second language. With respect to AoA, it is possible that the prolonged practice of being bilingual alters anatomical structures (Bialystok et al., 2012; Abutalebi & Green, 2008; Pliatsikas, DeLuca, Moschopoulou, & Saddy, 2017), which in turn has consequences for behaviour. Becoming bilingual early in life also has another obvious advantage: namely, early bilinguals have spent a greater length of time being bilingual, and therefore have more experience in managing two language systems. The effects of age in a broader sense have been investigated by looking at bilinguals from birth to old age (see Bialystok, 2017 for a detailed review), but AoA variations within these broader groups have also been examined. However, thorough investigations of AoA effects on cognitive control, particularly in young adults, remain sparse. One of the aims of the current study is to add to this limited literature.

In a study focusing specifically on AoA effects, Tao, Marzecová, Taft, Asanowicz, and Wodniecka (2011) used the ANT to examine a group of Chinese-English bilinguals. The participants were classified as Early or Late acquirers, based on their age of arrival in Australia. Two possibilities were suggested as a result of becoming bilingual earlier or later in life. The first was that early bilinguals would enjoy a greater advantage as a result of a longer length of bilingual exposure, and the second, that older bilinguals would enjoy a greater advantage due to needing to use executive control networks to suppress interference from their weaker second language, as suggested by Abutalebi and Green (2007). Supporting the bilingual cognitive control advantage, this study revealed better efficiency across networks for bilinguals compared to monolinguals, but when the AoA groups were compared, another finding emerged. While early bilinguals had faster overall RTs, it was the late bilingual group that showed improved Alerting and Executive Control.

A subsequent study by Marzecová et al. (2013) of a mix of early Polish-L2 and Slovak-L2 bilinguals (where L2 could be Czech, Ukranian, Russian, or Belarussian; AoA was defined by age of first exposure) who were living or working in their L2 environment, however, found an Executive Control network advantage as well as an Alerting advantage even for early bilinguals. In contrast to Tao et al.'s (2011) findings, no global RT advantages were found; an RT advantage only became apparent on conflict trials. The authors suggest that bilingualism does impact both conflict resolution and monitoring, but possibly in an independent manner. This suggests that while becoming bilingual at any age confers an executive advantage, there are differences in the type of advantage. Results of the two studies were interpreted as dissociating the conflict resolution advantage (for late bilinguals) from a monitoring advantage (for early bilinguals, as evidenced by faster RTs). However, there were other differences between the early groups (e.g., where the L2 was learned) that may also have contributed to the different results.

A different approach to the AoA issue was taken by Luk, de Sa, and Bialystok (2011), who examined the onset age of active bilingualism, the basis for classification as Early or Late bilingual in this study, in young adults using a flanker task. Onset age of active bilingualism is defined as the age at which a bilingual started using both languages daily, with earlier onset resulting in a greater length of bilingual experience. Once again, while an overall bilingual advantage was found, the early bilingual group showed the greatest ability to suppress interference in the flanker task. Interestingly, there were no differences in cognitive control ability between the late and monolinguals groups. This finding could be the result of less experience in being bilingual. A correlation analysis showed that earlier bilingualism, and therefore longer bilingual experience, did lead to higher L2 proficiency and better cognitive control.

Pelham and Abrams (2014) also investigate Early and Late bilinguals, basing groups of English-Spanish bilinguals on the age at which they became fluent in their L2. This study examined both lexical access and cognitive control, and found that while the bilinguals certainly had a lexical access disadvantage in a picture naming task (as demonstrated by Bialystok et al., 2008), they showed better performance in an ANT task relative to monolinguals. However, there were no significant differences between the two bilingual groups. Therefore, the advantages for the bilingual groups were attributed to the constant use of two languages, rather than to the length of time spent being bilingual.

Yow and Li (2015) investigated young adult early Mandarin-English bilinguals who were born in and living in Singapore at the time of the study. All participants had learned their L2 before the age of 7, the mean AoA for the group was 3.14 (SD=1.85). Although all of the participants had acquired their L2 early in life, because they differed slightly in the age at which they began to learn the L2 (either English or Mandarin), they consequently had a different balance of use and proficiency for each language. They were tested on the Stroop task, a number-letter task, the flanker task, and an n-back task, and while the latter two tasks showed no impact of bilingualism, there were strong bilingual effects for the Stroop and number-letter tasks, with earlier AoA, and therefore more balanced bilinguals, showing better interference suppression than those who acquired their L2 later. No proficiency effects were found.

Similarly, AoA effects, with AoA operationalized as the age of beginning an immersion program in school, were also observed by Sabourin and Vīnerte (2015; 2018), who looked at only early English-French bilinguals of similar proficiencies, differentiating them into simultaneous and early sequential groups, and found that even these two early AoA groups differ in their interference and facilitation effects. Furthermore, these effects were different in the bilinguals' L1 and L2, with simultaneous bilinguals showing greater interference in their dominant language, and early sequential bilinguals showing greater facilitation in their L1 and greater interference in their L2. The authors conclude that cognitive control skills are tuned by not only the AoA, but also the language environment.

From these six studies, one point quickly becomes apparent: while all studies examine the same variable, AoA, they all take a very different approach to defining it. Tao et al. (2011) use the age of immigration, Marzecová et al. (2013) use the age of first exposure, Luk et al. (2011) use onset of active bilingualism, Pelham and Abrams (2014) define groups by the age of becoming fluent, Yow and Li (2015) treat AoA as a continuous variable based on when the bilinguals began to learn the L2 at home or in school, while Sabourin and Vīnerte (2015; 2018) use the age of beginning a school immersion program. All are measures of AoA, and all lead to some positive outcomes, yet all do not lead to the same outcomes, nor should we expect them to. The experience of becoming bilingual as a result of immigration may be quite different from becoming fluent in a second language in your country of birth. Despite these differences, AoA appears to be an important factor in the development of cognitive control for bilinguals. A drawback of these studies is that due to a lack of monolingual control groups in many, interpreting findings in terms of support for the bilingual advantage hypothesis is difficult, as all experimental groups are made up of bilinguals. But from these studies taken together, a complex picture emerges of the effects of bilingualism, with not only bilingual status but also the type of bilingual experience playing a role.

2.3.2 The Bilingual Environment

While bilingualism has been characterized in terms of factors such as the age at which one starts learning the L2, ultimate proficiency, as well as balance of language use, it is important to remember that these are all facets of an experience that occurs in a broader setting outside the laboratory, in the real world. Green (2011) suggests that some of the variability seen in cognitive control studies may stem from what he calls "the behavioural ecology of bilingual speakers" (p.1), referring to the patterns of language use in a community of speakers. In other words, the conditions under which the two languages are used, and whether or not the people in the bilingual's environment[7] keep their languages separate or mix them regularly. As proposed by Green and Abutalebi's (2013) Adaptive Control Hypothesis, described in Section 2.1.2, each of three types of language environments, characterized by the degree of mixing the two languages, leads to the development of different cognitive control skills. In a

[7] The ACH also describes these as "contexts". For the sake of clarity, I will use "environment" to talk about broader real-world conditions, and "context" to discuss task-level conditions.

single-language environment, each language is used in a separate setting, training goal maintenance and interference control; in a dual-language environment, each language is used with a different speaker, but in the same setting, and this trains the aforementioned skills even more, in addition to developing cue detection, selective response, and engagement and disengagement of attention; finally, in the dense code-switching environment, where both languages are used with the same speaker in the same setting, opportunistic planning is the control process developed. However, although some studies have considered task-level contexts that mimic natural environments (e.g., Wu & Thierry, 2013; Sabourin & Vīnerte, 2015; Ye, Mo, & Wu, 2017) few studies have investigated the effects of the broader environment, and systematic examinations of the link between the linguistic environment and cognitive control processes other than switching are just beginning[8].

Two studies that have considered the broader linguistic environment are Heidlmayr et al. (2014) and Verreyt et al. (2016). Controlling for AoA and proficiency, Heidlmayr et al. (2014) looked at the relative frequency of use of the two languages by different populations of bilinguals and how these affected inhibitory control in a Stroop task, reasoning that in an L2 environment, there would be greater activation and therefore inhibition of L2, which would in turn lead to stronger inhibitory abilities in general. They thus examined L1 French late learners of L2 German in both France and Germany. Although they found no significant effect of the environment, they found that the duration of immersion in the L2 was a significant factor, with bilinguals immersed in the short-term showing better inhibitory control than those immersed for longer periods of time, contrary to the authors' expectations. The authors explain such

[8] As previously mentioned, although there is a wealth of studies on code-switching, a thorough examination of these is beyond the scope of the current work.

seemingly contradictory findings through the automatization of cognitive control, with greater cognitive control needed at the *beginning* of immersion when control of the L2 is not yet automatic. Furthermore, they showed that the frequent use of a third language in the environment resulted in decreased Stroop interference. The authors conclude that inhibitory control skills are modulated by the duration of immersion in the L2 environment, as well as the use of a third language.

Different results were obtained by Verreyt et al. (2016), who looked at the degree of language-switching experience and performance on Simon and flanker tasks. Their participants were students at the University of Ghent in Belgium, with L1 Dutch, L2 French, and good knowledge of L3 English, who were divided into groups of bilinguals who were non-balanced, balanced but non-switching, or balanced and switching. Results showed that in both the Simon and the flanker tasks, balanced bilinguals who switched between languages frequently showed smaller interference than those balanced bilinguals who did not, and both groups performed better than non-balanced bilinguals. In line with the work of Costa and colleagues (e.g., 2008) and Bialystok and colleagues (e.g., 2008), this study also found a global RT advantage, with bilinguals who switch frequently showing faster RTs in both congruent and incongruent trials. The authors conclude that active and frequent switching between languages in the environment entails constant activation of representations in the two languages, therefore necessitating constant control, and leading to improvements in cognitive control. Referencing Green and Abutalebi's (2013) ACH, they acknowledge that it may also be the type of switching, not just switching in general, that tunes cognitive control.

Although the two studies use different methods and show different outcomes, they both agree that the environment plays an important role in the development of cognitive control. Particularly interesting is Green (2011) and Green and Abutalebi's (2013) prediction that speakers from dense code-switching communities may show different advantages than those where code-switching is limited. This seems to be confirmed by Verreyt et al. (2016), who showed differences between balanced switching and non-switching bilinguals. However, it must be mentioned that Verreyt and colleagues' groups appear to show *opposite* advantages of what is predicted by the ACH: while dense code-switching (i.e. frequent switching) is predicted to only affect opportunistic planning, dual-language (i.e. balanced, but less switching) is the usage pattern predicted to lead to the greatest benefits. However, this still provides support for the bilingual environment as a possible influence on bilingual cognitive control abilities. And as Bialystok (2017) adds, although the ACH is a promising framework, it requires further testing (see also Morales et al., 2016 for a summary of their research with simultaneous interpreters).

It may thus be that the environment in which one becomes bilingual and uses the two languages influences the cognitive control networks that are enhanced. This is particularly relevant in cases of immersion or immigration, since patterns of language use change from community to community. For example, even in a single country such as Canada, while using both languages is a frequent occurrence in the National Capital Region and Montreal, this is far less common in the Niagara region. And in Toronto, where many of Bialystok and colleagues' studies are conducted, language use may even vary by community within the city. Luk (2015) therefore specifically suggests that reporting the social environment of participants is necessary. This, however, is currently not standard practice. Furthermore, as Verreyt et al. (2016) also discuss, testing in different environments may contribute to the varied experimental outcomes. For example, Costa and colleagues' participants come from Catalonia, where Catalan-Spanish bilinguals switch between the two languages frequently, while the environment is unknown in Paap and Greenberg's (2013) study.

Previous studies of bilingual executive control have looked at participant groups from different environments, which may result in there being hidden factors for performance on executive control tasks that are not necessarily related to bilingualism. Matching participant groups is difficult when groups are from different cultural backgrounds or are bicultural (Paap & Greenberg, 2013), and results seen in executive control studies may be the result of different external factors. The Paap and Greenberg (2013) study, while concluding that there is "no coherent and compelling support for the hypothesis that the bilingual experience causes improved executive processing" (p.256), admits the task of investigating cognitive control advantages in bilinguals to be a difficult one.

The idea of the linguistic environment in bilingual cognitive control development is in line with bilingualism and its results being viewed from a more holistic perspective. As Valian (2015) discusses, children and young adults particularly have a multitude of cognitively-enriching experiences available in their environment, and Kroll and Bialystok (2013) view simplifying the bilingualism-cognitive control relationship to single components in tasks as being insufficient to capture this experience. Just like tasks, they say, participants' individual characteristics vary greatly, and results should therefore be examined in light of this. Baum and Titone (2014) agree, arguing in favour of considering the variability. And as Green (2013) enthusiastically says, "We have to make use of variety, not throw it away." Green (2013) also discusses how the brain is able to adapt to a task over the course of a single experiment; if there is such rapid adaptation over the time-course of a single experiment, it is clear that experiences shape cognitive function and development. The overall experience of being bilingual may therefore confer greater cognitive flexibility (Stocco & Prat, 2014). Therefore, it may be worthwhile to look at how specific experiences, especially the type of experience brought about by the society bilinguals live in, impact the development of cognitive control.

2.3.2.1 Language Pairings and Writing Systems

Different bilingual environments are not only characterized by the frequency of language switching, but also by the languages in that environment. This is not limited to the languages heard and spoken, but also includes the languages read and written. The current study is also interested in whether the writing system can affect bilinguals' cognitive control abilities specifically in linguistic tasks. In many previous studies, bilinguals' languages have both used the same writing system (e.g., Spanish and Catalan; Costa et al., 2008), but the possibility of the writing system as a variable in bilingual cognitive control, has not been greatly explored.

The issue of writing systems in bilingual cognitive control was explored by Coderre and van Heuven (2014), who examined same-script bilinguals and different-script bilinguals to determine whether script similarity can modulate cognitive control advantages by testing bilinguals whose two languages vary in the degree of orthographic overlap. This study included English-German bilinguals, who use the same alphabetic script, and there is a great degree of phonological and orthographic overlap; English-Polish bilinguals, who use the same alphabetic script, but there is less overlap; and English-Arabic bilinguals, who use alphabetic and abjad (i.e., where written symbols represent consonants) writing systems, which have little to no overlap. Based on the BIA+ model (Dijkstra & Van Heuven, 2002), which suggests that the amount of cross-linguistic activation may be modulated by the amount of orthographic overlap in the two languages, the authors discuss the possibility that greater orthographic similarity and therefore greater cross-linguistic activation requires single-script bilinguals to use greater amounts of cognitive control to manage the interference between their languages.

The authors test two hypotheses: the first is that same-script bilinguals will be at a cognitive control advantage due to needing to manage more interference from both languages because of greater similarity and therefore cross-language activation, and the second is that different-script bilinguals will be at an advantage due to their ability to use script as a cue to aid lexical selection, as shown by Linck, Hoshino, and Kroll (2008) and Bialystok et al. (2005) in a non-linguistic Simon task.

Results from Stroop and Simon tasks are contradictory. Arabic-English bilinguals show smaller Stroop effects compared to the other groups, but there are no differences in Simon task performance. However, Arabic-English bilinguals also show the longest global RTs in both tasks. The authors attribute the Stroop task results to differences in script processing, but based on the Simon task, in which the same-script bilinguals showed the most efficient cognitive control, Coderre and van Heuven (2014) conclude that same-script bilinguals have better general cognitive control abilities. Despite the inconsistent findings, this study demonstrates that the script of the L1 and L2 may be another variable that should be considered in tasks of cognitive control. This is particularly important for tasks that use written words as stimuli, such as the

Stroop task presented in Chapter 4, and will therefore be a factor explored for the linguistic task.

2.4 Summary

Although early literature viewed bilingualism as having a negative impact on cognition, more recent evidence suggests that cognitive control abilities may in fact benefit from bilingualism. Although limited, theories linking language processing and cognitive control have examined the issue both from a theoretical and a neurophysiological perspective, and have proposed various mechanisms for the bilingual advantage hypothesis. While no clear mechanism has been identified, empirical evidence has shown faster reaction times and better interference control for bilinguals relative to monolinguals. Such results, however, have been challenged in recent literature, and inconsistencies in results, particularly for young adults, have been pointed out. Reasons for the inconsistency in findings has been attributed to a variety of factors, including publication biases, the lack of understanding of cognitive control processes, and methodological issues across studies and participant groups.

However, evidence in favour of a bilingual advantage continues to be published, and researchers are increasingly investigating, both at a behavioural and neurophysiological level, the factors that may contribute to the presence or the absence of bilingual effects. Among the factors investigated are the AoA and the bilingual environment. The AoA has been operationalized in a number of ways, including the age of first exposure, the age of balanced use, the age of immigration, and the age of immersion in school programs. These latter two operationalizations entail an environment in which the bilingual is immersed in their second language, and according to the neurophysiologically-motivated Adaptive Control Hypothesis, the environment itself has a great impact on which cognitive processes are used and how they are tuned. However, such environments have yet to be systematically investigated in relation to the bilingual advantage hypothesis. Given the inconsistencies in the current cognitive control literature, particularly with respect to young adults, it is worthwhile to further investigate the bilingual advantage hypothesis to determine when, where, and why bilingualism makes a difference.

2.5 The Current Study

2.5.1 Research Questions

The current study uses both the non-linguistic ANT (Fan et al., 2002) and the linguistic Stroop (Stroop, 1935) tasks, and aims to examine the conditions under which bilingualism impacts linguistic and non-linguistic cognitive control in a sample of age- and education-matched non-immigrant young adult bilinguals and monolinguals in Canada and in Japan. Rather than focusing just on the presence or absence of bilingual advantages, I specifically focus on the differences among groups, and seek to link these to the type of bilingual experience. I examine the following two primary research questions: 1) Which, if any, cognitive control abilities are enhanced by bilingualism? and 2) Does the type of bilingual experience modulate observed effects? Specifically, I focus on the AoA and the bilingual environment as part of the bilingual experience. I also pose a third, exploratory question: 3) Does the writing system impact performance in linguistic cognitive control tasks? Little work has looked at the effect of different types of scripts, especially in the Stroop task, and I therefore explore the effect of writing systems in a language-based task by comparing bilinguals with an alphabetic vs. logographic writing system in their L1.

I take into consideration the heterogeneous nature of bilingualism, and rather than being separated based on monolingual or bilingual status only, the bilingual sample is subdivided into Age of Acquisition (AoA) groups. Based on previous work in the ERPLing Lab in the Department of Linguistics at the University of Ottawa, I operationalize AoA as the Age of Immersion (AoI): the age at which an individual became immersed in his or her second language in a school setting through a French immersion program (i.e., the student is exposed to French not only in a language class, but also takes courses such as, for example, mathematics, science, and history in French, thereby being immersed in the French language for a significant part of his/her day) in the case of sequential bilinguals, or in the case of simultaneous bilinguals, through daily significant exposure to both languages through primary caregivers (e.g., one English and one French speaking parent). Immersion has been identified as a factor in linguistic cognitive control by Heidlmayr, et al. (2014) and in subcortical brain organization (Pliatsikas et al., 2017), yet few cognitive control studies have explored this variable. Also, while previous studies have looked at early bilinguals, often defined as those who have acquired a second language before the age of 6 or 7 (Tao et al., 2011), following previous work (Sabourin, Brien, & Burkholder, 2014; Sabourin & Vīnerte, 2015), I further subdivide this group into Simultaneous and Early bilinguals, an approach rarely taken in the existing literature.

Following Luk's (2015) recommendations, I take the linguistic environment of participants into consideration. Canadian participants are drawn from the Ottawa community, in the predominantly English-speaking province of Ontario. Gatineau, in the predominantly French-speaking province of Quebec borders Ottawa, and although both cities are geographically separated by the Ottawa River, they form the National Capital Region of Canada and the populations of both frequently mix for work and travel. By self-report, simultaneous bilinguals grow up in bilingual households, and all other participants are frequently exposed to both English and French in the community. Based on Green and Abutalebi's (2013) Adaptive Control Hypothesis, the National Capital Region likely consists of dual-language and dense code-switching environments, where both languages are in use in the same environment.

Japanese participants are drawn from the Konan University community in the city of Kobe in Hyogo prefecture of Japan. Japan is highly homogeneous, with 98.5% of citizens being ethnically Japanese (CIA World Factbook, 2017), and the prevalence of languages other than Japanese is low. Although English is part of the standardized school curriculum, the use of English is largely restricted to the classroom, where the focus is on reading and writing rather than communication skills. As such, even in an international port city such as Kobe, participants are exposed to minimal English in their daily lives, which may make this a single-language environment according to the Adaptive Control Hypothesis.

To minimize the amount of variability, all Canadian participants are born in Canada, as are their parents, and are English-French bilinguals, with little significant exposure or education in any other language. The majority of participants are from the National Capital Region of Canada, where they currently pursue an undergraduate degree. Japanese participants (as well as their parents) are all born in Japan, and are currently pursuing or have recently completed an undergraduate degree in Japan. Studies such as Bialystok et al. (2008) and Paap & Greenberg

(2013) included a large variety of language pairs, which greatly increases the variability of the sample and may in part contribute to inconsistent results; therefore, the current study restricts language pairings to English-French and Japanese-English for Canadian and Japanese participants, respectively. As these language pairings involve different writing systems, these are acknowledged and investigated separately.

The following chapters examine non-linguistic cognitive control using an ANT task and linguistic cognitive control using a bilingual Stroop task. Given the heated debate and current controversy surrounding the bilingual advantage hypothesis (e.g. Della Sala & Grafman, 2015), I seek to identify what, if any, advantages in linguistic cognitive control are conferred by bilingualism, and how these manifest in terms of performance on the linguistic Stroop task for English-French and English-Japanese bilinguals. Due to neurobilogically-based proposals that the experience of being bilingual is not just a quantitative change (i.e., more information in the same networks) but also a qualitative one (i.e., changes in the structure of the brain), which may make the bilingual brain more efficient, I follow the Generalized Cognitive Advantage hypothesis, and predict that the impact of bilingualism will be holistic in nature, and while an early AoA will result in better interference suppression as seen by shorter RTs in incongruent conditions in both the ANT and Stroop tasks, these effects will also be modulated by the type of linguistic environment. Furthermore, I predict that different attentional networks in the ANT will be enhanced for Canadian and Japanese participants due to the different language demands of their respective environments, as outlined in Green and Abutalebi's (2013) Adaptive Control Hypothesis. Finally, there will be differences in Stroop task performance based on the writing system combination of the language pair. Specific hypotheses and predictions for the Stroop and ANT tasks are discussed in their respective chapters. While the results of this study cannot be generalized across different cognitive control tasks, they may give an insight into language processing and control in bilinguals.

Chapter 3. Study 1- Examining Non-Linguistic Cognitive Control through the Attention Network Test

3.1 The Attention Network Test

Because bilinguals have to manage the competition caused by two simultaneously-active languages, the bilingual advantage hypothesis proposes that their non-linguistic cognitive control skills are enhanced relative to monolinguals (e.g., Bialystok, 2017). Much of the research investigating the bilingual advantage has focused on these domain-general abilities, using tasks such as flankers (e.g., Luk et al., 2011; Kousaie & Phillips, 2012) and the Simon task (e.g., Bialystok et al., 2008; Paap & Greenberg, 2013). While some have found improved interference suppression as a result of bilingual experience (e.g., Bialystok et al., 2008), others have not (e.g., Paap & Greenberg, 2013). Such inconsistency, especially for the young adult population, has been found across studies (Hilchey et al., 2015) and ignited considerable controversy regarding the existence of the bilingual advantage.

In this chapter, I discuss the Attention Network Test (ANT; Fan et al., 2002), a modified non-linguistic flanker task. This simple psychological task has been used to investigate attentional abilities in both child (e.g., Poarch & van Hell, 2012; Antón, Duñabeitia, Estévez, Hernández, Castillo, Fuentes, Davidson, & Carreiras, 2014) and adult (e.g., Pelham & Abrams, 2014) participants, and with diverse populations (e.g., children with ADHD; Kratz, Studer, Malcherek, Erbe, Moll, & Heinrich, 2011; adults with schizophrenia; Hahn, Ta, Hahn, Kuehl, Ruehl, Neuhaus, & Dettling, 2011). Of specific interest to the current work is the task's use in investigations of bilingual cognitive control, and particularly in examinations of bilingual young adults' inhibitory and attentional abilities. Therefore, the vast literature on attention in general will not be reviewed. I briefly discuss the nature of the ANT and some methodological considerations, and then present the results of an ANT task conducted with two different young adult populations- Canadian and Japanese. Finally, I discuss the findings in light of different AoAs and language environments.

The ANT is designed to quickly and efficiently test three separate attentional networks (Fan et al., 2002).The task combines cued reaction time (Posner, 1980) and a modified Erkisen flanker task (Eriksen & Eriksen, 1974), in which Control, Congruent, and Incongruent arrows are preceded by attentional cues. The Control condition is formed by a single arrow pointing left or right and flanked by dashes on either side. In the Congruent condition, the central arrow appears with flankers pointing in the same direction, while in the Incongruent condition, the flankers point in the opposite direction of the central arrow, thus creating a conflict situation similar to tasks such as the Stroop, in which information from two sources competes and interference from the irrelevant source must be suppressed in order to successfully complete the task. The arrows can appear either above or below the fixation cross, and participants respond by indicating the direction of the central arrow, which is the target for the task. The target arrows are preceded by either a fixation cross only (a No-cue condition), or a fixation cross and one of 3 different attentional cues (asterisks; *): Central cue, where the asterisk appears over the fixation cross; Double cue, where an asterisk appears above and below the fixation cross simultaneously; or a Spatial cue, which can be an asterisk appearing above or below the fixation cross, indicating the location of the subsequent target. The task conditions and cues are shown in Figure 3.1.

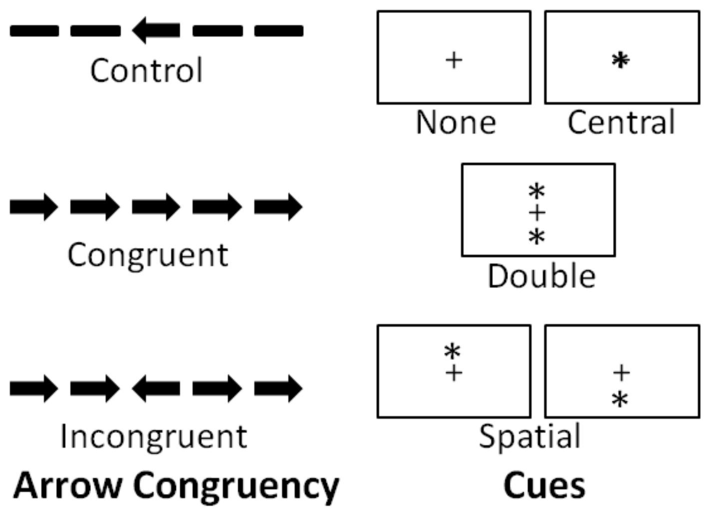

Figure 3.1. ANT Arrow and Cue Conditions. Neutral, facilitating, or interfering flanking arrows shown on the left. The middle arrow is the target of the task, and participants must indicate whether it points to the left or to the right by pressing a button. Targets are preceded by one of the 5 different cues, shown on the right. One cue appears randomly before every target.

The arrows and cues shown in Figure 3.1 are used to assess the efficiency of three attentional networks (Alerting, Orienting, and Executive Control; reviewed in detail below) proposed by Posner and Petersen (1990; in Fan et al., 2002). To calculate the efficiency of each network, the formulas in Figure 3.2 are used. For Alerting and Orienting network efficiency, RT differences between cue types are calculated. This calculation is collapsed across flanker types (e.g., all trials, whether neutral, congruent, or incongruent, with a double cue are used in the Alerting calculation). For Executive Control network efficiency, the RT differences between Incongruent and Congruent flakers are calculated. This calculation is collapsed across flanker conditions (e.g., all congruent trials, whether with no cue, double cue, central cue, or spatial cue are used in the calculation). Only correct trials are used to calculate the networks.

$$\text{Alerting} = RT_{(\text{no cue})} - RT_{(\text{double cue})}$$
$$\text{Orienting} = RT_{(\text{central cue})} - RT_{(\text{spatial cue})}$$
$$\text{Executive Control} = RT_{(\text{incongruent trials})} - RT_{(\text{congruent trials})}$$

Figure 3.2 Formulas for Calculating ANT Network Efficiency

The Alerting network, defined as achieving and maintaining an alert state (i.e., being aware of stimuli in the environment), prepares the attentional system for any incoming information. This network may therefore allow the bilingual to be aware of the languages in his or her surroundings. Alerting is calculated by subtracting RTs of trials with a Double cue from trials with no cue. Since the Double cue provides temporally (but not spatially) relevant information by signalling the onset of an upcoming trial, it is expected to reduce RTs for the trial compared to a trial with no such warning cue, which is essentially a continuation of the constantly-present fixation cross.

The Orienting network, which is the selection of specific elements of the input, directs attention to relevant information in the environment. With respect to bilingualism, it may allow the individual to tune attention toward one or the other language. In this calculation, RTs of trials with a Spatial cue are subtracted from those with a Central cue. Both the Spatial and Central cues provide temporally-relevant information (i.e., they signal the onset of the upcoming trial), but only the Spatial cue signals the location of the upcoming trial, which is expected to reduce RTs for this trial. Later adaptations of the ANT also incorporate valid and invalid Orienting cues (Fan et al., 2009; Marzecová et al., 2013, using a lateralized ANT), where the cue may indicate either the location where the target will appear (valid), or the opposite location (invalid). In addition to orienting speed, this can measure the cost of orienting to the incorrect target.

The final network, Executive Control, is involved in monitoring and conflict resolution, error detection, and inhibition. These same processes are implicated in the resolution of competition from two simultaneously-active languages. Executive Control efficiency is calculated as the difference in RTs between Congruent and Incongruent conditions, regardless of the preceding cue type. In the Incongruent condition, flankers face in the opposite direction of the target, thereby presenting conflicting information which is expected to slow RTs for the trial. In contrast, in the Congruent condition, all the arrows point in the same direction, with no conflict. If the lifelong practice with controlling two languages does enhance conflict resolution and inhibition, bilinguals are predicted to excel in suppressing interference in the incongruent condition and show faster RTs compared to monolinguals.

The three networks are proposed to be independent and linked to separate brain regions. Fan et al. (2005) used fMRI to determine which regions are active for each network, identifying concentrated parietal activation, with some frontal and thalamic activation, for the Alerting network. This activation was stronger in the left hemisphere compared to the right. For the Orienting network, superior parietal sites and frontal eye fields were activated, and for the Executive Control network, there was activation of the previously-discussed frontal cortex and the ACC. The authors note other active areas as well, concluding that these result from the complex nature of the task. In addition to separate anatomical areas, McConnell and Shore (2011) summarize work showing different neurochemical circuits for each network: Alerting is associated with the neurotransmitter noradrenalin; Orienting involves the acetylcholine neurotransmitter; while the Executive Control network is regulated by dopamine. The association of networks with different anatomical regions and neurotransmitters demonstrates that these mechanisms are separate, and supports a view of attention as being made up of interacting components, rather than being a single, unified mechanism.

Although the networks are structurally independent, they may not be entirely functionally independent. Fan et al. (2002) conclude that there are no correlations between the efficiency of the three networks (i.e., each network functions independently), but they do note some interactions between the types of cues and flankers. Particularly, when the alerting Double cue was present, interference from flankers was stronger. The authors suggest that this may be because the cue diffuses attention, directing focus away from the target, which may result in decreased ability to manage interference from the flankers. In addition, they note that while raw RT data has high test-retest correlation, the networks themselves vary (test-retest correlations are .52, .61, and .77 for the Alerting, Orienting, and Executive Control networks, respectively). The authors therefore suggest that networks may not be fully functionally independent under all circumstances.

These interactions are explored in more detail by Fan et al. (2009), MacLeod, Lawrence, McConnell, Eskes, Klein, and Shore (2010), and McConnell and Shore (2011), who confirm a flanker-by-cue effect. Furthermore, Fan et al. (2009) find improved RTs with the alerting Double cue, but confirm that it increases interference in the flanker task. This finding is also supported by McConnell and Shore (2011), who also note that unlike the alerting Double cue, the orienting Spatial cue improves performance on incongruent trials. Unlike the Double cue, which divides attention, the Spatial cue specifically focuses attention on the location of the upcoming trials, which may enable a more efficient response to the flanking arrows in the trial. MacLeod et al.'s (2010) psychometric assessment of the ANT tasks also concludes that although the networks are reliable, they are not entirely functionally independent. Still, the ANT is considered a suitable measure of attentional abilities.

With respect to investigations of bilingual cognitive control, the ANT is a relatively new task and therefore used in fewer studies. Still, inconsistency in groups and outcomes such as discussed in Chapter 2 can be seen across studies using the ANT as well. In particular, there is a variety of outcomes reported for the attentional networks. Some studies show faster global RTs (Costa et al., 2008; Tao et al., 2011; Yang & Yang, 2016) and bilingual advantages for Alerting and Executive Control networks, but not for the Orienting network (Costa et al., 2008; Tao et al., 2011; Marzecová et al., 2013), others show advantages for the Executive Control and Orienting, but not the Alerting network (Yang & Yang, 2016), while others still show only an Executive Control advantage (Pelham & Abrams, 2014; although, the authors did not specifically examine the effect of cues in their ANT task). Results not showing global effects or advantages for any attentional networks have also been found (e.g., Paap & Greenberg, 2013). Such inconsistency may certainly be the result of factors discussed in Chapter 2, but also, as MacLeod et al. (2010) point out, the flanker-cue interactions may also influence how often different network effects are seen across studies (i.e., if the interactions themselves aren't consistent, the networks effects may also not be consistent). However, in the bilingual cognitive control literature, the focus is largely on network effects. With the exception of one study (Costa et al., 2008, who found no bilingual differences), the flanker-cue interaction among groups remains largely unexplored, motivating the analysis in the current work.

Despite the functional non-independence of networks, the design of the ANT makes it a useful task for studies of cognitive control. While the Executive Control network makes the task similar to the Stroop in its ability to examine inhibition and conflict resolution, the addition of cues allows it to also measure the attentional networks of Alerting and Orienting. The task thus not only provides a non-linguistic measure of cognitive control, but it also allows for an examination of specific attentional processes, and therefore an overall measure of attentional control in bilinguals. Although they are not equivalent (see Miyake &Friedman, 2012 and Chapter 2 of the current work), the current study will pair the non-linguistic ANT task described here with the linguistic Stroop task in the following chapter. In the following sections, I examine the ANT task in two different environments, looking at the effects of AoI in each environment, and then compare AoI groups from both.

3.2 Methods

3.2.1 Participants

A total of 149 participants (21 male) between the ages of 17 and 30 from Canada (n=87) and Japan (n=62) took part in this study. Canadian participants were recruited through the university's Integrated System of Participation in Research and received 1 point credit toward their 1st year psychology or linguistics courses and light refreshments (e.g., cookies, candy, juice). Japanese participants were recruited from Konan University and Kobe College's undergraduate programs through posted advertisements and word of mouth and received 2% toward an assignment in an English class and a small thank-you gift consisting of Canadian souvenirs (e.g., key chains, stickers, pencils). Participants self-reported as right-handed, with normal or corrected-to-normal vision, normal colour vision, and no history of brain injury. Canadian participants completed a detailed language background questionnaire (Sabourin, Leclerc, Lapierre, Burkholder & Brien, 2016), in which they indicated their ages of exposure and immersion in both English and French, their use of both languages (and any others), and assessed their proficiency in each. In addition, they completed an English Cloze task (Brown, 1980) and French Cloze task (Tremblay, 2011). Japanese participants completed a modified version of the Sabourin et al. (2016) questionnaire, which was translated into Japanese by Dr. Yoriko Aizu, a native speaker of Japanese who is herself a researcher in the field. In addition, they completed Brown's English (1980) Cloze task and a Japanese Cloze task (Komori & Tamaoka, 2010).

Participants were classified based on the age at which they were immersed in their L2. Simultaneous bilinguals (henceforth, "Simultaneous") were immersed in both languages from birth, Early Sequential (henceforth, "Early") were immersed between the ages of 1 and 6, and Late Sequential (henceforth, "Late") were immersed at the age of 8 or older. To maintain clear separation, data collected from participants who reported being immersed at the age of 7 were excluded. Functional monolinguals (henceforth "Monolingual") were included as a control group. In addition, a separate group of Late bilinguals who had participated in international exchange programs and were therefore briefly immersed in an English-speaking country were identified in Japan, and included as a separate Short Late-Immersion (henceforth "Short Late") group. Detailed participant information is provided in Table 1, and further information for English-French (EF) bilinguals in Canada and Japanese-English (JE) bilinguals in Japan is given in Experiment 1 and Experiment 2, respectively.

Table 3.1. Participant Description for ANT. Average values for participant groups provided, standard deviation in brackets. Individual participant profiles are provided in Appendix E.

Country	Group	N*	Age	Age of 1st L2 Exposure	Age of Immersion	L1 Proficiency (%)	L2 Proficiency (%)**	Self-rated L2 proficiency (/20)
Canada (Expt.1)	Simultaneous EF Bilingual	23	18.5(0.8)	0.0 (0.0)	0	80.8(9.5)	60.1(19.4)	18.7(1.3)
	Early Sequential EF Bilingual	20	19.1(1.7)	4.4(1.2)	1-6	80.4(10.7)	45.3(16.6)	14.8(2.9)
	Late Sequential EF Bilingual	22	18.4(1.7)	7.5(3.9)	8+	84.3(13.9)	36.3(27.7)	9.8(5.8)
	Functional English Monolingual	22	18.5 (2.7)	8.9(2.4)	N/A	83.4(10.7)	1.4(10.7)	5.0(3.3)
Japan (Expt.2)	Late Sequential JE Bilingual	21	19.8(1.6)	10.0(2.8)	8+	93.8(4.0)	36.7(6.7)	8.1(2.7)
	Late Short-Immersed JE Bilingual	14	21.4(1.7)	11.1(3.1)	8+	93.9(2.5)	35.0(14.7)	10.1(2.1)
	Functional Japanese Monolingual	19	20.4(2.7)	11.2(2.4)	N/A	91.1(6.1)	18.2(10.3)	6.0(3.1)

*The same participants completed both the ANT presented here and the Stroop task presented in Chapter 3. However, not all Japanese participants completed the ANT (e.g., task malfunction; withdrawing after completing only one task in order to get to class on time); therefore, only the subset that completed the ANT is included in this Table.

** Due to the relatively greater difficulty of the French Cloze task, all participants scored lower on this task. However, there are no significant differences between the scores of natives speakers of French (matched sample tested separately) and the Simultaneous group (p=1.00).
In addition, for Japanese participants, L2 written proficiency scores overlapped between the groups, and it was therefore necessary to also use self-reported percentage of immersion to separate monolinguals from late-immersed bilinguals. Monolinguals reported using English under 30% of the school day, while bilinguals reported using English over 50% of their day.

3.2.2 Stimuli and Design

An ANT task was programmed using Neurobehavioral Systems Presentation v.14.9 software. Stimuli were presented using a PC desktop computer with a Windows Vista operating system, on a 19-inch screen. Participants used a Cedrus RB-830 button box equipped with 3 active buttons to respond: a button was designated for the left and the right arrow response, and a third button was designated as a "continue" button to be pressed after instruction screens and self-timed breaks. To minimize cognitive demand of responses, the left and right response buttons were placed on the left and right side, respectively. Button layout on the button box is shown in Appendix D.

In the current study, as in the original test, the stimuli used were left-pointing and right-pointing arrows, and asterisks (*) were used as cues. Arrow congruency and Cue types are shown in the aforementioned Figure 3.1. The arrows could appear in either the Control, Congruent, or Incongruent conditions, either above or below a central fixation cross, combined with any of the four Cue types. Any of the cue types could precede any of the arrow types, with a randomized cue-arrow pair in each trial. An ANT task with 288 trials was created and separated into two identical blocks, each consisting of 144 trials. Trials were randomized, but each block contained equal numbers of Control, Congruent, and Incongruent trials, and equal numbers of each of the 4 Cues.

3.2.3 Procedure

All participants signed an informed consent form (Appendix A), and then completed the language background questionnaire (Sabourin et al., 2016; Appendix B) followed by the English Cloze task (Brown, 1980) and French Cloze task (Tremblay, 2011) in the case of English-French bilinguals and Japanese Cloze task (Komori & Tamaoka, 2010) in the case of Japanese-English bilinguals. Proficiency tasks are provided in Appendix C. The ANT trial began with a fixation cross at the centre of the screen for 250-1500ms (randomized), followed by a 100ms presentation of the cue. The cue disappeared, and 250ms later the target appeared on screen until the participant responded or 2000ms had elapsed. Participants responded by pressing either the left or the right button to indicate the direction of the arrow they had seen. The next trial began immediately following the button press. Each block was preceded by 15 practice trials, and blocks were separated by a self-timed break. Throughout the blocks, trials were randomized using Presentation's randomization command, and the 288 experimental trials and practice blocks took approximately 20 minutes to complete. See Figure 3.3 for a sample trial with a Spatial Cue and an Incongruent target.

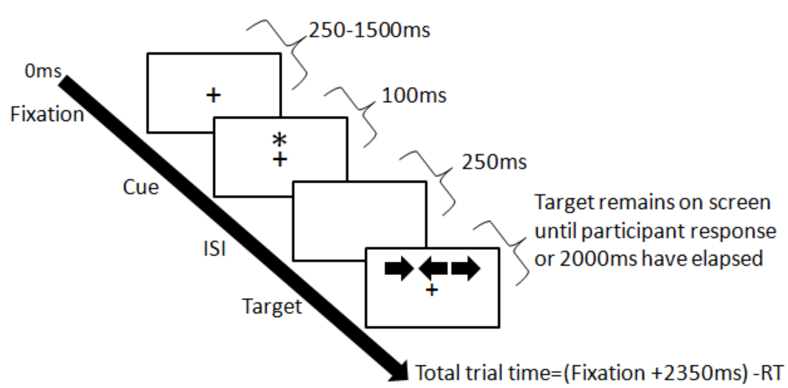

Figure 3.3. ANT Trial. A spatial cue and incongruent flanking arrows are shown. Each trial begins with variable onset and terminates when the participant presses a response button.

3.3 Experiment 1. Effects of AoI on Attentional Networks for Young Adults in Canada

A total of 87 participants (6 male) between the ages of 17 and 27 took part in the Canadian component of the study, which was conducted in Ottawa, Canada. All participants were native speakers of English and all reported using English on a daily basis. Based on the language background questionnaire, participants were divided into three bilingual AoI groups: Simultaneous bilinguals, immersed in both English and French from birth as a result of being part of a bilingual household (often, with one Anglophone and one Francophone parent), Early bilinguals immersed in French between the age of 1 and 6, and Late bilinguals, immersed in French after the age of 8. In the latter two groups, immersion was in the form of French immersion programs in school, where participants received significant exposure (operationalized as half a day of school instruction or more) to French, not only through French language classes, but also by taking classes such as mathematics, science, history, and geography in French. In addition, a Monolingual control group was included. As part of their Canadian education, these individuals have taken core French classes (approximately 45 minutes of French instruction per day) up until about grade 10, but had never been immersed in French, and currently have little to no written or oral communication proficiency.

Based on Burkholder's (2018) investigation of language mixing in the National Capital region and the language background questionnaire of the current study, Simultaneous bilinguals routinely code-switch, while Early bilinguals use each language with a separate interlocutor. According to the ACH (Green & Abutalebi, 2013), these behaviours may constitute a dense code-switching environment and a dual-language environment, respectively. Late bilinguals with English as an L1 may also fall in the dual-language category.

3.3.1 Hypotheses

Three hypotheses are tested in this experiment. First, as a result of using cognitive control processes to manage two languages, bilinguals will show improved Executive Control network efficiency compared to monolinguals (i.e., results will support the bilingual advantage hypothesis). This is predicted to manifest as a smaller difference between congruent and incongruent trials, resulting in a smaller Executive Control network effect magnitude. Second, as a result of becoming bilingual earlier in life and therefore having more experience in using cognitive control skills to manage two languages, bilinguals with an earlier AoI are expected to show greater Executive Control efficiency compared to bilinguals with a later AoI. Finally, although the Alerting and Orienting networks are treated as exploratory by the current study, it is hypothesized that if bilingualism results in general cognitive advantages, these networks will also be more efficient for bilingual compared to monolingual participants. This will manifest as faster RTs in the presence of specific cues that engage and orient attention in comparison to trials without these cues, resulting in greater Alerting and Orienting effect magnitudes.

3.3.2 Analysis

For the 87 participants, RT data from missed or incorrect trials was removed and individual participant responses that were 2.5 standard deviations above or below the mean for that participant were removed, resulting in the removal of 4.7% of the trials. Mean RT for each participant was calculated, and box plots were conducted for each condition. Boxplots of average RTs revealed 3 participants as significant outliers (1 Monolingual, 1 Simultaneous and 1 Late bilingual) and their data was subsequently removed. Participant removal accounted for the removal of a total of 3.4% of the data. Because of high accuracy (>95% correct trials) and no significant group differences on accuracy (all *p's* = 1.00), further analysis of accuracy was not conducted, and only RT data from the remaining 84 participants was analysed.

AoI is based on the age at which participants became immersed in a school program, and the programs begin at ages determined by the school curriculum; participants therefore fell into overall uniform groups (i.e., there was little variation in AoI among the groups). Because participants fell into natural groups, rather than on a continuum, the statistical approach chosen was an Analysis of Variance (ANOVA). To account for violations of sphericity, Greenhouse-Geisser corrected values are reported.

3.3.2.1 General Analysis of Reaction Time

Average RTs were 451.66ms (SE=6.91, 95% CI [437.90, 465.43]) in the Congruent condition, 510.99ms (SE=7.28, 95% CI [496.50, 525.48]) in the Incongruent condition, and 446.96ms (SE=6.23, 95% CI [434.55, 459.37]) in the Neutral condition. With no cue, average RT was 501.77ms (SE=7.38, 95% CI [487.07, 516.47]), and was decreased in the presence of a central cue (mean=468.73ms, SE=6.52, 95% CI [455.74, 481.71]) and a double cue (mean=462.87ms, SE=6.53, 95% CI [449.88, 475.86]), and especially in the presence of a spatial cue (mean=446.12ms, SE=6.74, 95% CI [432.71, 450.53]). For average cue and congruency RTs for each participant group, please refer to Appendix G.

To examine these RTs for each AoI group, a Cue (None, Central, Double, Spatial) x Congruency (Neutral, Congruent, Incongruent) x AoI (Simultaneous, Early, Late, Monolingual) repeated measures ANOVA was conducted. This analysis revealed the expected Congruency effect ($F(2, 115.84)=399.45$, $p<.001$), demonstrating facilitation for the congruent compared to the neutral condition (mean difference=44.70ms, $p=.017$) and interference for the incongruent compared to neutral condition (mean difference=64.03ms, $p<.001$). Furthermore, there was an effect of Cue ($F(3, 196)=223.00$, $p<.001$), with faster RTs confirmed in the presence of the Double (mean difference=38.91ms, $p<.001$), Central (mean difference=33.05ms, $p<.001$), and Spatial (mean difference=55.75ms, $p<.001$) cues compared to trials with no cue. There was also an interaction between Congruency and AoI ($F(6, 116)=2.58$, $p=0.036$), as well as the interaction between Cue and Congruency ($F(6, 425)=14.28$, $p<.001$) that has been observed in previous studies. To interpret these interactions, Fan et al.'s (2002) ANT analysis method was followed. This looked at the individual effect sizes for the different networks and examined each attentional network separately.

3.3.2.2 ANT Network Effect Sizes

The Alerting, Orienting, and Executive Control effects were calculated for each participant using the formulas shown in Figure 3.2 and repeated here for convenience:

$$\text{Alerting} = RT_{(\text{no cue})} - RT_{(\text{double cue})}$$
$$\text{Orienting} = RT_{(\text{central cue})} - RT_{(\text{spatial cue})}$$
$$\text{Executive Control} = RT_{(\text{incongruent trials})} - RT_{(\text{congruent trials})}$$

Looking at the Alerting network, average effect size was 40.77ms (SD=25.09, 95% CI [29.35, 52.19]) for Monolinguals compared to 47.09ms (SD=24.94, 95% CI [35.74, 58.44] for the Simultaneous, 39.74ms (SD=22.94, 95% CI [29.01, 50.48]) for Early, and 28.01ms (SD=24.86, 95% CI [16.37, 39.65]) for the Late bilingual groups. For the Orienting network, average effect size was 21.34ms (SD=19.41, 95% CI [12.50, 30.18]) for Monolinguals compared to 21.83ms

(SD=15.70, 95% CI [14.68, 28.98] for the Simultaneous, 27.50 (SD=16.38, 95% CI [19.84, 35.17]) for Early, and 19.75 (SD=14.39, 95% CI [18.94, 26.22]) for the Late bilingual groups. For these two networks, a larger effect size indicates better network efficiency.

Looking at the Executive Control network, where a smaller effect size indicates better efficiency, the Monolingual group's average effect size was 69.39ms (SD=33.42, 95% CI [54.17, 84.60]). In contrast, the average effect size was 48.38ms (SD=16.44, 95% CI [40.90, 55.87]) for the Simultaneous, 55.94ms (SD=22.68, 95% CI [45.33, 66.56]) for the Early, and 63.60 (SD=22.93, 95% CI [52.86, 74.33]) for the Late bilingual groups.

An analysis of the effect sizes for each attentional network was conducted using a one-way ANOVA with AoI as the between-participants factor. The analysis of the Executive Control network revealed significant differences between the groups ($F(3,78) = 2.86$, $p = .042$), and planned pairwise comparisons showed that this effect is driven particularly by the Simultaneous group's increased efficiency compared to the Monolingual group (mean difference=21.00ms, $p = .044$). However, there were no between group differences for the Alerting ($p = .101$) and Orienting ($p = .480$) networks. These network effects are shown in Figure 3.3.

Typically, in an analysis of the ANT task, the Executive Control network is calculated as the difference between the congruent and incongruent conditions; however, these are collapsed across all cue types. The interaction between Cue and Congruency in the General Analysis suggested further analysis in an attempt to disentangle the effects of each factor for different bilingual groups.

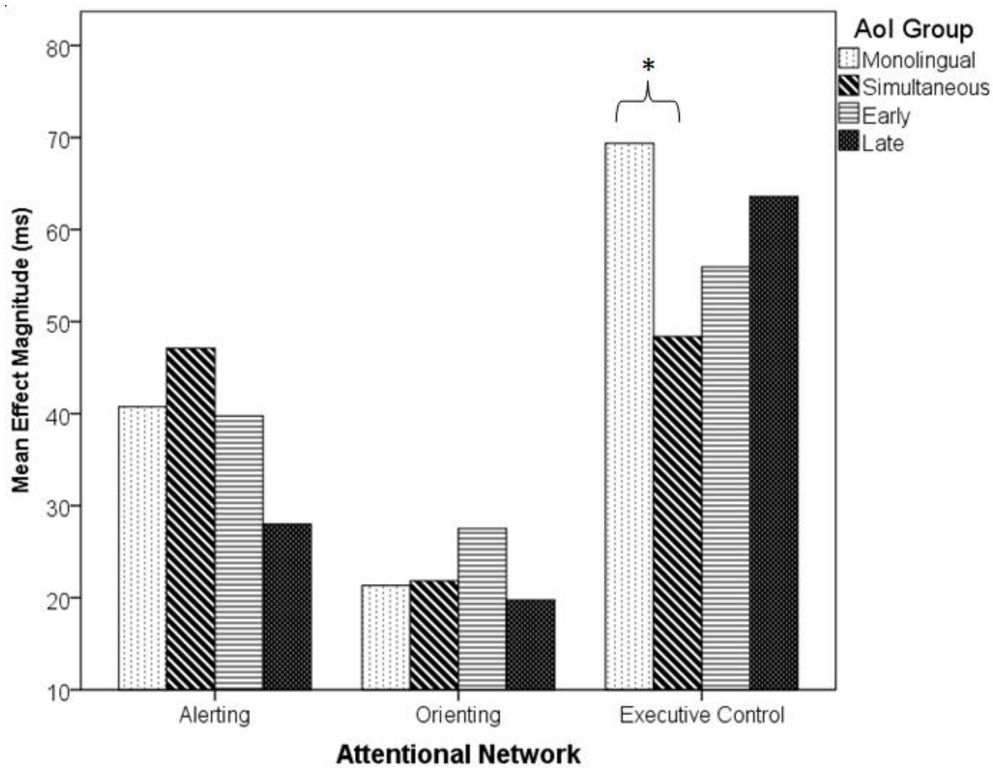

Figure 3.4.Attentional Network Effects by AoI Group. Calculated network effects shown. For Executive Control network, lower effect magnitude indicates greater network efficiency, while for the Alerting and Orienting networks, greater efficiency is indicated by greater effect magnitude. Individual group RTs and standard deviations are provided in Appendix G.

3.3.2.3 Cue Effects for the Executive Control Network

Although there was no significant interaction between the Cue, Congruency, and AoI, the interactions between Cue and Congruency suggested an exploration of cue effects. I examined the patterns for the Executive Control network, calculating the effect size for the network for each separate cue type. Overall, Executive Control network effect size when no cue was present was 41.40ms (SD=35.20, 95% CI [33.66, 49.16]). With the addition of cues, the effect size was 69.83ms (SD=38.72, 95% CI [61.32, 78.34]) with a central cue, 71.31ms (SD=34.29, 95% CI [63.79, 78.85]) with a double cue, and 54.71ms (SD=36.75, 95% CI [46.64, 62.79]) with a spatial cue. Effectively, the addition of cues decreased the efficiency of the Executive Control network; however, each AoI group showed different efficiency under each of the cues.

Looking at AoI groups, when no cue appeared before the target, the Executive Control effect sizes were 41.85ms (SD=45.23) for Monolinguals, and 36.72ms (SD=29.25) for Simultaneous, 43.73ms (SD=36.37) for Early, and 43.51ms (SD=29.52) for Late bilinguals. With a central cue, the effect sizes were 86.27ms (SD=45.47) for Monolinguals, and 62.64ms (SD=34.35) for Simultaneous, 62.75ms (SD=39.80) for Early, and 67.20ms (SD=31.20) for Late bilinguals. With a double cue, effect sizes were 79.54ms (SD=37.56) for Monolinguals, and 55.27ms (SD=22.72) for Simultaneous, 66.65ms (SD=27.06) for Early, and 84.21ms (SD=41.16) for Late bilinguals. Finally, with a spatial cue, the effect sizes were 69.89ms (SD=52.96) for Monolinguals, and 38.91ms (SD=26.82) for Simultaneous, 50.63ms (SD=27.11) for Early, and 59.47ms (SD=27.21) for Late bilinguals.

Statistical analysis of Executive Control in the non-cued condition (None) found no differences between groups ($F < 1$, p=.914). Similarly, no differences were seen with the Central cue (F=1.81, p=.152). However, when looking at Executive Control in the Double cue and Spatial cue conditions, there are significant differences between the groups ($F(3,78)$=3.25, p=.026 and $F(3, 78)$=2.87, p=0.042, respectively). Simultaneous bilinguals benefit most in both conditions, showing less interference compared to the Late group (mean difference=28.94ms, p=.037) in the Double cued condition, and compared to the Monolingual group (mean difference=30.98ms, p=.036) in trials with a Spatial cue. These effects are shown in Figure 3.5.

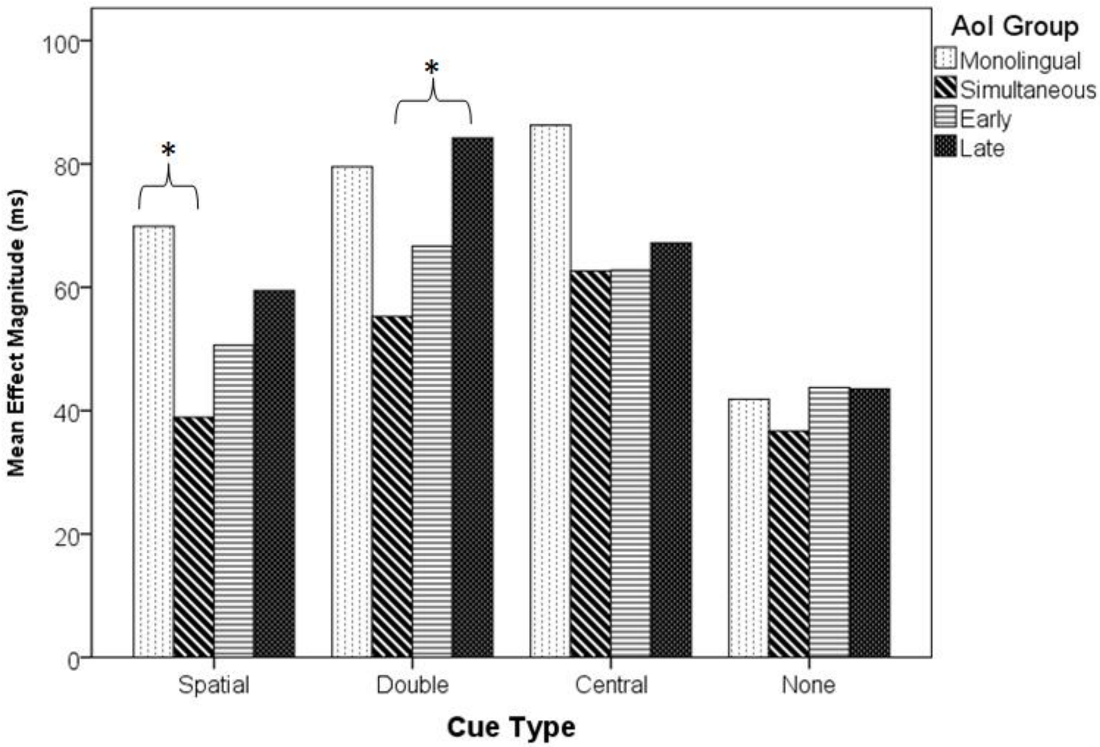

Figure 3.5. Executive Control Network Efficiency by Cue Type for AoI Groups. Calculated network effects shown for each cue type. Lower effect magnitude indicates greater network efficiency. Individual group RTs and standard deviations are provided in Appendix G.

3.3.3 Discussion of ANT Results for Young Adults in Canada

Examining the attentional networks of the ANT for young adults in Canada, it was found that while there was no effect of bilingualism on the Alerting and Orienting networks, Simultaneous bilinguals showed significantly improved efficiency compared to their monolingual counterparts. Effectively, there is an Executive Control advantage for the most bilingual participants (those immersed in two languages from birth) relative to the least bilingual participants (those who, while having some exposure to French, have never been immersed and have low proficiency). Such results support the primary hypothesis, the bilingual advantage view, and are in line with previous studies (e.g., Costa et al., 2008; Marzecová et al., 2013), which also found Executive Control advantages for bilingual groups.

Although these differences do not reach significance, the pattern of results seen in Figure 3.4 appears to support the second hypothesis examining earlier vs. later bilingual groups. Executive Control networks of earlier bilinguals appear to benefit relative to the Monolingual group, as was shown by Pelham and Abrams (2014). However, contrary to the hypothesized advantage for Early compared to Simultaneous bilinguals, due to Early bilinguals' dual-language environment, although Simultaneous bilinguals appear to show slightly less interference compared to the Early group, no significant differences were found. This lack of difference will be further discussed in the General Discussion of this chapter.

No Alerting or Orienting attentional network effects were found for any groups; however, this may in part be the result of these network calculations collapsing cues across all congruencies. In an attempt to disentangle cue effects from congruency, the Executive Control network was examined under different cue conditions. Seen in Figure 3.5, Simultaneous bilinguals benefited from the Double cue and the Spatial cue, the two cue types specifically associated with the alerting and orienting of attention. The Double cue alerts participants to the imminent onset of the target, engaging their attentional resources, while the Spatial cue signals the exact location of the upcoming target, engaging attentional resources and directing them toward the relevant task. It may be that this group's experience in tuning attention from one language to the other allows them to take advantage of such facilitating cues in non-linguistic tasks as well. Looking at the effect size among other bilingual groups relative to the monolingual one, distinct benefits of the attentional cues can also be seen for the Early group, with some benefits for the Late group, suggesting that while not as significant as for the Simultaneous group, these groups also benefit from facilitating attentional cues more than monolinguals.

Interestingly, there are no differences among the groups when no cue is present, suggesting two possibilities for the cued vs. non-cued trials: 1) In the non-cued trials, without engaging attention, all groups are functioning at peak efficiency, and therefore there are no differences in among them, or 2) By introducing the cues, distractors that divert attention away from the target are also introduced, thereby increasing the difficulty of the task. Under these latter conditions, it may be the bilingual groups who are best able to tune attention to minimize distraction and use this additional information to complete the task, leading to improved Executive Control. However, the additional information provided by the cues distracts the monolingual group, and this distraction leads to a less efficient Executive Control network. To determine this, however, further investigation is needed.

3.4 Experiment 2. Effects of AoI on Attentional Networks for Young Adults in Japan

A total of 66 participants (15 male) between the ages of 18 and 30 took part in the Japanese component of the study, which took place in Kobe, Japan. However, due to technical issues, only 54 participants completed the study. All participants are native speakers of Japanese and all reported using Japanese on a daily basis. Due to differences between the Canadian and Japanese education system, however, the Japanese groupings were not equivalent to the Canadian ones. Simultaneous and early bilingualism, although increasing, is still rare in Japan. Japanese students begin formal English classes in school in Grade 6 of elementary school (approximately 10-11 years of age), and although this age has been decreased to Grade 5 (approximately 9-10 years of age) as of 2011 (T. Kano, personal communication, February 26, 2018), all participants in the current sample followed the old system, making them late L2 learners. Furthermore, immersion programs are not part of the English curriculum in elementary, junior high, and senior high school, and only become an option in university.

Based on the language background questionnaire (Sabourin et al., 2016), participants were divided into three AoI groups. Late Sequential bilinguals ("Late") in Japan were classified as ones who became immersed in L2 English after the age of 8, although due to the aforementioned lack of immersion programs before university, the majority of participants actually became immersed in the first year of university (at the age of 18) when they began to major in English-related programs (e.g., English Literature, American Culture). It must be mentioned that even these programs emphasize reading and writing, with less focus on oral communication and production. In examining the Late group, it became apparent that a subset of the participants had completed short-term study abroad programs ranging from 3 to 14 months (mean duration= 6.6, SD=3.7 months) in Canada, the United States, Australia, or New Zealand during their university studies. Because these programs provided true immersion in the L2 environment, where participants also had practice in oral comprehension and production, this subset was classified as a separate group, the Late Short-Immersed Sequential bilinguals (“Late Short-Immersed”). In addition, a Functional Monolingual ("Monolingual") control group was included. As part of their regular English curriculum, these individuals have taken basic English classes (approximately 45-90 minutes of English instruction per day; consisting mostly of grammar and reading, with 1 oral communication class a week) from Grade 6 until Grade 12, but have never been immersed in English. They currently have little to no oral communication proficiency, although due to the heavy focus on reading and writing in the school system, this group does have some written proficiency. Because of this, there was some overlap in proficiency scores between the Late and the Monolingual groups; however, the monolingual was never immersed in English, and their exposure to English at the time of testing was low.

According to the language background questionnaire and a language switching questionnaire (Appendix F), all Japanese-English bilinguals in the sample tested rarely use English outside of school, and typically do not switch between languages. Theirs may therefore be classified as a single-language environment according to the ACH.

3.4.1 Hypotheses

As with the English-French bilinguals in Canada, it is hypothesized that as a result of using cognitive control processes to manage two languages, bilinguals will show improved Executive Control network efficiency compared to monolinguals (i.e., results will support the bilingual advantage hypothesis). This will manifest as less interference in incongruent trials, leading to a decreased Executive Control effect magnitude. Since the Japanese study includes only late bilinguals, it is not possible to test an AoI range in this group; however, effects of short-term immersion at a later age are explored. The Alerting and Orienting networks are also explored, and it is hypothesized that if bilingualism results in general cognitive advantages, these networks will also be more efficient for bilingual compared to monolingual participants. This will manifest as faster RTs in the presence of specific cues that engage and orient attention in comparison to trials without these cues, resulting in greater Alerting and Orienting effect magnitudes.

3.4.2 Analysis

For the 54 participants, data from missed or incorrect trials was removed and individual participant responses that were 2.5 standard deviations above or below the mean for that participant were removed, resulting in the removal of 4.9% of trials. Mean RT for each participant was calculated, and box plots were conducted for each condition. Average RTs revealed 2 participants as significant outliers (1Monolingual and 1 Late bilingual) and their data was subsequently removed. Participant removal accounted for the removal of a total of 3.7% of the data. Because of high accuracy (>95% correct trials) and no significant group differences (all *p's* = 1.00), further analysis of accuracy was not conducted, and only RT data from the remaining 52 participants was analysed. As with the Canadian group, the statistical method chosen was ANOVA. To account for violations of sphericity, Greenhouse-Geisser corrected values are reported.

3.4.2.1 General Analysis of Reaction Time

Average RTs were 458.37ms (SE=7.61, 95% CI [443.08, 473.66]) in the Congruent condition, 522.16ms (SE=8.84, 95% CI [504.41, 539.92]) in the Incongruent condition, and 454.94ms (SE=7.36, 95% CI [440.14, 469.74]) in the Neutral condition. With no cue, average RT was 513.68ms (SE=8.49, 95% CI [496.61, 530.74]), and was decreased in the presence of a central cue (mean=476.98ms, SE=7.59, 95% CI [461.72, 492.23]), a double cue (mean=469.68ms, SE=7.62, 95% CI [454.36, 485.00]), and a spatial cue (mean=453.62, SE=7.98, 95% CI [437.58, 469.67]). For average cue and congruency RTs for each participant group, please refer to Appendix G.

Analysing RTs for each AoI group, a Cue (None, Central, Double, Spatial) x Congruency (Neutral, Congruent, Incongruent) x AoI (Late, Late Short-Immersed, Monolingual) repeated measures ANOVA revealed a Congruency effect (F(2, 98)=283.79, p<.001), demonstrating the expected interference for the incongruent compared to neutral condition (mean difference=67.22ms, p<.001); however, facilitation for the congruent compared to the neutral condition was absent (mean difference=3.43ms, p=.191). There was also an effect of Cue (F(3, 147)=168.93, p<.001), with faster RTs in the presence of the Double (mean difference=43.99ms, p<.001), Central (mean difference=36.70ms, p<.001), and Spatial (mean difference=60.01ms, p<.001) cues compared to trials with no cue.

Results also revealed an interaction between Cue and Congruency (F(6, 294)=3.49, p=.007), and a trend toward a Cue and AoI interaction (F(6, 147)=2.33, p=.06). To interpret these interactions, I again followed Fan et al.'s (2002) ANT analysis method which looked at the individual effect sizes for the different networks and examined each attentional network separately.

3.4.2.2 ANT Network Effect Sizes

As with the Canadian participants, the three attentional networks were calculated for each group. Looking at the Alerting network, average effect size was 36.70ms (SD=19.01, 95%

CI [27.29, 46.20]) for Monolinguals compared to 38.01ms (SD=21.42, 95% CI [27.69, 48.34]) for the Late and 57.32ms (SD=29.87, 95% CI [40.07, 74.56]) for the Late Short-Immersed bilingual groups. For the Orienting network, all groups performed very similarly, and average effect size was 22.89ms (SD=12.29, 95% CI [16.97, 28.81]) for Monolinguals compared to 23.76ms (SD=21.08, 95% CI [13.59, 33.92]) for the Late and 23.57ms (SD=16.69, 95% CI [18.75, 28.04]) for the Late Short-Immersed bilingual groups. For these two networks, a larger effect size indicates better network efficiency.

Looking at the Executive Control network, where a smaller effect size indicates better efficiency, the Monolingual group's average effect size was 66.18ms (SD=24.97, 95% CI [54.15, 78.22]). Similar results were seen for the bilingual groups, where the average effect size was 65.56ms (SD=21.97, 95% CI [54.97, 76.15]) for the Late and 59.56ms (SD=31.04, 95% CI [41.63, 77.48]) for the Late Short-Immersed groups.

A statistical analysis of the effect sizes for each attentional network was conducted using a one-way ANOVA with AoI as the between-participants factor. The analysis of the Alerting network revealed significant differences between the groups ($F(2,49)=3.74$, $p=.031$), and planned pairwise comparisons showed that this effect is driven particularly by the Late Short-Immersed group's increased efficiency compared to the Monolingual group (mean difference=20.62ms, $p=.047$). There was also a trend toward increased Alerting efficiency for the Late Short-Immersed vs. Late bilinguals (mean difference= 19.30ms, $p=.07$). However, there were no between group differences for the Orienting ($p=.987$) and Executive Control ($p=.734$) networks. These network effects are shown in Figure 3.6. Interestingly, visual inspection shows the Monolingual and Late groups patterning similarly on the Executive Control network, both showing less efficient Executive Control than the Late Short-Immersed group. An independent-samples t-test confirms that there are no differences between the Monolingual and Late groups (*t*(36)=.082, *p*=.935), although the difference between these two groups and the Late Short-Immersed do not reach significance (*t*(50)= -.793, *p*=.432).

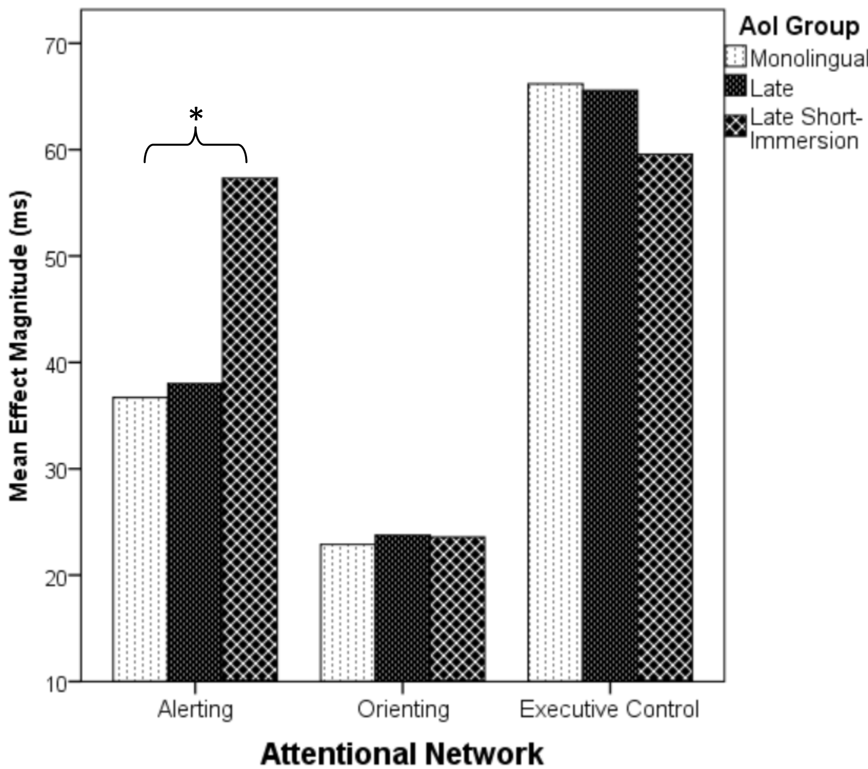

Figure 3.6.Attentional Network Effects by AoI Group. Calculated network effects shown. For Executive Control network, lower effect magnitude indicates greater network efficiency, while for the Alerting and Orienting networks, greater efficiency is indicated by greater effect magnitude. Individual group RTs and standard deviations are provided in Appendix G.

3.4.2.3 Cue Effects for the Executive Control Network

As with the English-French bilinguals, although there was no significant interaction between the Cue, Congruency, and AoI, the interaction between Cue and Congruency prompted an exploration of Executive Control under different Cue conditions. Overall, Executive Control network effect size when no cue was present was 57.63ms (SD=49.52, 95% CI [44.12, 71.15]). With the addition of cues, the effect size was 76.23ms (SD=41.88, 95% CI [64.80, 87.66]) with a central cue, 69.15ms (SD=47.82, 95% CI [56.09, 82.20]) with a double cue, and 64.47ms (SD=45.24, 95% CI [52.12, 76.82]) with a spatial cue. Effectively, the addition of cues again decreased the efficiency of the Executive Control network.

Looking at AoI groups, when no cue appeared before the target, the Executive Control effect sizes were 63.43ms (SD=55.93) for Monolinguals, and 54.93ms (SD=43.61) for Late and 53.24ms (SD=50.61) for Late Short-Immersed bilinguals. With a central cue, the effect sizes were 89.56ms (SD=44.91) for Monolinguals, and 69.84ms (SD=31.40) for Late and 66.31ms (SD=48.16) for Late Short-Immersed bilinguals. With a double cue, effect sizes were 84.19ms (SD=60.36) for Monolinguals, and 58.75ms (SD=43.70) for Late and 62.50ms (SD=25.38) for Late Short-Immersed bilinguals. Finally, with a spatial cue, the effect sizes were 65.92ms (SD=55.95) for Monolinguals, and 68.67ms (SD=35.58) and 68.67ms (SD=35.58) for Late and 56.41ms (SD=42.64) for Late Short-Immersed bilinguals.

Unlike for the English-French bilinguals, however, none of the group differences reached significance. What did emerge was an interesting pattern: In the presence of the Double, Central, and No cues, the two bilingual groups showed more efficient Executive Control than the monolingual group. In the presence of a Spatial cue, only the Late Short-Immersed group showed more efficient Executive Control. These patterns are shown in Figure 3.7.

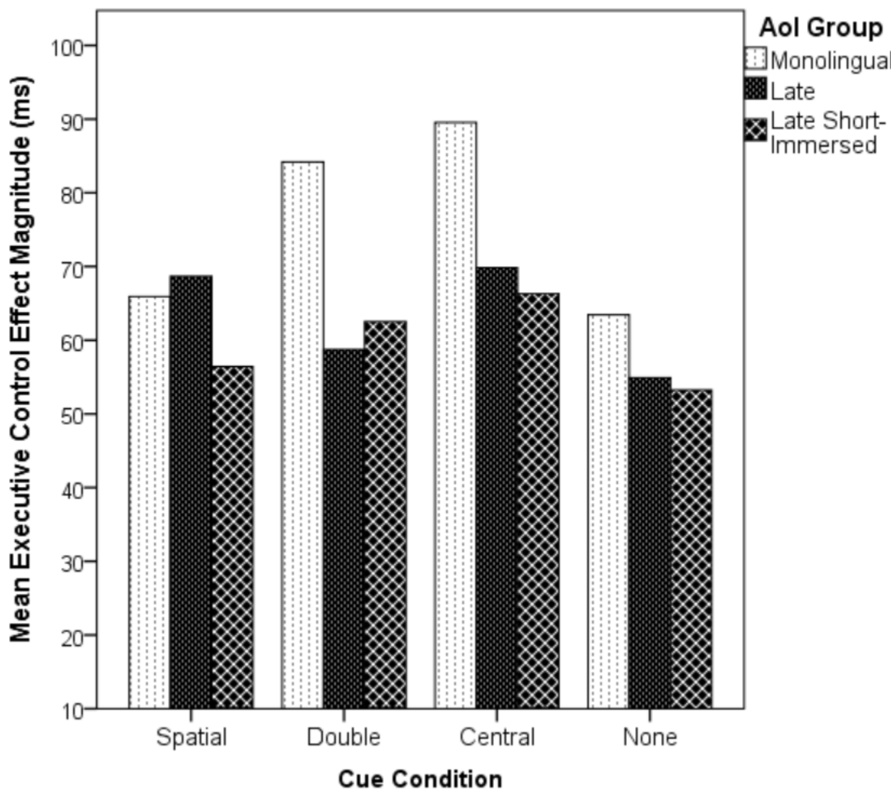

Figure 3.7. Executive Control Network Efficiency by Cue Type for AoI Groups. Calculated network effects shown for each cue type. Lower effect magnitude indicates greater network efficiency. Individual group RTs and standard deviations are provided in Appendix G.

3.4.3 Discussion of ANT Results for Young Adults in Japan

Examining the attentional networks of the ANT for young adults in Japan, it was found that while there was an effect of bilingualism on the Alerting network, with Late Short-Immersed bilinguals showing significantly improved efficiency compared to Late and Monolingual groups, there were no significant differences between groups for the Orienting and Executive Control networks (Figure 3.6). While the absence of a bilingual advantage in Executive Control for Late bilinguals is in contrast with Pelham and Abrams's (2014) findings showing that even late bilinguals may benefit, it may not be altogether incompatible. Pelham and Abrams (2014) concluded that it is habitual use and proficiency in the L2 that confers advantages, but because of the late age of L2 acquisition and the linguistic environment in Japan, this is not the case for Japanese late bilinguals.

All participants began learning English relatively late (approximately at the age of 10), and those who were immersed in English were only immersed in adulthood (approximately at the age of 18) through a university program. As seen in Table 3.1, their objective and subjective L2 proficiency is low. In addition, most participants do not use English in spoken or in written form outside the classroom. It may therefore be that the resulting experience with L2 English is too limited to confer significant cognitive benefits to these late bilinguals. Furthermore, whatever benefits do arise may not be due to the practice of managing two languages; instead, it may be a benefit that stems from the process of learning the second language.

Still, when looking at Executive Control under different cue conditions, the patterns shown in Figure 3.7 do suggest some improvement for the two bilingual groups relative to the monolingual one. This is particularly apparent under the Double and Central cue conditions, the two types that signal an upcoming trial and thus engage attention. It may be that bilinguals are better able to take advantage of these attentional cues and use them to complete the task more effectively. This pattern suggests that even late bilingualism may confer some cognitive benefits; although, because these differences are non-significant, it cannot be interpreted as clear support for the bilingual advantage hypothesis.

Interestingly, while not showing Executive Control advantages, nor patterning differently from the Late bilingual group, the Late Short-Immersed bilinguals did show an Alerting advantage compared to the other groups. In discussing the Alerting advantage for bilinguals, Costa et al. (2008) note that the Alerting network, which allows the individual to be sensitive to incoming cues, may prepare the system for upcoming conflict monitoring and conflict resolution, and that greater Alerting may therefore result in better Executive Control. Costa et al. (2008) also note that the relationship between Alerting and Executive Control is complex, but still show that bilinguals benefit more than monolinguals. In the current experiment, although showing a pattern of reduced interference in the presence of Central and Double cues, significant Alerting was not accompanied by overall improvements in Executive Control for the Late Short-Immersed group. Despite being insufficient to decrease interference from conflicting stimuli in general, this short study-abroad experience, which constitutes true immersion in the L2 and increases individuals' awareness of English, may be enough to make the individual more sensitive to stimuli in the environment.

However, given the complicated relationship between networks, I interpret the Alerting advantage for the Late Short-Immersed group with caution, and acknowledge that it may not be their immersion experience that drives this effect. Students who participate in Konan University's short-term immersion programs are typically more driven to study English, and may therefore have other L2 experience. For example, some students have taken language classes at cram school, which provides up to 5 additional hours of English grammar practice a week. Others may have taken classes at an English conversation school or participated in their high school's English club, where the focus is largely on speaking. These types of programmes are highly variable, and therefore difficult to quantify, which makes assessing their impact more challenging. Thus, although the Late Short-Immersed group does show a significant Alerting advantage, it cannot be conclusively attributed to their participation in their study-abroad program.

3.5 Comparisons of AoI in Canada vs. Japan

Testing age- and education-matched young adults in two different settings with identical methodology allowed for comparisons of the two groups. In this subsection, I present the results of the combined groups tested in Canada and Japan. Because of their unique immersion experience, which may be accompanied with various other types of L2 experience such as cram school or conversational classes, the Late Short-Immersed group from Japan was excluded from this comparison, and only the Simultaneous, Early, Late, and Monolingual groups were compared. Although bilinguals in both countries differ in many respects, some interesting comparisons could still be made.

3.5.1 General Comparison of Network Effects

An initial comparison of AoI groups, with Simultaneous, Early, Late (Canada and Japan collapsed) bilinguals, and Monolinguals (Canada and Japan collapsed) as described in Table 1, revealed significant differences in Executive Control among the groups ($F(3, 133)=3.60$, $p=.015$). This was driven by greater network efficiency for the Simultaneous group compared to the Monolingual (mean difference=16.54ms, SE=5.73,$p=.027$), and Late (mean difference=15.31ms, SE=5.41, $p=.032$) groups. There were no differences in Alerting ($p=.254$) or Orienting ($p=.614$) when all groups were considered.

However, it quickly became apparent that neither the Monolingual nor the Late groups are equivalent. In school, Monolinguals in Canada begin Core French classes earlier (mean age=8.9, SD=2.4) than Monolinguals in Japan begin English classes (mean age=11.2, SD=2.4), and the daily exposure the L2 varies greatly (daily classes that combine reading, writing, listening, and speaking for the Canadian group vs. heavily grammar-focused classes and one weekly class with a conversational focus for the Japanese group). For the Late groups, both were immersed in a school setting; however, while the late immersion programs in Canada which my participants completed begin in elementary school, after the age of 7, the Japanese participants were immersed in university, after the age of 17, which effectively collapsed immersion in childhood and immersion in adulthood. Therefore, another comparison was made of the Canadian Early (no Japanese equivalent), Canadian Simultaneous (no Japanese equivalent), Canadian Late group reclassified as "Middle", Japanese Late, and Monolingual (Canadian and Japanese groups separate) groups.

Analysis of the groups reveals no differences in Alerting (p=.221) or Orienting (p=.795), but a trend toward differences in Executive Control (F(5,112)=2.16, p=.063). This trend appears to be driven by a more efficient network for Simultaneous bilinguals compared to both Canadian Monolingual (mean difference=15.31ms, SE=6.83) and Japanese Monolingual (mean difference=18.73ms, SE=7.02) groups, and Canadian Middle (mean difference=15.21ms, SE=6.82) and Japanese Late (mean difference=17.20ms, SE=6.92) groups. There is negligible difference between the Simultaneous and Early groups, however (mean difference=7.56ms, SE=6.83, p=1.00), showing that Executive Control efficiency for the two groups is the same. These patterns are shown in Figure 3.8. The significant improvement in Executive Control efficiency for Simultaneous bilinguals in Canada is indicated with an asterisk (*).

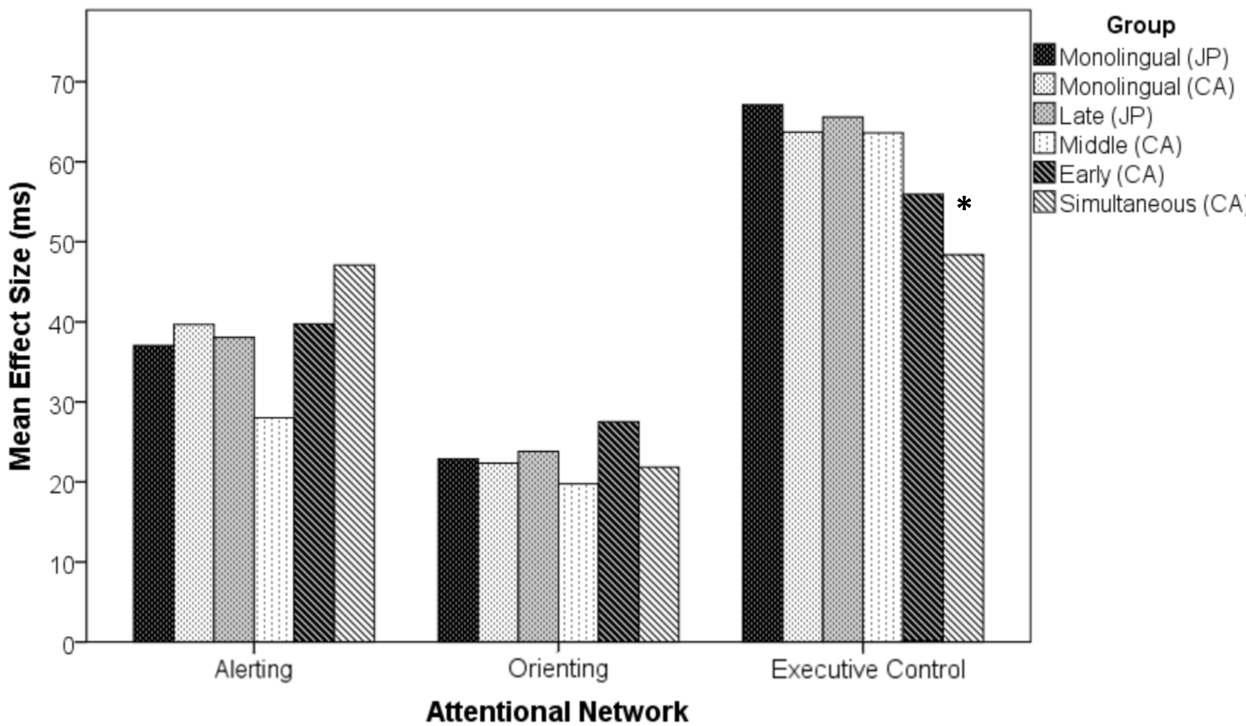

Figure 3.8. ANT Networks for Canadian and Japanese Groups. For Alerting and Orienting, larger effect size indicated greater network efficiency. For Executive Control, smaller effect size indicates greater efficiency. CA indicates Canadian group and JP indicates Japanese group. Groups are arranged from latest age of immersion (or exposure, for the functional monolinguals) to the earliest age of immersion. Individual group RTs and standard deviations are provided in Appendix G.

3.5.2 Cue Effects for Executive Control Network

As with each group individually, the patterns for the Executive Control network were examined, calculating the effect size for the network for each separate cue type. When looking at Executive Control in the non-cued condition (None), there were no differences between groups (p=.293). Similarly, no differences were seen with the Central cue (p=.113). However, when looking at Executive Control in the Double cue, there is a strong trend toward differences between the groups (F(5,114)=2.23, p=.058, and a weaker trend toward differences for Executive Control with a Spatial cue F(5, 114)=2.09, p=.072). These trends are again driven by the Canadian Simultaneous group. Furthermore, visually, regardless of the type of cue presented before the target, the Simultaneous group consistently shows the greatest Executive Control efficiency (i.e., the least amount of interference).

In addition to the within-country group differences discussed in the previous sections, although not reaching statistical significance, patterns suggest differences between the two countries as well. Specifically, in the most basic condition of the ANT, where no cue appears before the target thus effectively making it a standard flanker task, the Canadian groups appear to show less interference compared to both Japanese groups. With a Central cue, both Monolingual groups show more interference compared to the bilingual groups overall. These patterns are shown in Figure 3.9.

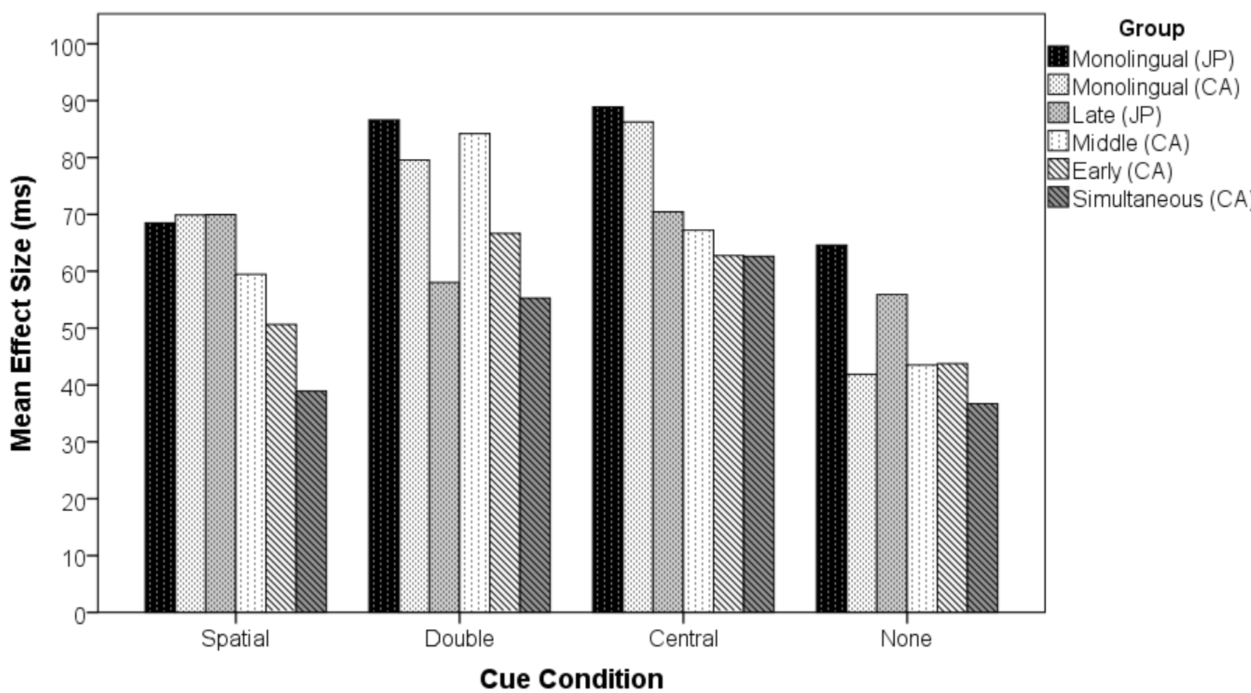

Figure 3.9. Comparison of Executive Control Network Efficiency by Cue Type for AoI Groups in Canada and Japan. Calculated network effects shown for each cue type. Lower effect magnitude indicates greater network efficiency. CA indicates Canadian group and JP indicates Japanese group. Groups are arranged from latest age of immersion (or exposure, for the functional monolinguals) to the earliest age of immersion.

3.6 ANT General Discussion

This study examined the effect of AoI on the Alerting, Orienting, and Executive Control networks of the ANT, testing bilinguals and monolinguals in two different environments- Canada and Japan- and using identical methodology. Looking at the groups tested in Canada, there were significant differences in Executive Control efficiency between the two ends of the bilingual spectrum, the most bilingual Simultaneous group who have been immersed in both languages from birth and the least bilingual Monolingual group who have never been immersed in their L2. Supporting the bilingual advantage hypothesis, the Simultaneous group outperformed the Monolingual group. Looking at the groups tested in Japan, however, there was no Executive Control advantage for the bilingual groups, all of whom were late learners, and an Alerting advantage only for late bilinguals who had been immersed through a short study-abroad program.

When comparing AoI groups in both countries, the finding that earlier AoI resulted in improved Executive Control held: Simultaneous bilinguals in Canada outperformed Late bilinguals, as well as Monolinguals, in both Canada and Japan, thus suggesting that earlier bilingualism confers greater cognitive benefits. This supports the idea that prolonged bilingual experience may alter neuroanatomical structures (e.g., Green & Abutalebi, 2008; Bialystok et al., 2012) and lead to improvements at the behavioural level, and the results found here support those of Luk et al. (2011), whose early bilingual participants also showed executive control advantages relative to later bilinguals. Yet, these findings are in contrast with those of Tao et al. (2011) and Pelham and Abrams (2014), who found benefits for both early and late bilingual groups relative to monolinguals. In the latter two studies, however, late bilinguals had achieved high proficiency in their L2 and were balanced in the use of both languages, but late bilinguals in Luk et al.'s (2011) study were not. Luk et al. (2011) specifically observed that bilinguals who had been using both languages for half their lives, unsurprisingly also having lower L2 proficiency, had similar executive control abilities to monolinguals. Similarly, the late bilinguals in the current study showed lower L2 proficiency and also patterned more closely to monolinguals.

Taken together, these findings are compatible with Pelham and Abrams (2014) suggestion that benefits for early and late bilinguals may arise from different sources: While advantages seen for earlier bilingualism may be linked to neuroanatomical development, where language and attentional development occur at the same time and the former enhances the latter, advantages for later bilingualism may be linked to more effortful use, and therefore training, of cognitive resources including attention to acquire and practice the L2. In the current study, the Simultaneous group may be benefitting from changes as a result of development. The Late bilingual groups in both countries, but especially in Japan, may not practice their L2 as actively, resulting in their lower proficiency. It is possible that because of less training in managing interference from the two languages, they do not show general cognitive control benefits, and any benefits that may appear may be the result of the process of leaning and L2 rather than managing bilingual competition.

Turning to a comparison of attentional networks of bilinguals in both countries, despite using identical methodology, the results of the two studies echo the inconsistency found in the bilingual cognitive control literature and among studies specifically investigating AoA as a factor. As discussed in Chapter 2, AoA has been operationalized in different ways (age of immigration, Tao et al., 2011; age of active onset of bilingualism, Luk et al., 2011; age of first exposure, Marzecová et al., 2013; age of becoming fluent, Pelham and Abrams, 2014; a continuous variable, Yow and Li, 2015). Although this work operationalized AoA as the AoI in a school setting for both the Canadian and Japanese participants, there were still differences between the groups that made the planned comparison of different environments more difficult. Specifically, the late groups in Canada and Japan were not equivalent; instead, they represented different points on the AoI continuum, with Canadian late bilinguals being immersed in childhood and Japanese late bilinguals being immersed in adulthood. The two functional monolingual groups also differed in the same way with respect to the age of first exposure. In addition, there were no Simultaneous and Early bilingual participants in the Japanese sample. Since this is an issue that affected both the ANT task in this chapter and the Stroop task presented in the next chapter, a thorough discussion of the Canadian and Japanese population differences will be left for the General Discussion in Chapter 6. Still, some comparisons could be made.

An interesting finding in the two experiments presented in this chapter is the interaction between Congruency and Cue. Although its existence has been acknowledged by Fan et al. (2002; 2009) and confirmed by MacLeod et al. (2010) and McConnell and Shore (2011), it has only been explored in one known study of bilingual control (Costa et al., 2008). Although Costa et al. (2008) found the interaction, because it was not affected by bilingual status, it was not explored in further detail. In this work, however, there were various interactions, which prompted an exploration of the Executive Control network when disentangled from the Cue. If different cues affect the degree of interference (e.g., the Double cue increases flanker effects;

Fan et al., 2009), I was interested in whether or not this could affect the general Executive Control network calculation, and therefore the presence or absence of a noticeable network effect.

The Executive Control network has already been discussed with respect to the Canadian and Japanese groups separately, but looking at all groups in Figure 3.9, there are interesting patterns which may be partly due to the linguistic environment in which the L2 was learned and is used. According to Green and Abutalebi's (2013) Adaptive Control Hypothesis, Canadian Simultaneous bilinguals could be classified as being a dense code-switching environment and Early bilinguals as being in a dual-language environment; Late bilinguals may be in either a dual-language or single-language environment. However, when looking at the University of Ottawa environment in general, it could be considered a dual-language environment, since both English and French are spoken at the University and used in all official communications, but they are used with different people. Such an environment is predicted to train goal maintenance, interference control, salient cue detection, selective response inhibition, and task engagement and disengagement. The fact that the University environment tends toward a dual-language one may also be one reason for Simultaneous and Early bilinguals' similar performance: even Simultaneous bilinguals, who regularly code-switch with peers, may have this code-switching constrained by the language use at the University. Japanese participants, however, are strictly in a single-language environment, as all communications at Konan University and Kobe College are in Japanese, students speak only Japanese, and English is used strictly in the English classroom. Such an environment is predicted to only weakly train goal maintenance and interference control.

Looking across groups, it appears that Canadian bilinguals' Executive Control benefits more in the presence of the Spatial cue, which is associated with more effective orienting of attention, compared to the Japanese groups. This may reflect improvements in salient cue detection and engagement and disengagement of attention, as predicted by the ACH, since Canadian participants have more exposure to their L2 French in their regular environment, and thus their attention is more trained to tune in to the second language than Japanese bilinguals who do not encounter their L2 English in their regular environment. In the presence of a Double cue, Canadian bilinguals with an early AoI appear to be better able to counter the diffusion of attention to focus on resolving the conflict of the flankers compared to Late bilinguals and Monolinguals. Interestingly, this also applies to the Japanese Late group, which may show a small boost given by bilingualism in a largely monolingual environment. In the presence of an alerting Central cue, which notifies participants of the upcoming trial, all bilingual groups benefit relative to the monolingual groups. These differences in RTs in the presence of different cues can be seen in Appendix G, where mean RTs in each condition and cue are provided for all the Canadian and Japanese groups.

What is particularly interesting with respect to the different environments is that all the Canadian groups, including the monolinguals, showed better interference suppression compared to the Japanese groups. This cannot be explained by one group being at the peak of cognitive control while the other is not, since the groups are matched for age and education. Nor can it be explained by the later AoI of the Japanese group, since even the monolingual groups show differences. However, it may be explained by the environments described by the ACH, where a dual-language environment (i.e., University of Ottawa) is predicted to strongly enhance interference suppression, while a single-language environment (i.e., Konan University) predicts only a weak enhancement. Although these differences are not statistically significant, the pattern suggests that different environments (i.e., different countries in the current study) may also play a role in the development of cognitive control. Because the ACH is a relatively new theory, and classifying environments is a challenging task (indeed, Green and Abutalebi, 2013, do not propose tools for doing so), this interpretation is made with caution, and should be more rigorously explored in the future.

Various mechanisms have been suggested to explain the Executive Control advantage for bilinguals, with a common one being conflict monitoring and resolution (Costa et al., 2008; 2009; Pelham & Abrams, 2014). According to this account, bilinguals' constant need to monitor for and resolve linguistic conflict in the environment leads to better cognitive control in tasks involving conflict. Bilinguals' heightened monitoring in conflict situations is suggested to affect performance in non-conflict situations, which accounts for global advantages. Another has been that of attentional control (e.g., Bialystok et al., 2004; 2008, Grundy et al., 2017), which proposes that bilingualism improves one's ability to manage attention when faced with complex and changing tasks. The engagement and disengagement of attention is more efficient, leading to bilingual advantages (see Grundy et al., 2017). The results of the current study support the latter mechanism, as seen by the examination of cue effects separately from congruency.

Taken together, these results demonstrate that earlier bilingualism is beneficial to domain-general cognitive control, and suggests that attentional processes benefit most from this experience. Furthermore, they suggest that not only the task, but also the task characteristics and analysis need to be taken in to consideration in bilingual cognitive control studies. Hilchey and Klein (2011) and Hilchey et al. (2015) consider a number of flanker tasks in their investigation of the validity of bilingual advantages, and conclude that there are inconsistencies among the results. However, as seen in the current study, no effects are apparent in the non-cued condition (essentially, the standard flanker task) within each group, but differences between groups do appear under different cues, and between groups from different populations. Thus, my results suggest caution when interpreting ANT network effects, and agree with MacLeod et al. (2010) who, in a psychometric assessment, note that the reliability of the Alerting and Orienting networks is low, and suggest that these networks may not be independent. This analysis, while not finding any Alerting and Orienting effect differences between the bilingual groups, only noted differences of the alerting and orienting cue types when cue type and congruency were disentangled.

Furthermore, there was a confound between AoI and environment, and environments were classified according to observed language use in the community. For future studies, it would be necessary to objectively classify the bilingual environments, and to explore matching AoIs in each. It would also be interesting to specifically test the differences between proficient and non-proficient bilinguals (and differentiating these from active learners) to truly disentangle AoA from proficiency. One possibility may be examining balanced and unbalanced Late bilinguals, as well as balanced early bilinguals with heritage speakers, as this latter group learns both languages early in life, but may not be equally proficient in both due to the dominant language of the community.

Chapter 4. Study 2- Examining Linguistic Cognitive Control through the Stroop Task

4.1 The Stroop Task

Bilinguals are experts at controlling language; therefore, to examine their language control abilities, a linguistic counterpart to the ANT task in Chapter 3 is included. It is important to remember, however, that no two tasks are equivalent. The Stroop task (Stroop, 1935), named after its creator John Ridley Stroop, has enjoyed over 80 years of popularity in the literature. This simple psychological task has been used in hundreds of studies, with different variants created to examine diverse populations and research questions in not only the field of psychology, but also in fields such as neuroscience and linguistics. Of specific interest to the current work is the task's use in investigations of cognitive control, and particularly in examinations of bilinguals' inhibitory and attentional abilities. I aim to determine what this task, in its linguistic variations, can tell us about the impact of bilingualism on cognitive control abilities in the L1 and L2. In this chapter, I discuss the nature of the Stroop task, the task's use and results in previous studies of bilingual cognitive control, and the potential impact of different writing systems on Stroop task performance. I then present the results of a bilingual Stroop task conducted with two different young adult populations- Canadian and Japanese- and discuss the findings in light of different language environments, including ones that contain different writing systems.

The Stroop task is a simple one, yet it allows researchers to examine language processes such as the automaticity of written word reading (MacLeod & MacDonald, 2000), as well as cognitive control processes such as inhibition needed to complete the task. From the results, a measure of the degree of language interference and an individual's inhibitory abilities can be obtained. In the original task, the colours red, green, blue, brown, and purple were used in a series of three experiments. In the first experiment, participants read aloud a list of colour words printed in incongruent colours (e.g., the word PURPLE printed in blue ink; correct answer "purple") and the same list printed in black ink. In the second experiment, participants said aloud the colour of the words in the list (e.g., the word PURPLE printed in blue ink; correct answer "blue") and also named the same colours presented simply as coloured squares. Finally, the third experiment examined whether practice of these tasks would affect the outcome, measured in all cases as the time required to read or to name the items in a given list.

The results revealed an interesting asymmetry between word-reading and colour-naming: the difference between reading words in different colours and in black was a nonsignificant 2.3 seconds (or a 5.6% increase in the time required to read the colour words), while the difference between naming the colours in which incongruent colour words were written and naming the colours of squares was a 47.0 seconds, or a significant 74.3% increase in naming time for the words (Stroop, 1935). In other words, colours did not interfere with word reading, but reading strongly interfered with colour naming. This increase in colour naming time in the presence of a conflicting written word has come to be known as the Stroop effect. Practice, as shown by Stroop's Experiment 3, can slightly reduce the magnitude of this effect, but the interference cannot be altogether eliminated.

Different theories have been put forth to account for the Stroop effect, and in an extensive review of 50 years of Stroop literature, MacLeod (1991) describes two of the more predominant ones. The first is known as "relative speed of processing", and under this view, words are read faster than colours are named. It is this difference in relative processing time that is the cause of the Stroop effect, i.e., because written words are read faster, they will be produced first. However, results from a number of studies in the 1980's found little empirical support for this view (see MacLeod & MacDonald, 2000), particularly as it was unable to account for the reverse Stroop effect, where presentation of a colour before the word should interfere with processing of that word (i.e. presenting a red screen before the word "green" should delay the reading of "green"). Also, a colour (e.g. red) before the onset of an incongruent colour word (e.g. the word green written in red) should result in decreased interference (because the colour is given a head start for processing). Yet, colours do not interfere with subsequent word naming, and even when a colour block is presented before an incongruent colour word, a Stroop effect still occurs (see MacLeod, 1991 and MacLeod & MacDonald, 2000 for a full review). Thus, it appears that it is not the relative speed of processing that is behind the interference seen in the Stroop task.

The second, currently more accepted view (e.g., Bialystok et al., 2008; Roelofs, 2010; Kousaie & Phillips, 2012; Coderre, et al., 2013) is that of "selective attention". Under this view, a greater amount of attentional resources are required for colour naming, which is a controlled process that requires cognitive effort, than for the process of reading, which is automatic and requires little effort for a proficient, literate individual (LaBerge & Samuels, 1974). These processes occur in parallel, and it is specifically the direct competition between diverging word and colour information that is the source of interference and the Stroop effect (MacLeod and MacDonald, 2000). Under this view, not only inhibition, but also attention becomes a major factor in resolving the competition between the word and colour. As the written word is read, it triggers the automatic processing of the colour term. However, the participant is asked to name the colour of the ink, which is in direct conflict with automatically-processed incoming information from the written word. By turning attention toward the colour rather than the written word, inhibitory processes needed to suppress the interference from the written word and resolve the conflict to correctly name the colour of the ink become more efficient.

Inhibition and attention are important language processing components for monolinguals and bilinguals alike, but as discussed in Chapter 1, the nature of the bilingual mental lexicon adds a level of complexity for bilingual processing. In a multi-dimensional visual world, as well as in a lexicon where many competing representations are available in two different languages, certain lexical items need to be chosen from among many, and irrelevant items, as well as the non-target language, need to be filtered out. Here, attention becomes an important process for selecting a specific lexical item and language on which to focus. Both conscious and subconscious elements can capture attention and influence cognitive control (Van Gaal, De Lange, & Cohen, 2012), and while this process may be more complex than previously thought, attention may assist in directing focus to the colour to be named, rather than to the automatically-read word.

Resolving the word-colour competition is a cognitively-demanding process, and one that requires inhibiting distracting information while turning attention to the goal of the task. In order to correctly name the colour, this interference from the automatically-processed written word must be suppressed, while attention must be turned to the less-practiced, and therefore controlled, task of colour naming. Thus, the Stroop task becomes a measure of not only inhibition, but also of attention, and through various manipulations, it allows different levels of cognitive control to be examined (Bugg, 2012). A full theoretical review of the Stroop task is beyond the scope of the current paper, but for detailed reviews, please refer to MacLeod (1991), MacLeod and MacDonald (2000), and Roelofs (2003). The current study adheres to the latter view of the Stroop effect as being a competition between an automatic and a controlled process, and decreased magnitudes of Stroop interference as indicative of better inhibition and attentional resource allocation. Although non-linguistic versions of the Stroop task exist (e.g., numerical, Hernández, et al., 2010; oculomotor, Singh & Mishra, 2012; spatial, Martin-Rhee & Bialystok, 2008; Blumenfeld & Marian, 2014), the current work is interested in linguistic cognitive control, and the remainder of the discussion will therefore be focused on the originally-linguistic version of the task.

The original Stroop task has undergone various modifications since 1935, and the task commonly used now includes a congruent condition where the colour word is presented in the colour it names (the word BLUE presented in ink; correct answer, "blue") and a control condition, which can be made up of coloured shapes as in the original task, asterisks (***), a row of symbols such as X's, %'s or #'s, or high-frequency, non-colour-related words (e.g., DOG). Full details of methodological variations will be presented shortly. These additions allow the Stroop task to examine facilitation effects, which are brought about by the convergence of information from the written word and the visual colour in the congruent condition and thereby speed up naming times (Roelofs, 2010; although see MacLeod & MacDonald, 2000 for reliability issues regarding facilitation effects), as well as to obtain baseline reading time or colour naming time measures using the control items, in addition to Stroop interference effects.

Facilitation and interference are defined as the difference in response time between the congruent and control, and as the difference between the incongruent and control trials, respectively, although the Stroop effect can sometimes be calculated as the difference between the congruent and incongruent trial, as in the original task (e.g., Bialystok et al., 2008). In the task, the congruent, incongruent, and neutral conditions can be presented in individual blocks (all congruent, all incongruent, or all neutral trials) or in a single block made up of all three conditions, and in a variety of languages. Two languages can even be used simultaneously to create a bilingual variant of the task, which allows bilingual interference, facilitation, and the Stroop effect to be assessed.

In the bilingual Stroop task, colour terms in the bilingual's first language (L1) or second language (L2), or both, may be presented, and participants may be instructed to name the colours in either of their two languages. This type of task allows researchers to examine both within-language interference (by having the participant name L1 words in the L1 and L2 words in the L2) and between-language interference (naming L1 words in the L2, and vice versa), giving greater insight into how bilinguals process and manage their languages. For example, between-language interference can tell us about lexical representation and the strength of connections between languages in the mental lexicon, and this interference is typically smaller than within-language interference (Brauer, 1998). A wide variety of language pairs have been used for the Stroop task's bilingual adaptation, including Chinese-English (Fang, Tzeng, & Alva, 1981; Coderre & van Heuven, 2014), Japanese-English (Fang et al., 1981; Sumiya & Healy, 2004), Spanish-English (Fang et al., 1981; Rosselli, Ardila, Santisi, Del Rosario Arecco, Salvatierra, Conde, & Lenis, 2002; Naylor, Stanley, & Wicha, 2012), French-Arabic (Zied, Phillipe, Pinon, Havet-Thomassin, Aubin, Roy, & Le Gall, 2004), Arabic-Hebrew (Tzelgov, Henik, & Leiser, 1990), English-Greek, English-German (Brauer, 1998), and Dutch-English (Roelofs, 2010),[9] and as Fang et al. (1981) noted, factors such as orthography in these languages can influence the magnitude of the within- and between-language interference. Still, despite differences in magnitude, the Stroop effect is always apparent, and it is particularly the Stroop task's ability to examine both attentional and inhibitory processes that make it so appealing as a task of cognitive control, as well as a test of the bilingual advantage hypothesis.

4.1.1 Methodological Considerations in the Stroop Task

While the studies reviewed in Chapter 2 show an impact of bilingualism on cognitive control, there seems to be little consistency across studies. Some show a smaller Stroop effect, while others show faster overall RTs. Others still show a mix of both, making it difficult to specify what advantages are conferred by bilingualism. In discussions of the inconsistency in results in cognitive control studies, several recurring points are present, and the problem of task impurity is among these. Miyake and Friedman (2012) bring up the issue of task impurity, and as the authors note, even in the Stroop task, there is systematic variability in colour identification and articulation speed. While this issue has been raised with respect to differences across various tasks of cognitive control in general, some of the varying findings in the Stroop task may be, in part, attributable to the different experimental designs and different measures obtained and examined within the Stroop task.

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[9] In addition to being able to examine cognitive control, the bilingual version of the task can also function as a picture-word interference task, and examine switch costs between languages (de Groot, 2011).

With respect to the Stroop task itself, there is no one, standard established task design. Excluding the numeric and non-linguistic Stroop tasks (see MacLeod & MacDonald, 2002 for examples), at first glance, the linguistic task seems to be separated into two versions- the monolingual and the bilingual Stroop task. In the monolingual task, participants are presented with only one language and must respond in that language (this can be the L1 or the L2), while in the bilingual version, both languages are presented, and a within-between language procedure is followed. In the latter version, participants can either respond in the L1 or L2 like in the monolingual version, which assesses within language interference, or switch between languages (e.g., a production task where the colour name is presented in one language and the response is required in the other) to assess between-language interference. Some designs may also incorporate elements of both, in addition to other tasks (e.g., switching between word reading and colour naming; Tao & Cai, 2018). However, upon closer look, even the two versions differ between experiments in terms of the response modality, the languages used, and even in the choice of control items. Table 4.1 describes this variation. For each study, the sample size, task type (whether the task was monolingual and used a single language or bilingual and used two, as well as the language(s) used), the type of response, participants' L1 and L2, and the type of control stimuli used are provided.

Table 4.1. Variation in the Stroop Task Used in Bilingual Studies. For each study, the sample size, task type (monolingual indicated that the language(s) were presented separately, and bilingual indicates two languages presented together in a single block), response modality, participants' language, and type of stimuli used in the control condition.

Study	Sample size	Task type	Response	Participant L1 and L2	Control
Bialystok et al. (2008)	96	monolingual English	vocal	L_x-English*	XXXX, words
Coderre & van Heuven (2014)	53	monolingual (L1 & L2)	manual	Chinese-English	%%%
Coderre et al. (2013)	60	monolingual (L1 & L2)	manual	Chinese-English	XXXX, %%%
Fang et al. (1981)	110	monolingual (L1 & L2), bilingual	vocal	Chinese-English, Spanish-English, Japanese-English	words, shapes
Goldfarb & Tzelgov (2007)	80	monolingual (L1 & L2)**	vocal	Hebrew-English	not included
Heidlymayr et al. (2014)	65	monolingual (L1 & L2)	manual	French-German	words
Heidlymayr et al. (2015)	44	monolingual (L1 & L2)	manual	French-German	words
Kousaie & Phillips (2012a)	51	monolingual English	manual	English-French	XXXXX
Kousaie & Phillips (2012b)	73	monolingual English	vocal	English-French	shapes
Naylor et al. (2012)	74	bilingual	vocal	Spanish-English	+++++
Okuniewska (2007)	44	monolingual (L1 & L2), bilingual	vocal	Polish-English	shapes
Roselli et al. (2002)	122	monolingual (L1 & L2), bilingual	vocal	English-Spanish	XXXX, words
Sabourin & Vīnerte (2015)	31	monolingual (L1 & L2), bilingual	manual	English-French	words
Śmiecińska et al. (2014)	50	monolingual (L1 & L2)	vocal	Polish-English	shapes
Tzelgov et al. (1990)	16	bilingual	vocal	Arabic-Hebrew	not included
Waldie et al. (2009)	18	monolingual English	manual	Macedonian-English	words
Wang et al. (2016)	60	monolingual (L1 & L2)	vocal	Chinese-English	not included
Yow & Li (2015)	72	monolingual English	manual	Mandarin-English	*****
Zied et al. (2004)	180	bilingual	vocal	French-Arabic	not included

*Note: L_X indicates a variety of first or second languages
**This study also included colour-associated target words

As Table 4.1 shows, despite using the same "Stroop task", the variability in experimental design goes beyond just "monolingual" and "bilingual" differences. First, the response modality between studies can vary, with either a vocal or a manual response used. In a vocal response task, participants are instructed to respond by verbally naming the presented colour, and naming latencies are measured as the RT from the onset of the stimulus to the onset of verbal response. Accuracy of response is also recorded by examining whether the participant produced the correct word. In the manual response task, participants are instructed to press a button on a mouse, keyboard, or button box input device that matches the colour of the presented word, and the RT recorded is the time from the onset of the visual stimuli to the time a button is pressed. These different response modalities provide two potentially different measures. As shown by Bialystok et al. (2008), Rosselli et al. (2002), and Pelham and Abrams (2014), bilinguals are actually at a *dis*advantage with respect to lexical access, showing slower word retrieval times than monolinguals. The vocal response RTs reflect not only cognitive control, but also lexical access, speech planning, articulation, and so forth, making it difficult to tease apart the effects of slowed lexical access from those of proposed cognitive control advantages. Therefore, some recent studies have turned to manual responses to avoid any confounds created by speech production (see MacLeod, 1991 for discussion of verbal vs. nonverbal response in the task). For this reason, direct comparisons between the vocal and manual task present a challenge (indeed, comparing vocal and manual responses on the same Stroop task, Repovš (2004) finds qualitative differences), although even these comparisons can be informative.

Looking at the languages in the Stroop task, various language pairs have been used[10], and these differ not only with respect to the degree of phonological overlap (e.g., Sumiya & Healy, 2004), but also with respect to orthographic overlap, in some cases having completely different writing systems altogether. Different processing pathways have been proposed for, for example, alphabetic and logographic writing systems (Sambai, 2011), and as shown by Fang et al. (1981) and Coderre and van Heuven (2014), the writing system used can affect overall RTs. The latter study also showed that script similarity can affect cognitive control due to larger orthographic overlap requiring greater control, which results in less interference for same-script compared to different-script bilinguals. Although Paap, Darrow, Dalibar, and Johnson (2014) claim that script effects are negligible, it is important to note that their claims are based on their composite database, which includes an overwhelming variability in other factors among the participants (e.g., different L1s and L2s, AoA's, immigration status.) Thus, because the Stroop task uses visually-presented words as stimuli, it is still worth considering what differences in lexical access for each script may contribute to the RTs obtained.

Finally, even the control items used differ between studies. While some studies follow the original Stroop (1935) design and use colour patches or non-word symbols (the plus and percent signs are a common choice), others use high-frequency non-colour-related words (e.g., cat, house, book). However, a symbol such as % is not equivalent to a written word or a colour patch, and there are differences in how visual objects and written words are processed (e.g., Levelt, Roelof, & Myers, 1999). In comparing picture naming with visual word recognition, i.e.

[10] And therefore, participants of various linguistic, cultural, and socioeconomic backgrounds have participated. The current work focuses on the task itself, rather than issues of participant grouping; however, for more on issues surrounding participant populations, see reviews such as Valian (2015).

reading, Levelt et al. (1999) propose different pathways for the two processes. This has implications for the type of control stimuli used in the Stroop task. In particular, since cognitive control studies using the Stroop task are concerned with demonstrating participants' ability to control interference caused by automatically-processed written word, symbols essentially add a non-linguistic element to a linguistic task. Because symbols do not recruit visual word recognition processes in the way that written words do, it is difficult to make comparisons with studies that are purely linguistic (i.e., use words as control items).

What do differences such as these mean for the Stroop task as a measure of cognitive control? And do these differences make comparisons across studies using the task impossible? Returning to Miyake and Friedman's (2012) discussion of task impurity, the authors further discuss the concepts of unity and diversity in experimental tasks, referring to observed correlations between different tasks which demonstrate that there are some common underlying cognitive processes, yet also that these processes are separable. To demonstrate this, the authors take a latent-variable approach to examine which abilities different tasks tap, and what are the correlations between them (see Miyake et al., 2000 and Miyake & Friedman, 2012 for full details). The results of their investigation identify specific cognitive processes that are primarily recruited by some common tasks. The authors include the Stroop task in their analysis, and note that the standardized factor loading for the Inhibition onto the Stroop task is .43 (with 1.0 being a perfect loading). They also note that there is residual variance (i.e., variance that cannot be explained by the latent variable) of .82. While this residual variance is quite high, it is perhaps not surprising considering the great variability in the Stroop task itself. And while a .43 loading is far from perfect, it is interesting to note that no other factor (e.g., switching) loads onto the Stroop task. Thus, while the Stroop task is certainly not a pure task of any one cognitive control ability, it does appear to be able to measure general cognitive control abilities.

4.1.2 Writing Systems in the Stroop Task

The Stroop task variants in Table 4.1 differ not only with respect to the degree of phonological overlap, but also with respect to orthographic overlap, in some cases having completely different writing systems altogether. While the Stroop task examines cognitive control and language processing, in many experiments this is done through visually-presented words (i.e., participants see a written word on the screen and must respond). This adds an element of reading and visual word recognition, making reading processes and factors that affect them an integral part of the task. However, examinations of the effects of different writing systems on Stroop task performance are few.

As early as 1981, Fang et al. noticed that there are differences in naming times based on the orthography of the stimuli in a Stroop task. Considerably greater naming times were required for Chinese compared to English, in both the Stroop condition and the control. For English colour words, Stroop naming times were 1169ms compared to 704ms for the control. For Chinese, naming times were 1321ms compared to 728ms for the control. The authors emphasize the need to determine whether it really is orthography, rather than phonology, that accounts for these differences, as orthographic similarity is often correlated with phonological similarity. To this end, the final part of the Fang et al. (1981) study looked at Japanese, and compared naming times of words written in two of the language's scripts, which allow the phonology to be held constant while varying the orthography, to naming times for English. The results showed that naming times differ depending on the script used, despite the phonology being identical. Furthermore, both Japanese scripts had greater naming times than English. Naming a Japanese colour word written in kanji took 1115ms on average, compared to 1064ms for hiragana, and 994ms for English. Thus, orthography appears to influence the Stroop task, which adds a layer of complexity in the case of bilinguals, especially ones whose two languages use different scripts.

Not only are both languages active during bilingual comprehension and production, but also this simultaneous activation is seen when bilinguals read, even if the scripts of their two languages are different (Hoshino & Kroll, 2008). Although, the nature of lexical access for each script, while having certain general processes in common, may differ in specific processes that are orthography-dependent (Wydell, 2006). While alphabetic languages can be classified as having shallow or deep orthography based on the grapheme-phoneme transparency, languages with other orthographies are so different in terms of visual complexity, word boundaries, as well as processing that they cannot even be classified on the same continuum (Schmalz, Marinus, Coltheart, & Castles, 2015). If there are differences in orthographic processing, given that the Stroop task is based on visual word recognition, how does combining such different orthographies affect task performance? The possibility of orthography as one of the variables in bilingual cognitive control, however, has been explored by only a few studies.

While not directly investigating script, Coderre et al. (2013) notice differences in processing of English and Chinese, which they suggest may be the reason for the previously-discussed cognitive control advantages they found for Chinese-English compared to English-

Chinese bilinguals. Examining the Stimulus Onset Asynchrony (SOA) manipulation in their study, the authors observe different timecourses for each script, with maximum interference occurring at -200ms for English and at 0ms for Chinese, which they suggest is a result of each script's processing mechanisms and timing. Processing mechanisms for Chinese, which uses a logographic writing system (i.e. a system of pictographic or ideographic representations), and other logographic languages are greatly debated (see *The effects of script* on page 437 of Coderre et al., 2013), and the authors say that it remains to be seen whether these effects can be replicated with other logographic languages. The current study therefore includes bilinguals whose two languages use different scripts, with specific interest in English-Japanese bilingualism and the Kanji logographic script.

4.2 Methods

4.2.1 Participants

The same participants completed both the Stroop and the ANT task. Please refer to Table 4.2 for participant demographics for the Stroop task. Canadian groups consisted of Simultaneous bilinguals, who were immersed in both languages from birth, Early bilinguals who were immersed in L2 French through a school immersion program between the ages of 1 and 6, and Late bilinguals who were immersed from the age of 8. Japanese groups consisted of Late bilinguals, who were immersed in L2 English through a school program from the age of 8 (although actual immersion occurred in university), and a Late Short-Immersed group who had participated in a short-term study-abroad program in university. Monolinguals groups were included in both countries for comparison.

Table 4.2. Participant Description for Stroop Task. Average values for participant groups provided, standard deviation in brackets. Individual participant profiles are provided in Appendix E.

Country	Group	N	Age	Age of 1st L2 Exposure	Age of Immersion	L1 Proficiency (%)	L2 Proficiency (%)*	Self-rated L2 proficiency (/20)
Canada (Expt.3)	Simultaneous EF Bilingual	23	18.5(0.8)	0.0 (0.0)	0	80.8(9.5)	60.1(19.4)	18.7(1.3)
	Early Sequential EF Bilingual	20	19.1(1.7)	4.4(1.2)	1-6	80.4(10.7)	45.3(16.6)	14.8(2.9)
	Late Sequential EF Bilingual	22	18.4(1.7)	7.5(3.9)	8+	84.3(13.9)	36.3(27.7)	9.8(5.8)
	Functional English Monolingual	22	18.5 (2.7)	8.9(2.4)	N/A	83.4(10.7)	1.4(10.7)	5.0(3.3)
Japan (Expt.4)	Late Sequential JE Bilingual	26	19.6(0.7)	10.4(2.9)	8+	94.0(3.1)	38.8(10.1)	8.9(2.2)
	Late Short-Immersed JE Bilingual	15	21.5(1.6)	11.1(3.0)	8+	93.9(2.4)	35.1(14.2)	10.0(2.1)
	Functional Japanese Monolingual	21	20.6(2.9)	11.2(2.3)	N/A	91.3(5.9)	17.7(10.2)	5.1(3.2)

* Due to the relatively greater difficulty of the French Cloze task, all participants scored lower on this task. However, there are no significant differences between the scores of natives speakers of French (matched sample tested separately) and the Simultaneous group (*p*=1.00).
In addition, for Japanese participants, L2 written proficiency scores overlapped between the groups, and it was therefore necessary to also use self-reported percentage of immersion to separate monolinguals from late-immersed bilinguals. Monolinguals reported using English 30% or less of the school day, while bilinguals reported using English over 50% of their day.

4.2.2 Stimuli and Design

An English-French and a Japanese-English bilingual Stroop task was programmed using Neurobehavioral Systems Presentation v.14.9 software. Stimuli were presented using a PC desktop computer with a Windows Vista operating system, on a 19-inch screen. Participants used a Cedrus RB-830 button box equipped with 7 active buttons to respond. Button layout on the button box is shown in Appendix D. A manual response device (i.e. the button box) was chosen rather than having participants verbally name the colours because it has been shown that bilinguals are at disadvantage for lexical retrieval (e.g. Bialystok et al., 2008; Pelham & Abrams, 2014). A study by Kousaie and Phillips (2012) showed that there were no bilingual advantages in the Stroop task; however, the participants in this study named colours verbally, which may have cancelled out any bilinguals advantages. Therefore, the current study uses a button box to avoid cancelling out the possible RT advantage by a naming disadvantage.

In the English-French task, the stimuli used were the words RED, YELLOW, GREEN, BLACK, SILVER, WHITE for English, and their translations ROUGE, JAUNE, VERT, NOIR, ARGENT, BLANC for French. Additionally, the high-frequency words TABLE, CHAIR, FORK, SPOON, HOUSE, and BOOK were included as control items for English, and CHAISE (*chair*), ARBRE (*tree*), SOURIS (*mouse*), STYLO (*pen*), MAISON (*house*), and LIVRE (*book*), [11] were included as control items for French. With respect to the colour terms, six English and French non-cognate colour words were necessary for the current study. Although "argent" also means "money" in French,

[11]The control items are not equivalent in English and French. This is because I tried to keep word length the same (3-6 letters, to match the word length of the colour terms). In retrospect, equivalent words may have been better. However, in the current study, this was deemed to not be a critical error, since I was aiming to establish baseline reading rate. A number of other Stroop studies have used symbols such as ### and %%% for the control conditions; however, since the Stroop task is essentially a reading-based task, I chose to use words.

participants were trained during practice to associate this word with the colour. This is confirmed by an items analysis that shows no difference in RTs or accuracy between "argent" and the other colour words, and the SILVER/ARGENT pair was therefore considered acceptable for the current study. Words were presented in capital letters in size 60 Times New Roman font in the centre of the screen.

In the Japanese-English task, the stimuli used were the words RED, YELLOW, GREEN, BLACK, BLUE, WHITE for English, and their translations 赤 (*aka*), 黄 (*ki*), 緑 (*midori*), 黒 (*kuro*), 青 (*ao*), 白 (*shiro*) for Japanese. Additionally, the words TABLE, CHAIR, FORK, SPOON, HOUSE, and BOOK were included as control items for English, and 木 (*ki- tree*), 本 (*hon- book*), 犬 (*inu-dog*), 川 (*kawa- river*), 花 (*hana- flower*), and 山 (*yama- mountain*), were included as control items for Japanese. As with the English-French stimuli, control words are not translation equivalents; they are high-frequency Kanji that are learned in the first grade, as are the Kanji for colours. English words were presented in capital letters in size 60 Times New Roman font in the centre of the screen, and Japanese Kanji were presented in size 60 MS Mincho font. All Japanese stimuli were presented in Kanji script for two reasons: 1) The set of words used are commonly written in Kanji and are therefore more familiar in this script for fluent adult readers, and 2) The use of Kanji allows for an examination of cognitive control in logographic-alphabetic bilinguals, as well as a comparison of this group with alphabetic bilinguals, which may shed light on the effects of script.

Three separate blocks were created, containing Control (e.g., TABLE, presented in any colour), Congruent (e.g., RED presented in red font), and Incongruent (RED presented in green font) trials. An English Block consisting of English Control, English Congruent, and English Stroop items intermixed; a French Block consisting of French Control, French Congruent, and French Stroop items intermixed for the English-French task and a Japanese Block consisting of Japanese Control, Japanese Congruent, and Japanese Stroop items intermixed for the Japanese-English; and a mixed block of Control, Congruent, and Incongruent items in both languages intermixed were created.

4.2.3 Procedure

After completing the language background questionnaire (Sabourin et al., 2016; Appendix B) and Cloze tasks (Brown, 1980; Komori & Tamaoka, 2010; Tremblay, 2011; Appendix C), participants completed the English, French, and Mixed blocks of the task. Three lists were created and blocks were counterbalanced for order of presentation. List 1 presented the English block first, followed by the French block, and ended with the mixed language block; List 2 presented the French block first, followed by the mixed language block, and ended with the English block; and List 3 presented the mixed language block first, followed by the English block, and ended with the French block. The order of presentation in each list ensured that each block appeared at the beginning, middle, and end of the task. Self-timed breaks appeared between blocks. The initial block was preceded by 15 practice trials in order to familiarize the participant with the procedure of the experiment, and 5 practice trials appeared before each subsequent block to re-familiarize the participant following the self-time break. In the experiment, participants were instructed to press a button to indicate the colour of the word on the screen, and it was emphasized that they should focus on the *colour* of the word. Each trial began with a fixation cross in the middle of the screen for 250ms. This was followed by the onset of the target. Once the target appeared on screen, it remained there until the participant responded or 4000ms had elapsed. Participants took approximately 10 minutes to complete the 3 blocks, containing 25 trials each of Control, Congruent, and Incongruent trials in each Single-language block, and 25 of each condition in each language for the Mixed-language block, for a total of 300 trials in the experiment. Please refer to Figure 4.1 for a sample trial.

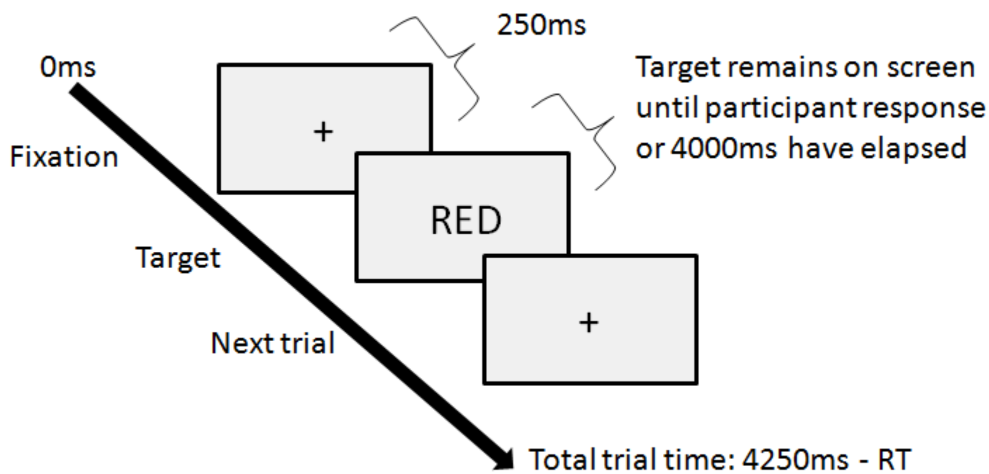

Figure 4.1. Stroop Task Procedure. An incongruent trial is shown. Trials begin with a 250ms fixation cross and terminate when the participant presses a response button or 4000ms have elapsed.

4.3 Experiment 3. Effects of AoI on Linguistic Control for Young Adults in Canada

A total of 87 participants (6 male) between the ages of 17 and 27 took part in the Canadian component of the study, which was conducted in Ottawa, Canada. The same English-French bilinguals, grouped into Simultaneous, Early, Late, and Monolingual groups, who took part in Experiment 1 also took part in Experiment 3. Simultaneous bilinguals were immersed in both languages from birth, Early bilinguals were immersed between the ages of 1 and 6, and

Late bilinguals were immersed at the age of 8 or older. To maintain clear separation, participants with AoI=7 were excluded. Monolinguals were included as a control group.

4.3.1 Hypotheses

Three hypotheses are tested in this experiment. The first is that as a result of using cognitive control processes to manage two languages, the bilingual advantage hypothesis will be supported and bilinguals will show improved interference suppression and overall more efficient task performance. This will manifest as shorter RTs in the incongruent condition for bilinguals compared to monolinguals, and shorter RTs overall for the bilingual groups. Among bilingual groups, two additional hypotheses are put forth: As a result of becoming bilingual earlier in life and therefore having more experience in managing two languages, bilinguals with an earlier AoI will show better interference suppression compared to bilinguals with a later AoIs. However, it is hypothesized that due to the differences in patterns of language use, even the Simultaneous and Early groups will differ in the degree of interference (i.e., RTs in the incongruent condition) and facilitation (i.e., RTs in the congruent condition) in the Stroop task. The nature of these differences is uncertain, however, and is therefore treated as exploratory.

4.3.2 Results

Of the 87 participants, three participants (1 Monolingual, 1 Simultaneous, 1 Early) were excluded from the analysis as a result of a data recording malfunction. For the remaining participants, data from missed or incorrect trials was removed, and individual participant responses that were 2.5 standard deviations above or below the mean for that participant were also removed, resulting in the removal of 4.8% of the data. Mean RT for each participant and each item was calculated, and box plots were conducted for each condition. No items were revealed as outliers, but the average RTs of 1 Simultaneous and 1 Late bilingual were considered as outliers, and their data was subsequently removed. Participant removal accounted for the removal of a total of 5.7% of the data. Because of high accuracy (>96% correct trials) and no significant group differences (all *p's*=1.00), further analysis of accuracy was not conducted, and only RT data from the remaining 82 participants was analysed. As in the ANT task in Chapter 3, the natural groups formed by school immersion programs (where participants begin the program at an age determined by the school curriculum, thereby resulting in little AoI variability within groups) motivated the use of ANOVA for statistical analyses. To account for violations of sphericity, Greenhouse-Geisser corrected values are reported.

4.3.2.1 English Stroop Task

In the English language task, average RT was the fastest for congruent trials (mean=701.06ms, SD=107.17, SE=11.83, 95% CI [677.52, 724.60]) and slowest for the incongruent trials (mean=798.91ms, SD=129.15, SE=14.00, 95% CI [771.03, 826.79]). The neutral trials fell in the middle, with an average RT of 741.68ms (SD=103.97, SE=11.32, 95% CI [719.14, 764.23]). Analysis of this RT data reveals an effect of Congruency ($F(2, 124)=68.61$, $p<.001$), showing the expected interference (indicated by slower responses in the Incongruent condition compared to the Control; mean difference=40.62ms, SE=6.01, $p<.001$) and facilitation (indicated by faster responses in the Congruent condition compared to the Control mean difference=57.23ms, SE=8.83, $p<.001$) for English colour-word stimuli. Interference and facilitation were present for all native speakers of English, but there was no interaction between Congruency and AoI ($p=.61$), indicating that responses were not influenced by their L2 French experience.

An examination of effect sizes confirms no differences between the AoI groups for Interference ($F(3,78)=.680$, $p=.567$) and Facilitation ($F(3,80)=.680$, $p=.567$). The RT analysis for English stimuli is shown in Figure 4.2A, and RTs for each AoI group in each condition are given in Appendix G.

4.3.2.2 French Stroop Task

In the French language task, average RT was the fastest for congruent trials (mean=720.46ms, SD=128.51, SE=14.32, 95% CI [691.95, 748.98]) and slowest for the incongruent trials (mean=803.96ms, SD=163.21, SE=17.70, 95% CI [768.73, 839.19]). The neutral trials fell in the middle, with an average RT of 758.94ms (SD=118.38, SE=13.07, 95% CI [732.93, 784.96]). Analysis of the RT data once again reveals an effect of Congruency ($F(2, 149)=54.51$, $p<.001$), and also an interaction between Congruency and AoI ($F(6, 149)=2.23$, $p=.041$). This interaction is driven by overall faster RTs for the Monolingual group (mean RT=716.00ms, SE=28.50) compared to the Simultaneous (mean RT=788.12ms, SE=28.50), Early (mean RT=780.19ms, SE=29.96), and Late (mean RT=760ms, SE=28.50) groups, and the difference likely reflects the Monolingual group's lack of experience with the French language seen by the fact that they show the smallest Stroop effect (i.e., difference between congruent and incongruent trials; Figure 4.2B). For RTs for each AoI group in each condition, please refer to Appendix G. An analysis of effect sizes also confirms a trend toward a smaller Interference effect for the Monolingual group ($F(3, 78)=2.36$, $p=.077$).

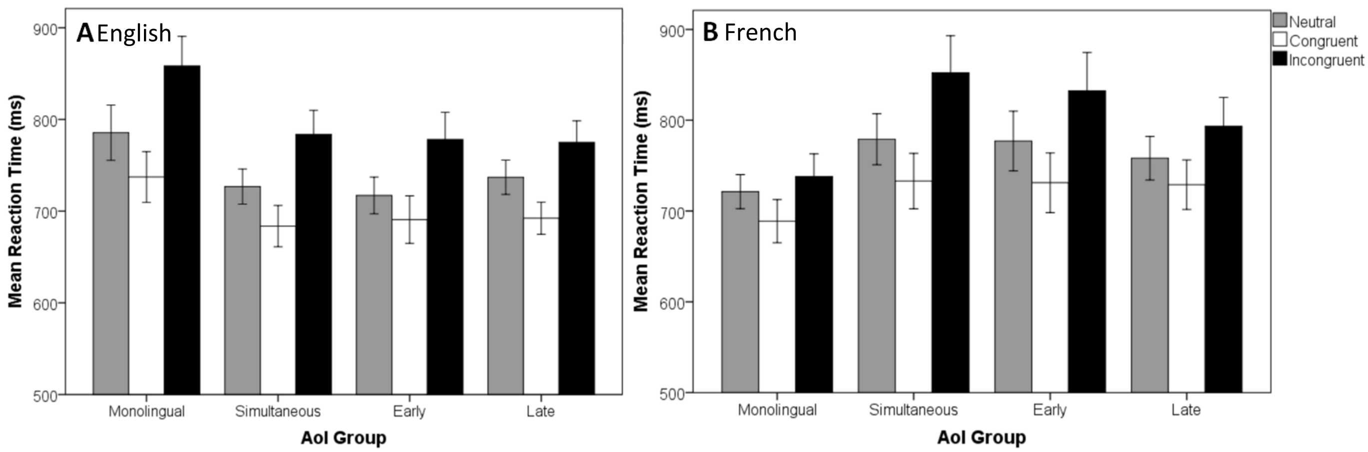

Figure 4.2. Mean Reaction Times by Condition for AoI Groups in the Single-Language Stroop Task. Error bars represent Standard Error. Panel A shows the English Stroop task, and Panel B shows the French Stroop task.

4.3.2.3 Mixed Stroop Task

In the mixed language task, average RTs for English stimuli were the fastest for congruent trials (mean=711.75ms, SD=99.58) and slowest for the incongruent trials (mean=802.74ms, SD=118.96) The neutral trials fell in the middle, with an average RT of 755.31ms (SD=110.82). Similarly, for French stimuli, the congruent condition was the fastest (mean RT=718.26, SD=101.722), followed by the neutral condition (mean RT=758.96, SD=107.05), and the incongruent condition (mean RT=794.91, SD=119.93). For RTs for each AoI group in each condition, please refer to Appendix G.

A repeated-measures ANOVA of the RTs in the Mixed Stroop task shows that just as in the English and the French tasks, there is an effect of Congruency ($F(2, 154)=116.78$, $p<.001$), with significant interference for incongruent trials (mean difference=37.96ms, $p<.001$), and significant facilitation for congruent trials (mean difference=50.78ms, $p<.001$), as well as a trend toward Language x AoI interaction ($F(6, 154)=1.98$, $p=.072$). Importantly, a significant 3-way interaction between Congruency, AoI, and Language ($F(6, 154)= 3.69$, $p=.003$) was found. To interpret this interaction, separate Congruency x Language ANOVAs were conducted for each AoI group.

For the Simultaneous group, there was an effect of Congruency ($F(2, 37)=25.53$, $p<.001$), indicating the expected interference (mean difference=55.56ms, $p<.001$) and facilitation (62.03ms, $p<.001$). In addition, there was an interaction between Congruency and Language ($F(2, 36)=5.54$, $p=.010$), which was examined further to reveal only interference (mean difference= 82.82ms, $p<.001$), but no facilitation (mean difference=7.18ms, $p=1.00$) for English stimuli, and facilitation (mean difference=35.17ms, $p=.03$), but no interference (mean difference=28.30ms, $p=.24$) for French stimuli.

Similarly, for the Early group, there was an effect of Congruency ($F(2, 35)=39.51$, $p<.001$), with significant interference (mean difference=47.09ms, $p=.007$) and facilitation (mean difference=60.40ms, $p<.001$). In addition, there was a trend towards an interaction between Congruency and Language ($F(2, 35)=2.94$, $p=.068$). This trend was explored, and revealed a pattern opposite of that for the Simultaneous group: Facilitation (mean difference=86.30ms, $p<.001$), but no interference (mean difference=29.30ms, $p=0.40$) for English stimuli, and interference (mean difference=68.87ms, $p=.001$), but only a trend toward facilitation (mean difference=24.51ms, $p=.091$) for French stimuli were found for the Early group.

For the Late group, there was again an effect of Congruency ($F(2, 35)=20.83$, $p<.001$), with significant interference (mean difference=27.35ms, $p=.018$) and facilitation (39.05ms, $p=.012$) effects. However, no interaction between Congruency and Language was found ($p=.110$). This same pattern was found for the Monolingual group, which showed a main effect of Congruency ($F(2, 35)=33.42$, $p<.001$), demonstrating both interference (mean difference=37.32ms, $p=.001$) and facilitation (mean difference=49.61ms, $p=.001$), but these showed no interaction with Language ($p=.125$). These results are shown in Figure 4.3. The asterisks indicate the particularly noteworthy significant opposite effects for the Simultaneous and Early groups in each of their languages. While Simultaneous bilinguals show significant interference, but not facilitation for English stimuli, the Early bilinguals show significant facilitation, but not interference, and this pattern is reversed for French stimuli.

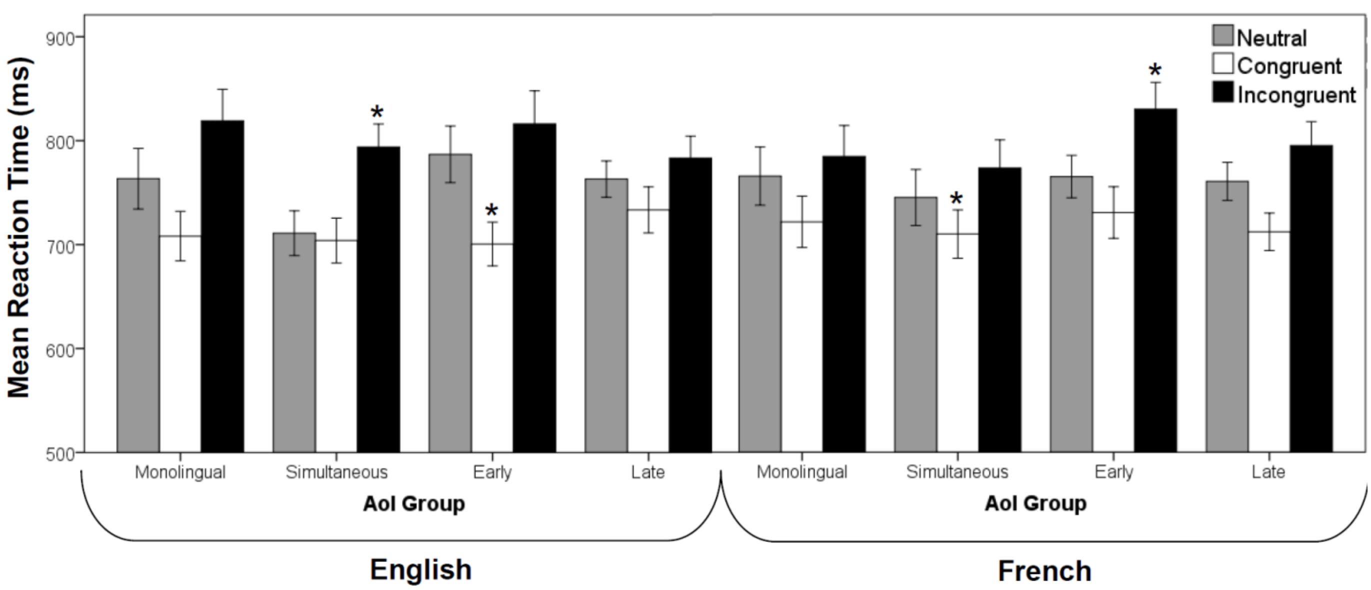

Figure 4.3. Mean Reaction Time by Condition for AoI Groups in the Mixed-Language Stroop Task. Error bars represent Standard Error. RTs for English stimuli are shown on the right and RTs for French stimuli are shown on the left. Asterisks indicate significant differences between the Simultaneous and Early groups.

4.3.3 Discussion of Stroop Results for Young Adults in Canada

The pattern of results obtained in Experiment 3, the linguistic Stroop task with English-French bilinguals, shows a complex interaction between language processing and control, and demonstrates differential effects based on the complexity of the task for young adult bilinguals. Examining each language separately (see Figure 4.2), the expected effects of congruency are present, but there is no interaction between the different AoI groups, and no apparent advantage for individuals who are more bilingual as a function of having been immersed in their L2 earlier in life. Such results are consistent with previous findings demonstrating no bilingual advantages in the Stroop task (Kousaie & Phillips, 2012). Looking at Figure 4.2B, it appears that the *monolingual* group has an advantage in processing the French stimuli; however, it is unlikely that this reflects improved cognitive control abilities. As this group, while having some exposure to their L2 French, has little proficiency in the language, it is more likely that the faster RTs reflect a lack of familiarity with French that leads to the monolingual group not processing French stimuli as language, but as simple colour items. Although they show some interference, this is considerably smaller than their bilingual counterparts, suggesting that the Monolingual group's processing of L2 French is not automatic.

As Costa et al. (2009) and Wu and Thierry (2013) show, bilingual effects become more apparent when the task difficulty is increased. Echoing our previous work (Sabourin &Vīnerte, 2015), in the current study, bilingual effects only became apparent when increasing the difficulty of the task. Looking at the Mixed Stroop task (Figure 4.3), where both English and French stimuli are present and intermixed, an effect of congruency was once again found; in addition, there was a strong three-way interaction among the groups between the congruency of the stimuli and the language in which they were presented.

In this interaction, particularly noteworthy is the opposite pattern of results for Early and Simultaneous bilinguals: while the Early bilinguals show only Facilitation in English and Interference in French, Simultaneous bilinguals show only Interference in English and Facilitation in French. The English-dominant Early bilinguals thus show a strong ability to manage the interference in their native language, while being able to use facilitating cues to speed performance. Although highly skilled in French, they are unable to control the interference from stimuli in their L2. For the linguistically-balanced Simultaneous group, their greater experience with French allows them to use facilitating cues to boost performance in French, while their experience of living in an English-dominant environment may result in greater interference from this language. It is important to note that in the case of the Simultaneous bilinguals, these differences cannot be attributed to differences between the first and the second language, as both languages are acquired at the same time. The results of the Early and Simultaneous bilinguals are in contrast with those of the Late bilinguals and Monolinguals, the latter two groups showing similar patterns of performance. Congruency effects are seen for both, but there are no differences in terms of Interference and Facilitation in the first or second language.

Taken together, these results suggest that there may be advantages to being immersed in a second language at a younger age. Furthermore, the different patterns of processing between Simultaneous and Early sequential bilinguals support our previous findings (Sabourin & Vīnerte, 2015) and suggest that although both of these groups are immersed in their second language from a very young age, their underlying language and cognitive processes are different. Thus, grouping them together, as is commonly done, may contribute to the lack of differences seen between monolinguals and bilinguals, even early ones, in some of the literature. If the groups are combined, the opposite Interference and Facilitation effects of the groups may cancel each other out, leading to apparent null effects.

However, to fully understand the differences between these groups, it may be necessary to use measures more sensitive than behavioural ones, such as event-related brain potentials (ERPs). While behavioural data shows the end-point of processing, it is not sensitive to the underlying mechanisms throughout this processing. Thus, any possible underlying differences are obscured. While the two groups look similar on the surface, the pathways that allow each group to arrive at the response may be vastly different. Even if the cognitive resources used are similar, there may be differences in underlying processing and in *how* and *when* each of these is resources is employed. Indeed, when behavioural measures have shown no between-group differences, an examination of neural processes reveals the opposite (e.g., Kousaie & Phillips, 2012). Therefore, as a starting point to such an investigation, I examine the English-French Stroop task using event-related brain potentials (ERPs) in Chapter 5.

4.4 Experiment 4. Effects of AoI on Linguistic Control for Young Adults in Japan

A total of 62 participants (15 male) between the ages of 18 and 30 took part in the Japanese component of the study, which took place in Kobe, Japan. The same Japanese-English bilinguals, grouped into Late, Late Short-Immersed, and Monolingual groups, who took part in Experiment 2 also took part in Experiment 4. Late bilinguals were ones who became immersed in L2English after the age of 8, although due to the aforementioned lack of immersion programs before university, the majority of participants actually became immersed in the first year of university Late Short-Immersed bilinguals shared the characteristics of the Late group, but were also immersed in an English-speaking country through a study-abroad program. In addition, a Monolingual control group was included for comparison.

4.4.1 Hypotheses

It is hypothesized that as a result of exercising cognitive control processes for a second language, bilinguals will show improved interference suppression and overall more efficient task performance, thus supporting the bilingual advantage hypothesis. This will manifest as shorter RTs in the incongruent condition for bilinguals compared to monolinguals, and shorter RTs overall for the bilingual groups. The possibility that there are differences between regular Late bilinguals and Late Short-Immersed bilinguals is also explored, and it is hypothesized that if short term immersion and its associated language experience positively affect cognitive control, Late Short-Immersed bilinguals will show an advantage over Late bilinguals.

4.4.2 Results

Of the 62 participants, data from missed or incorrect trials was removed, and individual participant responses that were 2.5 standard deviations above or below the mean for that participant were also removed, resulting in the removal of 4.8% of trials. Mean RT for each participant and each item was calculated, and box plots were conducted for each condition. No items were revealed as outliers, but the average RTs of 1 Late bilingual were revealed to be significant outliers, and the data was subsequently removed. Participant removal accounted for the removal of a total of 1.6% of the data. Because of high accuracy (>93% correct trials) and no significant group differences (all *p's*=1.00), further analysis of accuracy was not conducted, and only RT data from the remaining 61 participants was analysed. As with the Canadian participants, statistical analysese were conducted using ANOVAs, and to account for violations of sphericity, Greenhouse-Geisser corrected values are reported.

4.4.2.1 Japanese Stroop Task

In the Japanese single-language task, average RT was the fastest for congruent trials (mean=715.11ms, SD=75.93, SE=11.25, 95% CI [685.25, 730.28]) and slowest for the incongruent trials (mean=780.08, SD=97.76, SE=14.28, 95% CI [741.92, 799.68]). The neutral trials fell in the middle, with an average RT of 760.41ms (SD=89.16, SE=11.25, 95% CI [728.73, 781.47]). RTs for each separate AoI group in each condition are shown in Appendix G.

A repeated-measures ANOVA examining Congruency (Neutral, Congruent, Incongruent) x AoI was conducted for the Japanese language task. RT data reveals an effect of Congruency ($F(2, 110)=33.79$, $p<.001$), showing an interference trend (indicated by slower responses in the incongruent condition compared to the control; mean difference=21.4ms, $p=.075$) and the expected facilitation (indicated by faster responses in the congruent condition compared to the control; mean difference=46.1, $p<.001$) for Japanese colour-word stimuli. There was no interaction between Congruency and AoI ($p=.18$), indicating that responses were not influenced by their L2 English experience (Figure 4.4A).

4.4.2.2 English Stroop Task

In the English language task, average RT was the fastest for congruent trials (mean=706.21ms, SD=80.06, SE=10.55, 95% CI [686.37, 728.60]). Although incongruent trials were the slowest (mean=748.89, SD=108.39, SE=14.24, 95% CI [722.93, 779.92]), they did not differ greatly from neutral trials (mean=730.73ms, SD=89.64, SE=11.92, 95% CI [707.47, 755.18]). RTs for each separate AoI group in each condition are shown in Appendix G.

A Congruency (Neutral, Congruent, Incongruent) x AoI ANOVA of the RT data once again reveals an effect of Congruency ($F(2, 112)=13.54$, $p<.001$), but this is driven only by significant facilitation (mean difference=23.8ms, $p=.01$), without interference (mean difference=20.1ms, $p=.096$), for English colour-words. Again, there was no interaction between Congruency and AoI ($p=.67$). This is shown in Figure 4.4B. Visual inspection, however, shows that the Late Short-Immersed group does experience interference in English, and this interference is larger than that of the Monolingual and Late groups. While the effect does not reach significance for the Late Short-Immersed group ($p=.102$) and is 16.53ms smaller than for English-French bilinguals who are immersed in their L2, the pattern may reflect the Late Short-Immersed group's increased experience with English outside of the classroom via a study-abroad program.

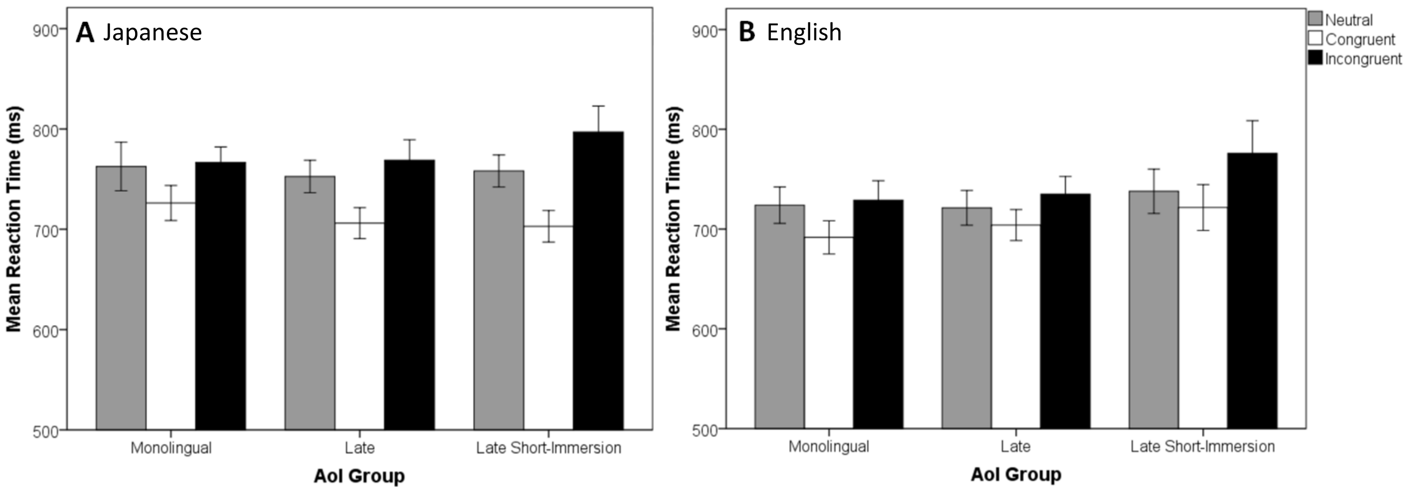

Figure 4.4. Mean Reaction Times by Condition for AoI Groups in the Single-Language Stroop Task. Error bars represent Standard Error. Panel A represents the Japanese Stroop task, and Panel B represents the English Stroop task.

4.4.2.3 Mixed Stroop Task

In the mixed language task, average RTs for Japanese stimuli were the fastest for congruent trials (mean=720.86, SD=78.94) and slowest for the incongruent trials (mean=782.36, SD=82.17) The neutral trials fell in the middle, with an average RT of 763.31 (SD=79.37). Similarly, for English stimuli, the congruent condition was the fastest (mean RT=715.81, SD=73.31), followed by the neutral condition (mean RT=757.99, SD=79.40), and the incongruent condition (mean RT=771.26, SD=81.48). For RTs for each AoI group in each condition, please refer to Appendix G.

A repeated-measures ANOVA of the RTs in the Mixed Stroop task shows that just as in the single-language tasks, there is an overall effect of Congruency ($F(2, 111)=62.57$, $p<.001$), with significant interference for incongruent trials (mean difference=41.64ms, $p<.001$), and facilitation for congruent trials (mean difference=17.40ms, $p=.003$), as well as a trend toward differences in Language ($F(1, 58)=3.48$, $p=.067$), with Japanese stimuli showing longer RTs (mean difference=8.34ms, *p*=.067) compared to English ones. This difference between languages prompted an examination of each language separately, and it was revealed that while there is both interference (mean difference=19.59ms, *p*<.001) and facilitation (mean difference=42.56ms, *p*=.05) for Japanese stimuli, English stimuli only show facilitation (mean difference=40.72ms, *p*<.001), but not interference (mean difference=15.22ms, *p*=.117). These results are shown in Figure 4.5, where significant interference and facilitation are indicated with asterisks. Visually, similarly to the single-language English task, the Late Short-Immersed group appears to show greater interference in English in the mixed-language task. This interference, however, does not reach significance (*p*=.092).

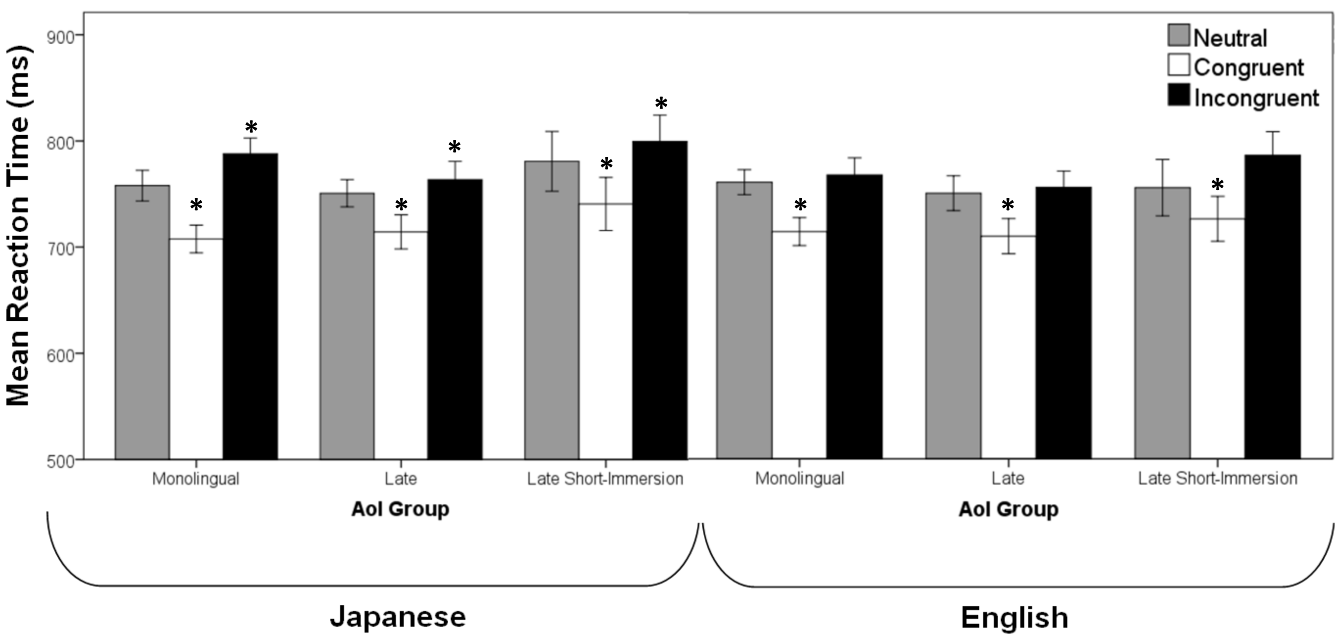

Figure 4.5. Mean Reaction Times by Condition for AoI Groups in the Mixed-Language Stroop Task. Error bars represent Standard Error. RTs for Japanese stimuli are shown on the right and RTs for English stimuli are shown on the left. Asterisks indicate a significant difference relative to neutral trials.

4.4.3 Discussion of Stroop Results for Young Adults in Japan

Experiment 4, while demonstrating the expected interference for incongruent relative to neutral stimuli and the expected facilitation for congruent relative to neutral trials for Japanese stimuli, did not find these effects for English stimuli. Furthermore, it did not find any differences between the Monolingual, Late, and Late Short-Immersed groups, regardless of the language of the stimuli or whether the languages were presented separately or together. These results may reflect the participants' low L2 English reading proficiency and the late immersion of the bilingual groups. In addition, it may reflect their status as learners of the L2, rather than bilinguals who must manage competition between two languages.

Interference in the Stroop task is largely attributed to selective attention (e.g., Bialystok et al., 2008; Roelofs, 2010; Kousaie & Phillips, 2012; Coderre et al., 2013), where a greater amount of attentional resources are required for the controlled process of colour naming than the automatic process of reading. The direct competition between automatic reading, which is difficult to stop once initiated, and controlled naming is the source of interference and the Stroop effect (MacLeod & MacDonald, 2000). This interference is apparent for Japanese colour words, but is absent for colour words presented in English. This difference likely reflects the participants' native proficiency in Japanese, but their limited experience with the English language.

As LaBerge and Samuels (1974) observed, reading is an automatic process that requires little effort for proficient, literate individuals. However, although the Japanese participants here are literate in English, they are not proficient readers. This is to be expected of the Monolingual group, who have learned to read and write the alphabet usually at the end of elementary school or at the beginning of junior high school (approximately grade 7 or 8), but rarely use it. The process of reading in English is therefore not automatic for this group. From the results of this study, it appears that reading in English may also not be automatic for the bilingual groups. Although the bilingual participants do take classes in English, due to their external language environment, in which nearly all written information is in Japanese and the frequency of the alphabet is low, the participants have less familiarity and proficiency with written English. Such results are compatible with those of Tse and Altarriba (2012), who found that increasing proficiency in the L2 also increases Stroop interference. Thus, the lack of reading proficiency and familiarity with English for both monolinguals and bilingual groups in the current study is likely to have resulted in the lack of interference observed for English stimuli. Interestingly, although not significant, the bilinguals who have participated in a short-term immersion do seem to show more interference than those who have not, as seen in Figure 4.4, but this remains to be explored in the future.

The lack of differences in English (both single-language and mixed) between AoI groups may be linked to the bilinguals' low reading proficiency in their L2 English. In addition, it may also explain why English stimuli show faster RTs compared to Japanese stimuli: if participants are not proficient readers, they may simply be treating the words on the screen similarly to patches of colour. Yet, that does not explain the absence of differences among AoI groups for Japanese stimuli. Here, if bilinguals had a cognitive control advantage, this would manifest as less interference and/or faster RTs. However, this is absent, and such results may be due to the groups' late AoI.

As previously mentioned, Japanese students are first exposed to English around the age of 10. Much of this early exposure is in the form of learning basic vocabulary and set phrases, with more intensive learning often beginning in junior or senior high school[12]. For those that are immersed in English, this immersion begins only in the first year of university (i.e., adulthood). Since the bilingual participants were in university at the time of testing, their duration of English immersion was under 4 years, and this limited experience combined with the late onset of learning the L2 may not be enough to confer cognitive benefits for linguistic tasks. In addition, it is possible that because these participants are essentially still learners of the L2, and therefore no sufficiently proficient in both languages to necessitate regular management of two languages, they may not yet have reached a stage where their L2 becomes beneficial for their cognition. Early bilingualism, although slowly increasing, is still relatively rare in Japanese universities, and it was therefore impossible to examine its impact in Experiment 4.

4.5 Comparisons of Canadian and Japanese Groups

One objective of the current study is to examine differences in Stroop performance caused by different writing systems, which makes a comparison of Canadian participants with L1 English, which uses and alphabetic writing system, and Japanese participants with L1 Japanese, which uses a logographic writing system, particularly interesting. In an analysis of RT, the expected congruency effects were present in both the single-language task ($F(2,195)=74.69$, $p<.001$) and the L1 stimuli of the mixed-language task ($F(2, 225)=94.90$, $p<.001$). There was also a trend toward interaction between Congruency and AoI in the single-language condition

[12] This is certainly not the case for all students, as there are schools that begin teaching English more intensively earlier, but based on self-report, many of my participants were significantly exposed to English only in high school.

($F(2,195)=1.91$, $p=.056$) and a significant interaction between Congruency and AoI in the mixed-language task ($F(2,225)=3.33$, $p<.001$). However, it was difficult to interpret whether these interactions were the result of AoI or writing system in which the stimuli were presented (alphabet for the Simultaneous, Early, Late, and Monolingual participants in Canada, and logographs for the Late and Monolingual participants in Japan).

A Congruency x Writing System (alphabetic vs. logographic) x AoI ANOVA was therefore conducted, and an interaction between Congruency and Writing System was revealed in the single-language condition ($F(2,201)=6.68$, $p=.003$) and a trend in the mixed-language condition ($F(2, 234)=2.53$, $p=.082$).To interpret these results, effect sizes for Interference (Incongruent-Neutral trials) and Facilitation (Congruent-Neutral trials) were examined. In the single-language condition, there was a difference between groups in Interference ($F(1,131)=8.10$, $p=.005$), with less interference for the logographic system compared to the alphabetic (17.60ms, SD=70.80 vs. 55.81ms, SD=79.83). In the mixed-language condition, there was a trend ($F(1,131)=3.86$, $p=.052$), and once again, there was less interference for the logographic vs. alphabetic writing system (15.73ms, SD=57.47 vs. 37.74ms, SD=67.63). This suggests that there is altogether less interference for the logographic writing system compared to the alphabetic one. Because the results of Experiment 4 suggest that Japanese participants are likely not processing their L2 English automatically, this comparison focused only on the L1 Stroop task.

4.6 Stroop Task Discussion

This study examined the effect of AoI on Stroop task performance, testing bilinguals and monolinguals in two different environments- Canada and Japan- and using identical methodology, but adapting the task to use the bilinguals' respective language pairs. Although the AoI group differences warrant further investigation, Experiments 3 and 4 suggest that among other factors, task complexity, the bilingual environment, and the languages used in the task are important factors in determining performance in the Stroop task.

While in the single-language Stroop tasks all groups behaved similarly, it was only when the difficulty was increased by mixing the languages that bilingual effects became apparent for the Canadian groups, and interference and facilitation became more pronounced for the Japanese groups. As discussed in previous studies (e.g., Costa, 2008; 2009), young adults are at their prime in terms of cognitive processing. In the case of the Canadian participants, this leaves little room for improvement caused by bilingualism, and may contribute to the lack of observed bilingual effects when looking at performance in single language conditions such as those used here. In the case of the Japanese participants, although they do not benefit from bilingualism due to their late immersion and limited experience with the L2, they do only show significant interference in the mixed-language task. This suggests that young adults are particularly affected by the nature of the cognitive control task itself. Looking at Table 4.1, a wide variety of task designs are seen, with some using only one language, and other using both languages but presenting them in a monolingual format (i.e., single-language) or bilingual format (i.e., mixed-language), and this may be a contributing factor to the inconsistency seen in bilingual cognitive control literature on young adults.

In addition to task characteristics, it is also possible that the results found here also reflect processing as a result of the participants' linguistic environment. Green (2011) discusses differences in how different bilingual communities use their two languages, and expands upon this idea in the Adaptive Control Hypothesis (Green & Abutalebi, 2013), proposing different cognitive effects as a result of patterns of language use in the environment. The Canadian participants live in an environment where both languages are heard and read regularly, and this is true for even our Monolingual and Late bilingual participants. As a result of this language experience, it is particularly the mixed language task, reflecting their mixed language environment, where our participants' specific skills can be observed. The Japanese participants, on the other hand, live in an environment where their two languages are rarely mixed. In addition, their native language, in both the written and spoken form, is dominant, and exposure to their L2 English is limited. In such an environment, English reading especially is not present frequently enough for the process of reading to become automatic. Therefore, the faster RTs shown for English compared to Japanese stimuli likely reflect low proficiency in English, similarly to how Canadian Monolingual participants show less interference in French. This raises another interesting question for the Stroop task: to what degree does reading proficiency affect results in the Stroop task? And what role does being in the process of learning an L2 play? How do these affect apparent cognitive control abilities in linguistic tasks? While some work has been done on learners, largely focused on children, this remains an interesting avenue for further investigation.

Although one of the aims of this work was to explore how different environments with respect to Abutalebi and Green's (2013) ACH affect cognitive control, because AoI and country were confounded, such a comparison was not possible. One interesting comparison that could be made, however, was between an alphabetic and a logographic writing system, both of which were L1s, in the Stroop task. In this comparison, there were no differences between the RTs of the writing systems between the Canadian and Japanese groups, but Japanese logographs show smaller Stroop interference compared to English alphabet. As seen from monolingual and bilingual, as well as AoI comparisons, this is unlikely to be the effect of better cognitive control for Japanese compared to Canadian participants; instead, it may be the effect of the script. Such possibility has been discussed for Chinese vs. English by Coderre et al. (2013), who notice a different timecourse for their participants' different scripts and consider the relative speed of processing for each language as a possible cause. As the authors point out, there is controversy regarding the differences in processing for alphabetic vs. logographic script. However, for Chinese logographs, due to the complex nature of each character, some have argued that unlike for alphabetic systems which have a strong link between orthography and phonology, logographs have a stronger link between orthography and semantics, i.e., the written form activates the meaning of the character (e.g., Tan & Perfetti, 1997 as cited in Coderre et al., 2013; Chen, Yamauchi, Tamaoka, & Vaid, 2007). Essentially, as Coderre et al., 2013 summarize, because processing the alphabetic script of English entails strong phonological activation before semantic activation and the logographic script of Chinese takes a more direct route to semantics, the additional step for the alphabet slows down lexical access, which may have resulted in the researchers' different findings for Chinese- vs. English-speaking participants. Similar differences in script processing may have been responsible for the differences between L1 English and L1 Japanese participants' performance in the current Stroop task.

Lexical access and retrieval for Japanese has been investigated by a number of studies (e.g., Wydell, Patterson, & Humphreys, 1993; Saito, Masuda, & Kawakami, 1999; Wu, Koh, Ho, Miyakoshi, Nakai, & Chen, 2014; Hino, Kusunose, Miyamura, & Lupker, 2017; Vīnerte, Li, &

Sabourin, 2017; under review), and just as with Chinese logographs, strong links between the written form and meaning are found. Thus, it is feasible that the longer lexical access for English alphabet vs. Chinese logographs in Coderre et al.'s (2013) study is also present in the current study. This may offer an explanation for the reduced interference seen for Japanese vs. English stimuli: If lexical access is indeed faster for logographs, this may allow less time for the spreading activation of concepts in the lexicon, resulting in less interference in the Japanese Stroop task compared to its English counterpart. In other words, there is simply less time for interference to take place, which decreases its magnitude. This would explain both the lack of interference found in Experiment 4, as well as the decreased interference for Japanese participants compared to their Canadian counterparts. Importantly, this demonstrates another direct effect of task manipulation on Stroop task performance, and suggests that care should be taken in comparing bilingual cognitive control not only using different Stroop task designs, but also using different languages in the task.

Overall, while the Stroop tasks in Experiments 3 and 4 show different patterns of results for each of the AoI groups, these results demonstrate differences in *language* control and processing among bilinguals with different L2 experience, but do not speak to general cognitive control abilities. Indeed, Hilchey and Klein (2011) specifically do not include the Stroop task in their analysis due to its close relationship to language, and say that in order to demonstrate the benefits of bilingualism on general cognitive control, tasks that are not language-driven are required. Still, the Stroop task is highly informative with respect to language processing and widely used in investigations of cognitive control. But as the current work shows, it is sensitive to not only participant factors, but also to task factors. Therefore, for truly compare bilingual cognitive control based on the Stroop task, it is necessary to take an array of factors into consideration. Further investigation of this issue is also needed, and I am therefore currently involved in a meta-analysis project examining how various experimental manipulations in the linguistic Stroop task affect the presence of bilingual cognitive control advantages (Vīnerte, Tsui, & Sabourin, 2017). Such a meta-analysis may reveal more conclusively whether or not bilingual cognitive control advantages exist in the Stroop task, as well as the conditions under which they do or do not appear.

Chapter 5. Study 3- Examining Underlying Processes in Stroop Task via Event-Related Potentials

Investigations of the impact of bilingualism on cognitive control are growing more sophisticated not only with respect to the questions asked, but also with respect to the methods used to investigate this phenomenon. Moving away from a simple yes-no debate regarding the existence of bilingual benefits, researchers are examining which specific factors affect the development of cognitive control and in what ways these effects manifest. In addition to behavioural measures such as RT and accuracy, studies are also using neurophysiological measures such as electroencephalography (EEG) to look at the underlying neural processes of cognitive control skills including attention, response inhibition, and conflict monitoring.

Using these neurophysiological measures in addition to behavioural ones has considerable advantages. This chapter focuses on EEG methods, specifically ERPs, and their use in investigating a well-known cognitive control paradigm-the Stroop task. It begins with an overview of the ERPs, followed by a review of the literature on the ERP Stroop task from the limited bilingual studies available. It then presents the current investigation of underlying neural processing during an English-French bilingual Stroop task by simultaneous and early sequential bilinguals and functional monolinguals in the Ottawa-Gatineau area.

5.1 Electroencephalography and Event-Related Potentials

In 1875, the British Medical Journal published a short account by Richard Caton which described electrical currents in the brains of rabbits and monkeys. Using a galvanometer[13], Caton showed that placing two electrodes on the surface of the skull reveals an electrical current that varies in direction depending on sensory stimuli input. He noted that these electrical currents appear to be related to the function of the gray matter. This short note is now considered to be the first description of the EEG (Coenen & Zayachkivsa, 2013). Over 140 years later, this technique is used widely in medical imaging, and is increasing in popularity among researchers in many different fields, including linguistics. What makes this electrophysiological method a particularly useful option for cognitive control studies is its non-invasive nature and ease of use, its ability to capture underlying neural processes in real time, and its strength in examining unconscious, automatic processing with a high degree of temporal precision.

In a typical EEG experiment, a participant is fitted with a snug cap that contains small electrodes, each of which is filled with a highly conductive saline gel. The electrodes rest against the surface of the scalp, and aided by the conductivity of the saline, are able to pick up small fluctuations in electrical activity at the scalp. This activity reflects unconscious, automatic brain processes (Luck, 2005; 2014). Once the electrode cap has been fitted, the participant is comfortably seated and can perform an experimental task, while simultaneously, each electrode in the cap records the ongoing electrical activity at its specific location. The activity at each electrode is amplified and represented as a respective continuous EEG waveform that can

[13] An instrument used for detecting and measuring small electrical currents.

be recorded and analysed. Thus, without discomfort to the participant, researchers are able to examine brain activity as it occurs throughout the experimental task.

The continuous EEG waveform is the product of a large number of active underlying neurons. Specifically, much of the observed activity is caused by the flow of sodium, potassium, calcium, and chloride ions across the neuronal membrane of pyramidal cells in the cerebral cortex (Teplan, 2002; Beres, 2017). When an action potential triggers neurotransmitter release at the apical dendrite, this neurotransmitter enters the synaptic cleft, from where it binds to the postsynaptic membrane, causing ion channels to open. This in turn triggers the flow of current (and influx or efflux of charged ions, depending on whether the neurotransmitter is excitatory or inhibitory) into the dendrite, leaving the dendrite and the extracellular fluid with opposite charges. The current in the dendrite propagates downward, with ions exiting the neuron a short distance away and effectively forming a dipole. It is these patterns of current flow that form the EEG signal. While the dipole of a single neuron is not detectable, the summation of thousands of neurons with similar orientation yields a signal that is large enough to be measured at the scalp (Luck, 2014; see also Chapter 4 of Bear, Connors, & Paradiso, 2006).

As Luck (2014) notes, the EEG in its raw form is of little use to researchers, since the signal is the combination of many sources of neural activity. Although it can be used is clinical settings, it is difficult to use this raw signal to examine specific cognitive functions (Beres, 2017). Rather than looking at the EEG as a whole, researchers benefit more from examining event-related potentials (ERPs). These are large evoked electrical changes (in other words, electrical *potentials*) generated in response to a specific stimulus *event,* and these can be isolated from the continuous EEG waveform by digital averaging, a process which serves to reduce noise from brain activity that is not of interest to the study and better show the ERP component of interest (Sabourin, Brien, & Tremblay, 2013). By presenting stimuli and recording the ERPs generated, it is possible to examine participants' neural responses to specific stimuli.

Cognitive processes such as perception, selective attention, and language processing happen at time ranges in the order of milliseconds (Teplan, 2002). Because it relies on the propagation of electrical signal, the transmission of which from its source to the scalp is nearly instantaneous, the EEG waveform reflects brain processes in real time, producing ERPs with high temporal resolution. This makes it an excellent method for the current study. As discussed in Chapter 4, a behavioural Stroop task requires participants to manually press a button in response to an on-screen colour-word stimulus, and the RT is measured. However, this RT represents only a processing endpoint, and the time course of the neural processes leading up to this manual press of a button are completely invisible in a behavioural task.

Much of the controversy regarding bilingual effects on cognitive control comes from a lack of observable differences between monolingual and bilingual groups. Using behavioural measures, some studies report similar RTs among these groups, leading to a conclusion that monolinguals and bilinguals do not differ (e.g., Paap, 2013). However, this may not be the case. While the two groups look similar on the surface, the underlying pathways that allow each group to arrive at the response may be vastly different. Even if the cognitive resources used are similar, there may be differences in underlying processing and in *how* and *when* each of these is resources is employed. Indeed, when behavioural measures have shown no between-group differences, an examination of neural processes reveals the opposite (e.g., Kousaie & Phillips, 2012; Berroir, et al., 2017). The insight into cognitive control processes provided by measuring the precise timing of neural activity may shed more light on the complex and sometimes contradictory results of behavioural studies, and combining the Stroop task with an ERP analysis will inform the current study of when and how bilinguals employ their cognitive control mechanisms.

5.2 ERPs and the Stroop Task

Electrophysiological investigations of the Stroop task have aimed to determine which neural processes are involved in the task and the relevant ERP components that reflect these processes. An ERP component can be defined as a systematic variability in the EEG waveform that reflects underlying neural activity (Luck, 2014). In other words, presenting specific variables to the participant will result in neural activity that creates an identifiable pattern of peaks and valleys in EEG data set, which, while having poor spatial resolution, offer a precise look at the timing of neural activity. These peaks and valleys, or positive- and negative-going deflections, along with their position in the waveform, are the basis of the majority of component nomenclature: an "N" prefix denotes a negative-going deflection, while "P" denotes a positive-going one, and the number following denotes either the latency, in milliseconds, of the positive or negative peak, or the ordinal position of the peak. To avoid confusion, the current study will use a three-digit number to indicate the latency, and a single-digit number to indicate the ordinal peak. For example, "N200" indicates a negative-going deflection at 200ms following the stimulus onset, while "N2" indicates the second negative peak[14].

[14] While this nomenclature follows the convention of previous studies, it is not the standard convention for all ERP studies. For discussion of the lack of a single nomenclature standard for ERP studies, refer to Chapter 1 of Luck, 2014.

While many studies have examined the ERP components involved in the Stroop task, only five known studies (Kousaie & Phillips, 2012; Naylor, Stanley, & Wicha, 2012; Coderre & van Heuven, 2014; Heidlmayr, Hemforth, Moutier, & Isel, 2015; Hannaway, Opitz, & Sauseng, 2017) have investigated the Stroop task as a measure of bilingual cognitive control. The components investigated in these bilingual studies are ones which have also been investigated in more general examinations of the Stroop effect. The following sections describe components associated with the Stroop task, and discuss their significance for both the task and bilingual cognitive control abilities. As the five bilingual studies vary greatly with respect to Stroop task type and experimental design, the focus here will be on common elements and comparisons of monolingual and bilingual groups. ERP components will be discussed in order of importance. For a more detailed task comparison, please see Chapter 4.

5.2.1 N450: The Stroop Component

Also known as mediofrontal negativity, Stroop N400, and N_{inc}, the N450 is the component most often associated with the Stroop task. It is a negative deflection peaking between 300 and 550ms post-stimulus with a fronto-central or centroparietal distribution that is more negative in the incongruent than neutral and congruent conditions of the Stroop task (Hanslmayr, Pastotter, Bauml, Gruber, Wimber, & Klimesch, 2008; Coderre, Conklin, & van Heuven, 2011; Tillman & Wiens, 2011; Caldas, Machado-Pinheiro, Motta-Ribeiro, & David, 2012). This component is generally thought to index cognitive control processes such as conflict detection and conflict resolution which are particularly necessary in the incongruent condition of the task

(Coderre et al., 2011), and the amplitude increases with increasing conflict (i.e. is more negative in incongruent compared to congruent trials) as shown by West (2003).

Although ERPs have poor spatial resolution, source localization techniques have identified the generator of the N450 in the Stroop task as the ACC in the prefrontal cortex (Hanslmayr et al., 2008; Badzakova-Trajkov, Barnett, Waldie, & Kirk, 2009), the same structure that Abutalebi and Green (2007; 2008) show is involved in language control and switching, and which comprises an important part of the cognitive control circuit (see Luk, et al., 2012). The ACC is particularly involved in governing cognitive control processes such as attention allocation, conflict detection, and conflict resolution, all of which are necessary for the Stroop task. Barzekova-Trajkov et al. (2009) further propose that different regions are involved in different phases of the task; while the ACC is responsible for the conflict detection and resolution, the prefrontal, posterior, and temporal areas of the cingulate may be involved in attention allocation. It is, however, difficult to make conclusive statements about the specific neural generators of each component using source localization, since ERPs are not reliable in this respect. Corroborative evidence regarding the ACC's involvement in cognitive control has been found using neuroimaging techniques such as functional magnetic resonance imaging (fMRI), but discussion of these findings is beyond the scope of the current work. Importantly, the link between the N450 and the ACC demonstrates the involvement in cognitive control networks in the Stroop task.

Turning to examinations of the N450 in a bilingual Stroop studies, Naylor et al. (2012), Coderre et al. (2014), and Heidlmayr et al. (2015) found that, consistent with previous observations in monolinguals, amplitude is greater for the incongruent compared to the congruent and neutral conditions, regardless of whether the task was completed in the L1 or the L2. Hannaway et al. (2017), while finding the aforementioned amplitude difference, did not find any differences between the two languages. Although the literature is limited, these studies support the N450's sensitivity to the conflict created by colour incongruence.

Comparing the monolingual and bilingual groups, both Coderre et al. (2014) and Heidlmayr et al. (2015) found that N450 amplitudes were reduced for bilinguals relative to monolinguals. Heidlmayr et al. (2015) interpret this as reflecting greater efficiency in inhibiting interference from the written word, while Coderre et al. (2014) take a different view: in their study, the N450 component was used to evaluate Hilchey and Klein's (2011) Bilingual Inhibitory Control Advantage (BICA) and Bilingual Executive Processing Advantage (BEPA) hypotheses, which predict an advantage for conflict-resolution specifically and an advantage for general cognitive control, respectively (see Chapter 2 for details). While there was some support for bilingual advantage in inhibition, they conclude that the bilingual advantage stems more from an overall general cognitive control advantage (i.e., the BEPA hypothesis is supported) due to bilinguals exhibiting smaller amplitudes in the control condition, coupled with overall faster RTs. There also appear to be differences between the two languages in this study, and the authors noted that for the L2, bilinguals showed a more sustained N450; however, onset times of the negativity were the same for all groups.

Testing only bilinguals, Naylor et al. (2012) also found that the N450 component was not affected by language in the between-language task, with similar amplitudes for both English and Spanish; however, this may have been due to testing bilingual groups who were balanced in the use of both languages, and as the authors state, it is possible that in such cases, the cognitive control demands of colour congruency and language congruency are equal. In contrast, Hannaway, et al. (2017) did find differences between English and German, but contrary to their expectations, N450 amplitudes increased when the language stimuli were dissimilar (e.g., Yellow/Gleb) compare to similar (e.g., Blau/Blue). However, as no difference in interference effects was found for both languages, the authors conclude that this provides support for the BEPA hypothesis. Although these bilingual studies differ in many ways, they do show a strong association of the N450 with cognitive control and suggest greater efficiency in conflict resolution for bilinguals. Still, it must be noted that there remains a debate regarding the functional significance of the N450 component (see Augustinova, Silvert, Ferrand, Llorca, & Flaudias, 2015), and further examination is required before strong conclusions can be made.

5.2.2 The N200: Conflict and Attention

The N200 component is a negative deflection peaking approximately 200-350ms post-stimulus, with a frontocentral (Kousaie & Phillips, 2012; Heidlmayr et al., 2015), sometimes right-lateralized (Naylor et al., 2012) distribution. Luck (2014) includes sensitivity to mismatch, especially when stimuli are attended, among the functions indicated by this component. In bilingual contexts, it may reflect attention allocation (Naylor et al., 2012) and conflict monitoring (Kousaie & Phillips, 2012; Heidlmayr et al., 2015), with larger amplitudes found in the incongruent condition, which requires a greater degree of conflict monitoring.

Comparing monolinguals and bilinguals, Heidlmayr et al. (2015) found no effect of language group, although differences were found when a more challenging negative priming condition was included. The authors suggest that this reflects the higher demands on the system, which bilinguals are better able to attend to. Finding the opposite, Kousaie and Phillips (2012) found that monolinguals displayed larger amplitudes, which may reflect better conflict monitoring by this group; however, these results were interpreted as less *active* monitoring by the bilingual group- an interpretation that is supported by Berroir et al.'s (2017) observation that monolinguals recruit more networks in the brain, suggesting that processing is not as efficient as bilinguals'.

Taking a different approach, Naylor et al. (2012) tested balanced bilinguals using a Stroop task with covert naming to examine between-within language Stroop effects. The authors found that the N200 displays a larger amplitude in incongruent compared to congruent trials; however, rather than reflecting conflict monitoring or attention allocation, they conclude that this component and its amplitude reflect processing of language congruence before colour congruence. Furthermore, they suggest that inhibitory control processes that permit better conflict resolution are the cause of the N200 in their study. Once again, there are differences in the proposed functional significance and in the results obtained, suggesting that further investigation is beneficial.

5.2.3 Sustained Potential

A late component that are has been linked to the N450 is the conflict Sustained Potential (SP), also known as the Late Sustained Potential and Sustained Negativity. The SP is a lingering negativity which follows the N450. It has been observed between 540-700ms with a frontal and centroparietal distribution (West, 2003), and similar to the N450, amplitudes are greater for incongruent conditions. There does not seem to be a consensus regarding the functional significance of the SP, but suggested processes include cognitive control process engagement (Hanslmayr et al., 2008), response selection (West, 2003), and conflict processing (Coderre et al., 2011; Naylor et al., 2012).

Examining the SP in the bilingual Stroop task, Heidlmayr et al. (2015) and Naylor et al. (2012) found a significant difference in the amplitude between the congruent and incongruent condition. However, comparing language groups, Heidlmayr et al. (2015) found that this effect was only significant for the monolinguals (i.e. amplitudes for bilinguals were smaller). This, according to the authors, suggests that bilinguals have a smaller cost associated with conflict processing. In light of Berroir et al.'s (2017) demonstration of differential connectivity between brain regions in the two groups, the larger effect may indicate a greater draw of cognitive resources for the monolingual group compared to the bilingual group.

5.2.4 The P300

The P300 component is a frontocentral positive-going deflection with a broad temporal distribution, peaking between 300 and 600ms (Kousaie & Phillips, 2012). Functions attributed to this component include strategic response to the environment and stimulus categorization (Luck, 2014), as well as resource allocation which varies with the task difficulty, with smaller amplitudes and longer latencies reflecting greater resource use (Polich, 2007).

While the P300 has not been extensively investigated in the Stroop task, existing research has been particularly useful in informing researchers of whether the interference seen in the task is caused by stimulus-level or response-level conflict. Ilan and Polich (1999) examined the P300 in a manual Stroop task to specifically examine this issue, predicting that if Stroop interference occurs at the stimulus categorization level (stimulus-level conflict), the P300 latency should be related to the task condition (i.e. faster for the congruent condition which would be easier to evaluate). The authors found no relationship between colour congruency and latency, and interpreted this as indicating that the conflict in the Stroop task occurs at the response level. A similar conclusion was reached by Qui, Luo, Wang, Zhang, and Zhang (2008), who investigated this component using a Chinese Stroop task. The waveforms of both of these studies also showed larger peaks for the congruent condition and smaller ones for incongruent, reflecting the difference in demand on processing resources by each of these conditions. While the simpler congruent condition requires fewer resources, the incongruent condition is more taxing. Extended to bilingual Stroop studies, the P300 component may reveal differences in resource allocation between groups.

Only one bilingual Stroop study has examined the P300 component. Kousaie and Phillips (2012) examined this component in the centroparietal areas, expecting longer latencies for incongruent trials compared to congruent ones. Furthermore, longer latencies were expected for monolingual participants compared to bilingual ones, reflecting bilinguals' enhanced cognitive control skills which allow for stimuli to be categorized more quickly. While the study did not find latency effects, it did find that amplitudes for incongruent trials were more negative, suggesting greater resource allocation for these more challenging trials- results that are in line with Polich (2007); however, the predicted group differences were absent for the linguistic Stroop task. They did become apparent for the non-linguistic Simon task, with bilinguals showing smaller amplitudes, which may reflect greater resource allocation by this group.

5.2.5 Summary of Previous Findings and the Current Study

Bilingual studies of the ERP Stroop task are still scarce, and the methodology used to investigate effects varies greatly from study to study. Table 5.1 provides a summary of the current findings for the major components examined.[15]

Table 5.1. Summary of ERP Components in the Stroop Task

Component	Function	Distribution	Findings	Studies
N450	conflict detection and resolution	frontocentral and centroparietal	Larger amplitude for incongruent vs. congruent stimuli; reduced amplitude for bilinguals;	Naylor et al., 2012 Coderre & van Heuven, 2014 Heidlmyer et al., 2015 Hannaway et al., 2017
N200	attention allocation and conflict monitoring	frontocentral (right-lateralized)	Increased amplitude when conflict increased; reduced amplitude for bilinguals	Kousaie & Phillips, 2012 Naylor et al., 2012 Coderre & van Heuven, 2014 Heidlmyer et al., 2015
SP	engagement of cognitive control processes for incongruent trials	frontal and centroparietal	Increased amplitude for incongruent vs. congruent trials; reduced amplitude for bilinguals;	Naylor et al., 2012 Heidlmyer et al., 2015
P300	response to environment, resource allocation	frontocentral	Reduced amplitude for bilinguals	Kousaie & Phillips, 2012

15 Kousaie and Phillips (2012) also examine the ERN and Hannaway et al. (2017) include the LPC. However, these components are poorly understood with respect to the Stroop task, and results in the respective studies are inconclusive. Therefore, these components will be left out of the current discussion.

It must be noted, however, that even more frequently examined components such as the N450 are not clearly understood, and overlap in suggested functional significance makes concrete conclusions difficult. There has been a focus on component amplitude, and although timing has also been examined, there is no consensus on what any differences in timing mean. Furthermore, the task requirements for the Stroop task itself are not completely agreed upon. For example, while the aforementioned studies of the P300 conclude that the conflict is at the response level, using the N450, others suggest that this conflict is present at both levels (Caldas et al., 2012) or is semantic in nature (Augustinova, et al. 2015). This problem is confounded by the various versions of the Stroop task as described in Chapter 4, different proportions of congruent and incongruent trials (Tillman & Wiens, 2011), and as Liotti, Woldorff, Perez, and Mayberg (2000) noted, even the response modality (covert button press vs. overt naming) make a difference in the effect sizes of different component.

5.2.6 The Current Study

The current pilot study compares monolingual vs. bilingual processing in the L1, focusing on the N200 and N450 components, and aims to add to the limited literature on bilingual cognitive control using the ERP Stroop task. While this pilot study is largely exploratory and seeks to examine how ERP components for monolingual and bilingual groups are affected by manipulations in the Stroop task, it hypothesizes that bilinguals, while behaviourally showing similar results in the single-language task, will differ in their attention allocation and conflict monitoring. Bilinguals may show more efficient conflict monitoring of the environment, which is predicted to be reflected by a smaller N200, compared to monolinguals, who may allocate greater resources to conflict monitoring, which may translate to larger N200 amplitudes. According to the bilingual advantage hypothesis, bilinguals may also show reduced interference. This is predicted to result in a smaller N450 amplitude in response to incongruent stimuli for the bilingual compared to monolingual participants.

5.3. Methods

5.3.1 Participants

A total of 28 participants (2 male) between the ages of 18 and 25 from the University of Ottawa took part in this study. Participants were recruited through the university's Integrated System of Participation in Research and received 2 points credit toward their 1st year psychology or linguistics courses and light refreshments (e.g., cookies, candy, juice). Participants self-reported as right-handed, with normal or corrected-to-normal vision, normal colour vision, and no history of brain injury. All participants completed a detailed language background questionnaire (Sabourin, et al., 2016), in which they indicated their ages of exposure and immersion in both English and French, their use of both languages (and any others), and assessed their proficiency in each. In addition, they completed an English Cloze task (Brown, 1980) and French Cloze task (Tremblay, 2011). In this preliminary study, Participants were functional Monolinguals (who, although having taken Core French classes, were never immersed in French, and currently have no functional proficiency) and Bilinguals (who were immersed in L2 French between the ages of 1 and 6; effectively, early bilinguals). Detailed participant information is provided in Table 5.2.

Table 5.2. Participant Description for ERP Stroop Task. Average values for participant groups provided, standard deviation in brackets. Individual participant profiles are provided in Appendix E.

Group	Monolingual	Bilingual
N	10	18
Age	18.9(1.5)	20.3(2.5)
Age of 1st L2 Exposure	8.4(1.8)	4.2(1.3)
Age of Immersion	N/A	4.6(0.9)
English Proficiency (%)	88.8(8.1)	88(7.2)
French Proficiency (%)	14(18.1)	32.6(20.2)
Self-Rated Proficiency (/20)	5.6(3.9)	10.4(3.6)

5.3.2 Stimuli and Design

The stimuli and design for the ERP Stroop task were identical to those used in the English-French behavioural version presented in Chapter 4. Please refer to Section 4.2.2. for a description of the stimuli.

5.3.3 Procedure

The procedure for the ERP Stroop task was kept consistent with the behavioural version described in Chapter 4, with only the following modifications to the timing of the task: The pre-stimulus fixation cross varied in duration between 250 to 1500ms to introduce a latency jitter and a 700ms interstimulus interval (ISI) consisting of a blank screen was added post-stimulus in order to capture any late components. This increased the maximum time of each trial to

4200ms, for a total maximum experiment time of 21 minutes. The ERP Stroop task procedure is given in Figure 5.1.

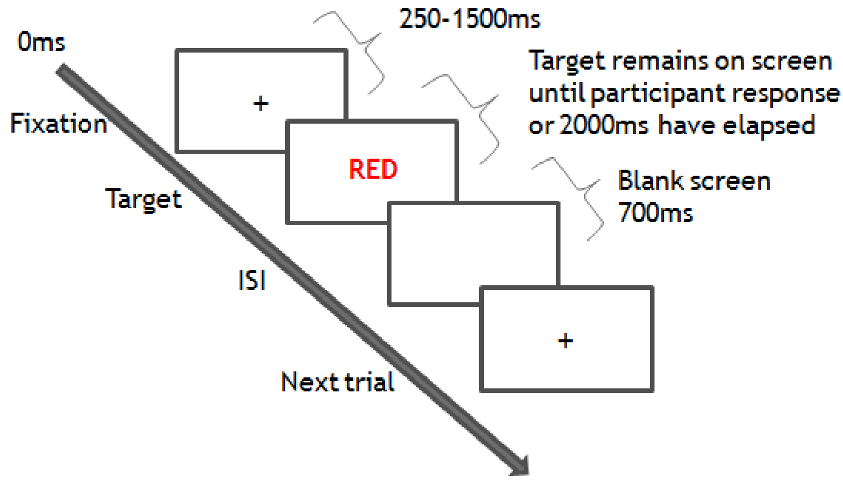

Figure 5.1. ERP Stroop Procedure*.* Each trial begins with a variable-length fixation cross and terminates when participants press a response button. A blank screen is presented for 700ms before the onset of the next trial.

5.3.4 ERP Data Acquisition

To acquire ERP data, before completing the task, participants were capped using the standard ERPLing Lab capping procedure. After cleaning and exfoliating the face and midline of the scalp to minimize impedances caused by sweat and other build-up, each participant's head was measured and fitted with a 64-channel Compumedics Quik-Cap electrode cap, which uses the 10-20 system for electrode placement. Measurements were made (nasion to inion, and ear to ear) to ensure that electrode Cz was centered. Four additional electrodes were placed on the participant's face to capture vertical and horizontal eye movements (electrodes $VEOU^+$ and $VEOL^-$ above and below the left eye, and $HEOR^+$ and $HEOL^-$ on the right and left temples), and two additional electrodes (M1 and M2) were placed on the mastoid processes behind the ears. Each electrode was filled with a saline-based gel to allow for the measurement of electrical activity at the scalp, and adjusted until all impedances were 10kΩ or lower. The cap was connected to a SnyAmps 2 amplifier, and responses to stimuli-locked targets were recorded at 1000Hz using Scan 4.3 software.

5.4 Analysis

ERP data from the single-language English and mixed-language English trials were analysed using EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014) data analysis packages for Matlab. Based on the literature, the frontocentral (Fz and FCz) and centroparietal (Cz, CPz, and Pz) electrodes were selected for analysis of the N200 and N450, respectively. These are shown in Figure 5.2. Electrodes surrounding the ones indicated were also included in an initial exploratory analysis, but because these components are centrally distributed, the final analysis was limited to Fz, FCz, Cz, CPz, and Pz.

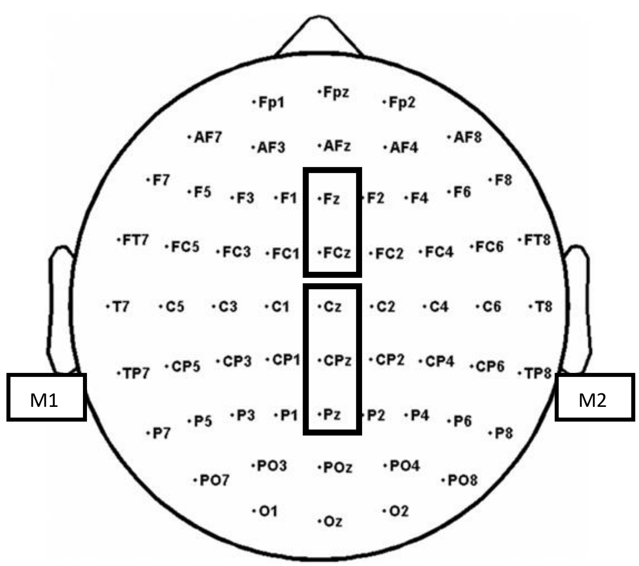

Figure 5.2. Electrodes Included in Analysis. Fz and FCz are used in the N200 analysis, and Cz, CPz, and Pz in the N450 analysis. All electrodes were re-referenced to the average of the mastoid M1 and M2.

During data processing, all electrodes were re-referenced offline from NeuroScan's central reference electrode to the average of the mastoids (M1 and M2) using EEGLAB's re-reference function. The continuous EEG data was segmented into 1000ms epochs, beginning 200ms before the onset of the stimulus to 800ms following the stimulus, and baseline corrected using the pre-stimulus interval. Although late effects (e.g., the SP) were not the focus, a long time window was chosen to explore any possible later components. A Parks-McClelland notch filter at 60Hz was applied to filter out electrical noise. All statistics and figures are for otherwise unfiltered data.

Artefact detection was then performed using ERPLAB's moving window peak-to-peak threshold set at 100µV. Participants with artefacts detected in 50% or more trials were excluded from further analysis (total of 9 participants, 1 Monolingual and 8 Bilinguals). For the remaining 19 participants, artefact-free trials were analysed. For Monolinguals, 88.6% (SD=10.3) of trials were included (English Neutral: M=80.6%, SD=31.2; English Congruent: 81.2%, SD=31.4; English Incongruent: 81.6%, SD=22.6; Mixed English Neutral: M=87.6%, SD=17.8; Mixed English Congruent: 85.8%, SD=14.3; Mixed English Incongruent: 85.8%, SD=18.7), and for Bilinguals, 80.1%, (SD=14.2) of trials were included (English Neutral: M=80.1%, SD=14.2; English Congruent: 56.3%, SD=34.2; English Incongruent: 61.5%, SD=34.4; Mixed English Neutral: M=80.4%, SD=13.9; Mixed English Congruent: 83.6%, SD=16.0; Mixed English Incongruent: 80.8%, SD=16.5). For each participant, average ERPs were calculated for each condition (Neutral, Congruent, and Incongruent), and grand averages were calculated for each participant group. Statistical analyses were conducted based on time windows identified in previous literature, and because filtering can distort data and create artificial peaks (Luck, 2014), all statistical analyses were performed on data that had only been notch filtered to remove electrical noise. All figures are also based on this otherwise unfiltered data. To account for violations of sphericity, Greenhouse-Geisser corrected values are reported.

5.4.1 Overview of Waveforms

In this exploratory study, prior to analysis of individual components of interest, the overall waveforms, collapsed across all participants, at the electrode sites identified in Figure 5.2 were examined visually and using ERPLAB's Viewer. ERPLAB's Viewer Measurement Tool also provided preliminary measurements of amplitude and latency. In the single-language English task, a small negative deflection of approximately -2μV was observed around 100ms. This negative deflection shifted to a positive one of approximately 7μV between 100ms and 150ms, and appears to generally plateau at the central electrode site Cz, while having a positive peak around 200ms at the frontal electrode sites and becoming more negative toward the posterior electrode sites. Another positive deflection is observed starting at approximately 300ms, and increasing in amplitude toward the posterior electrode sites. A similar pattern is observed in the mixed-language English task.

Looking at stimuli in different conditions, regardless of the electrode site, congruent stimuli elicit greater positivity than the neutral and incongruent stimuli. The neutral and incongruent stimuli appear to pattern similarly for the first 250ms. However, the neutral stimuli appear to elicit a greater negativity after approximately 300ms compared to the incongruent stimuli. These waveforms are shown in Figure 5.3, showing the single-language task, and Figure 5.4, showing the mixed-language task.

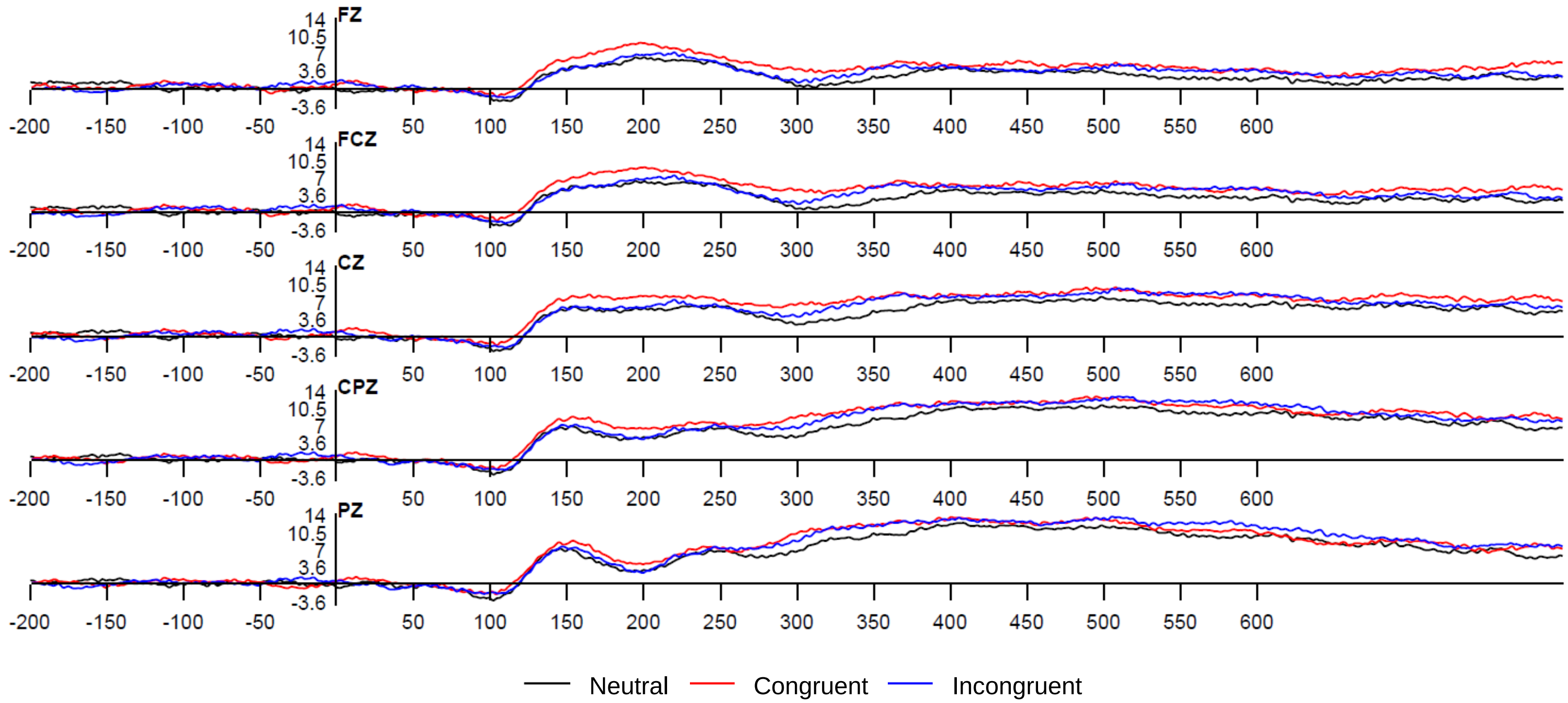

Figure 5.3. Overall Waveforms for the Single-Language English Stroop Task at Electrode Sites of Interest. Waveforms for each congruency are shown, with time in milliseconds (ms) on the x-axis and amplitude in microvolts (µV) on the y-axis and negative plotted down.

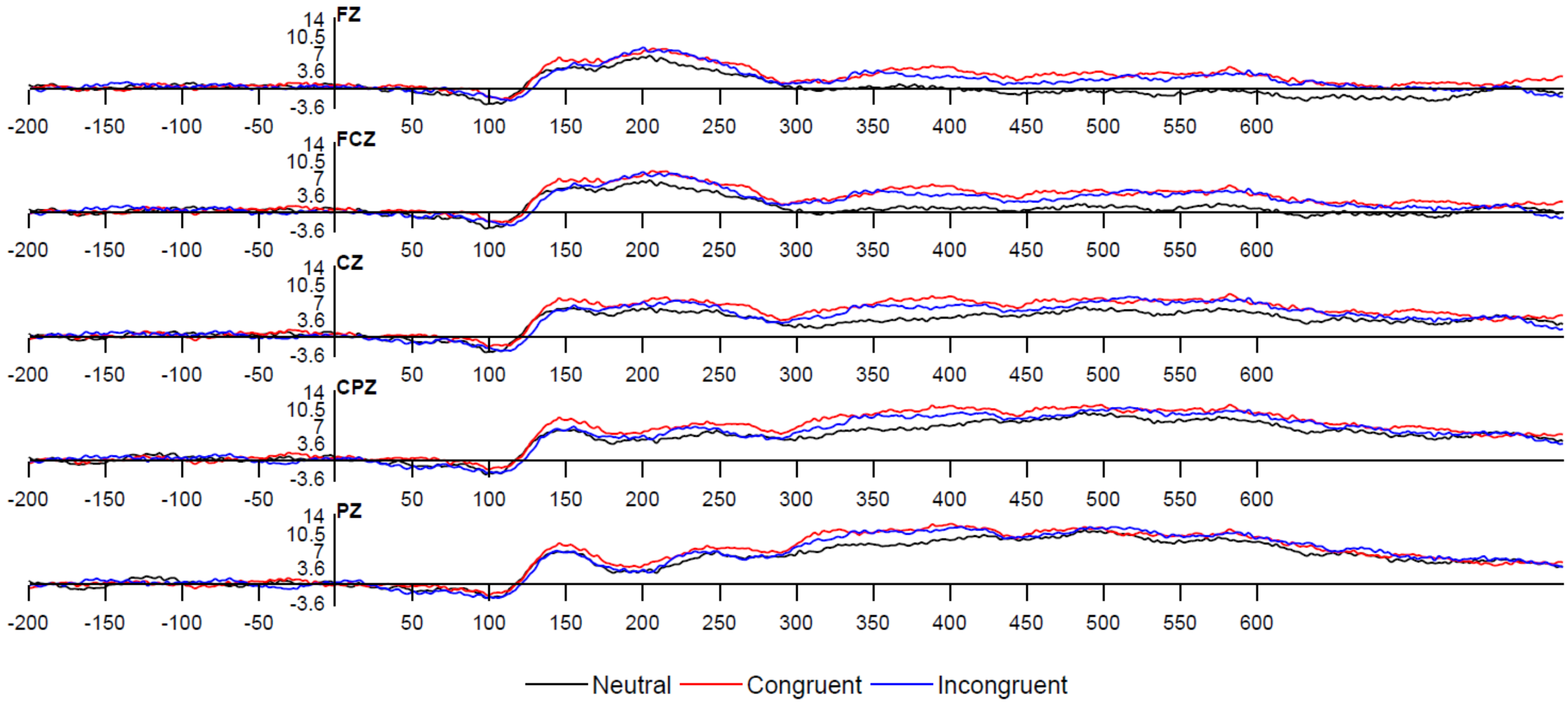

Figure 5.4. Overall Waveforms for the Mixed-Language English Stroop Task at Electrode Sites of Interest. Waveforms for each congruency are shown, with time in milliseconds (ms) on the x-axis and amplitude in microvolts (µV) on the y-axis and negative plotted down.

5.4.2 The N200

Based on previous literature, the frontocentral Fz and FCz electrodes were selected for analysis of the N200. Although the 200-350ms time window has been selected for analysis of this component in previous literature, based on the grand averages shown in Figures 5.3 and 5.4, the current exploratory analysis examined the 150ms-249ms and 250-300ms time windows, looking at the mean amplitude at each electrode site.

In the single-language condition, based on visual inspection of the waveforms in Figure 5.5A, there is a positive deflection that appears to peak at approximately 200ms and a negative deflection at approximately 300ms, with greater negativity for the incongruent compared to congruent stimuli, and for the neutral compared to both incongruent and congruent stimuli. Looking at the Monolingual and Bilingual groups, in panels B and C respectively, the amplitude of the deflection appears greater in both time windows (i.e., more positive in the 150-249ms time window and more negative in the 250-350ms time window) and peaks earlier for the Bilingual group compared to the Monolingual group. In addition, the difference between the congruent and the incongruent and neutral stimuli appear larger for the Bilingual group, particularly at the FCz electrode site.

In the 150-249ms time window, a Congruency (Neutral, Congruent, Incongruent) x Group (Monolingual vs. Bilingual) ANOVA confirms an effect of Congruency ($F(2,34)=7.77$, $p=.002$) at electrode Fz, with significant differences between the neutral and congruent conditions (Mean difference=2.52μV, SE=.588; $p=.002$), and a strong trend between the congruent and incongruent conditions (Mean difference=1.87μV, SE=.713, $p=.053$), but no difference between the neutral and incongruent trials (Mean difference=.64μV, SE=.682; $p=1.00$). Furthermore, there were no interactions between Congruency and Group (F(2,34)=.256, p=.766), and no differences between the two groups (Mean difference=1.21µV, SE=1.58, p=.455).

Similar results were found at the FCz electrode, where there was an effect of Congruency (F(2,34)=6.52, p=0.04), with differences between neutral and congruent stimuli (Mean difference=2.43µV, SE=.735, p=.013) and a strong trend toward differences between the congruent and incongruent stimuli (Mean difference=1.93µV, SE=.736, p=.053), but no differences between the neutral and incongruent stimuli (Mean difference=.59µV, SE=.657, p=1.00). Furthermore, there was no interaction between Congruency and Group (F(2,34)=0.14, p=.868), and no differences between groups (Mean difference=2.10µV, SE=1.75, p=.244).

In the 250-350ms time window, a Congruency (Neutral, Congruent, Incongruent) x Group (Monolingual vs. Bilingual) ANOVA again reveals an effect of Congruency (F(2,34)=5.35, p=.010) at electrode Fz, driven by the significant difference between the neutral and congruent conditions (Mean difference=2.37µV, SE=.806; p=.027), but there was no difference between the neutral and incongruent conditions (Mean difference=.72µV, SE=.707, p=.968). Although there appeared to be differences between the congruent and incongruent conditions (difference=1.65µV, SE=.713), these were not significant (p=.10). Furthermore, there were no interactions between Congruency and Group (F(2,34)=.243, p=.779), and no differences between the two groups (Mean difference=1.50µV, SE=2.12, p=.489).

Similar results were found at the FCz electrode, where there was an effect of Congruency (F(2,34)=6.12, p=0.07), with differences between neutral and congruent stimuli (Mean difference=2.76µV, SE=.902, p=.021) but no differences between the neutral and incongruent stimuli (Mean difference=1.09µV, SE=.714, p=.434) or congruent and incongruent stimuli (Mean difference=1.67μV, SE=.757, p=.125). Furthermore, there was no interaction between Congruency and Monolingual and Bilingual groups (F(2,34)=0.29, p=.731), and no differences between groups (Mean difference=.90μV, SE=2.21, p=.690).

Overall, in both time windows, while there were no significant differences between the Monolingual and Bilingual groups, three noteworthy effects were observed: First, regardless of the time window and electrode site, there were differences between the neutral and congruent stimuli, with neutral stimuli eliciting greater negativity compared to the congruent ones; second, there were no differences between the neutral and incongruent stimuli; third, the differences between the congruent and incongruent stimuli were greater in the earlier 150-249ms time window than the later 250-350ms time window. This can be seen in Figure 5.5.

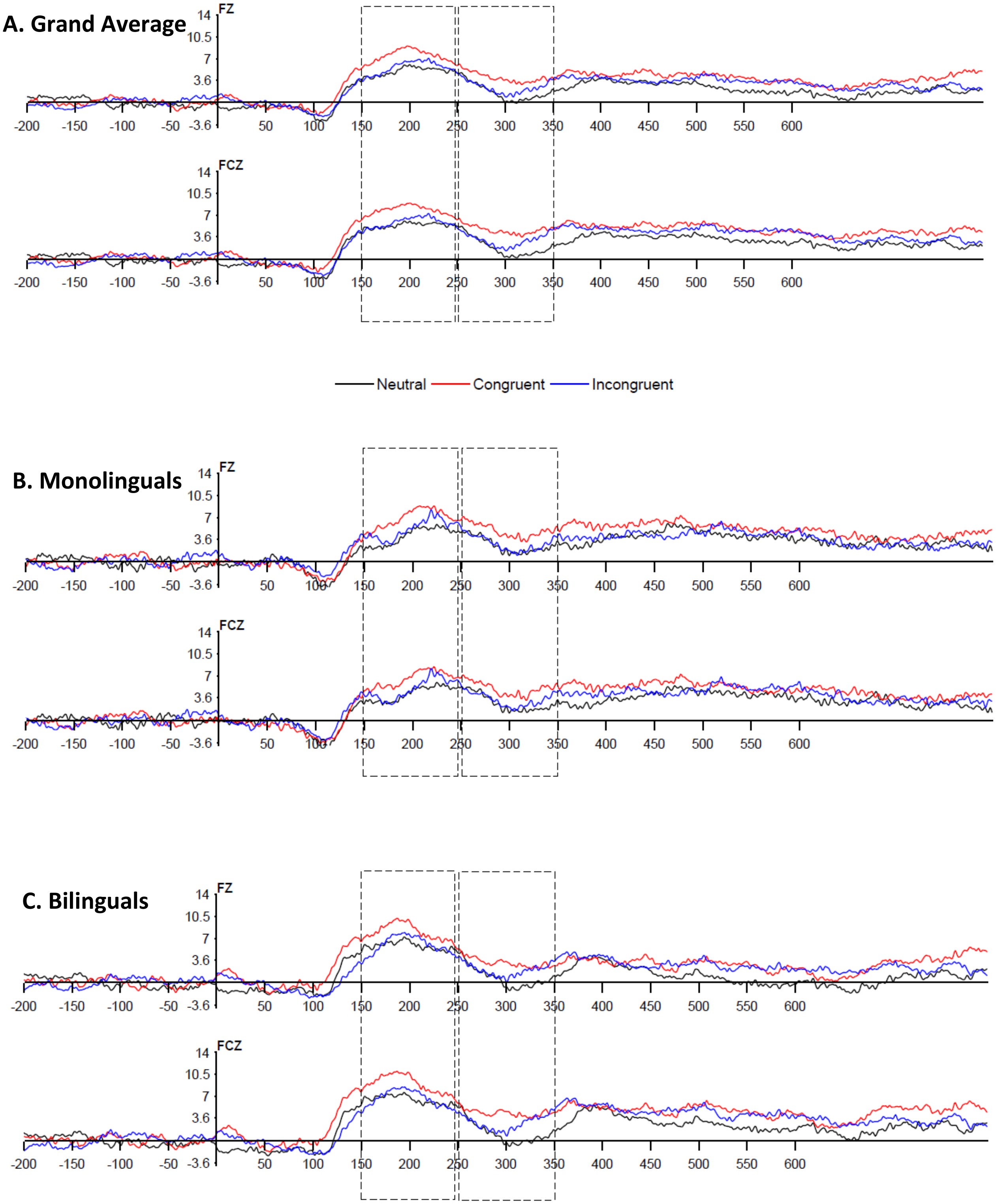

Figure 5.5. N200 in the Single-Language English Stroop Task. Waveforms for each congruency are shown, with time in milliseconds (ms) on the x-axis and amplitude in microvolts (µV) on the y-axis and negative plotted down. The dotted rectangles indicate the two time windows of interest, 150-249ms and 250-350ms. Panel A shows the overall waveform for each congruency, Panel B shows the Monolingual group, and Panel C shows the Bilingual group.

The same analysis was carried out for the English stimuli of the mixed language block. Visual inspection of the waveforms in Figure 5.6A again shows a positive deflection that appears to peak at approximately 200ms and a negative deflection at approximately 300ms, with greater negativity for the neutral compared to both incongruent and congruent stimuli, but no visual differences between the congruent and incongruent stimuli in either time window, and only a small differences between these and the neutral stimuli. Looking at the Monolingual and Bilingual groups, in panels B and C respectively, the amplitude of the deflection appears greater in both time windows (i.e., more positive in the 150-249ms time window and more negative in the 250-350ms time window) and peaks earlier for the Bilingual group compared to the Monolingual group. In addition, at both the Fz and FCz sites, there appears a sharp increase in voltage for the incongruent stimuli just before 200ms for the Bilinguals, but not for the Monolinguals.

In the 150-249ms time window at the Fz electrode site, the lack of difference between stimuli types were confirmed by a Congruency x Group ANOVA, which showed no effect of Congruency ($F(2,34)=2.39$, $p=.110$). There were no interactions between Congruency and group ($F(2,34)=.42$, $p=.655$), nor differences between groups (M=1.61, SE=1.82, $p=.389$). In the same time window at the FCz electrode site, where there was a trend toward Congruency ($F(2,34)=2.84$, $p=.075$), which upon closer examination was driven only by a trend between neutral and congruent trials (M=1.90, SE=.789, $p=.081$), and there were no interactions with group ($F(2,34)=.81$, $p=.449$), nor differences between groups (M=2.38, SE=2.02, $p=.255$).

In the 250-350ms time window at the Fz electrode site, again there was no effect of Congruency ($F(2,34)=2.42$, $p=.115$), and no interactions between Congruency and group ($F(2,34)=.11$, $p=.858$), nor differences between groups (M=1.35, SE=2.47, $p=.594$).

In the same time window at the FCz electrode site, however, where there was an effect of Congruency ($F(2,34)=4.4.9$, $p=.025$), which was driven by significant differences between neutral and congruent trials (M=2.27, SE=.617, $p=.006$) only. There were, however, no interactions with group ($F(2,34)=.45$, $p=.609$), nor differences between groups (M=.862, SE=2.77, $p=.760$).

Overall, in both time windows, while there were no significant differences between the Monolingual and Bilingual groups, and unlike in the single-language condition, there was only a significant effect of Congruency at electrode site FCz, where there were differences between the neutral and congruent trials in the later 250-350ms time window and a trend toward differences in the earlier 150-249ms time window. This can be seen in Figure 5.6.

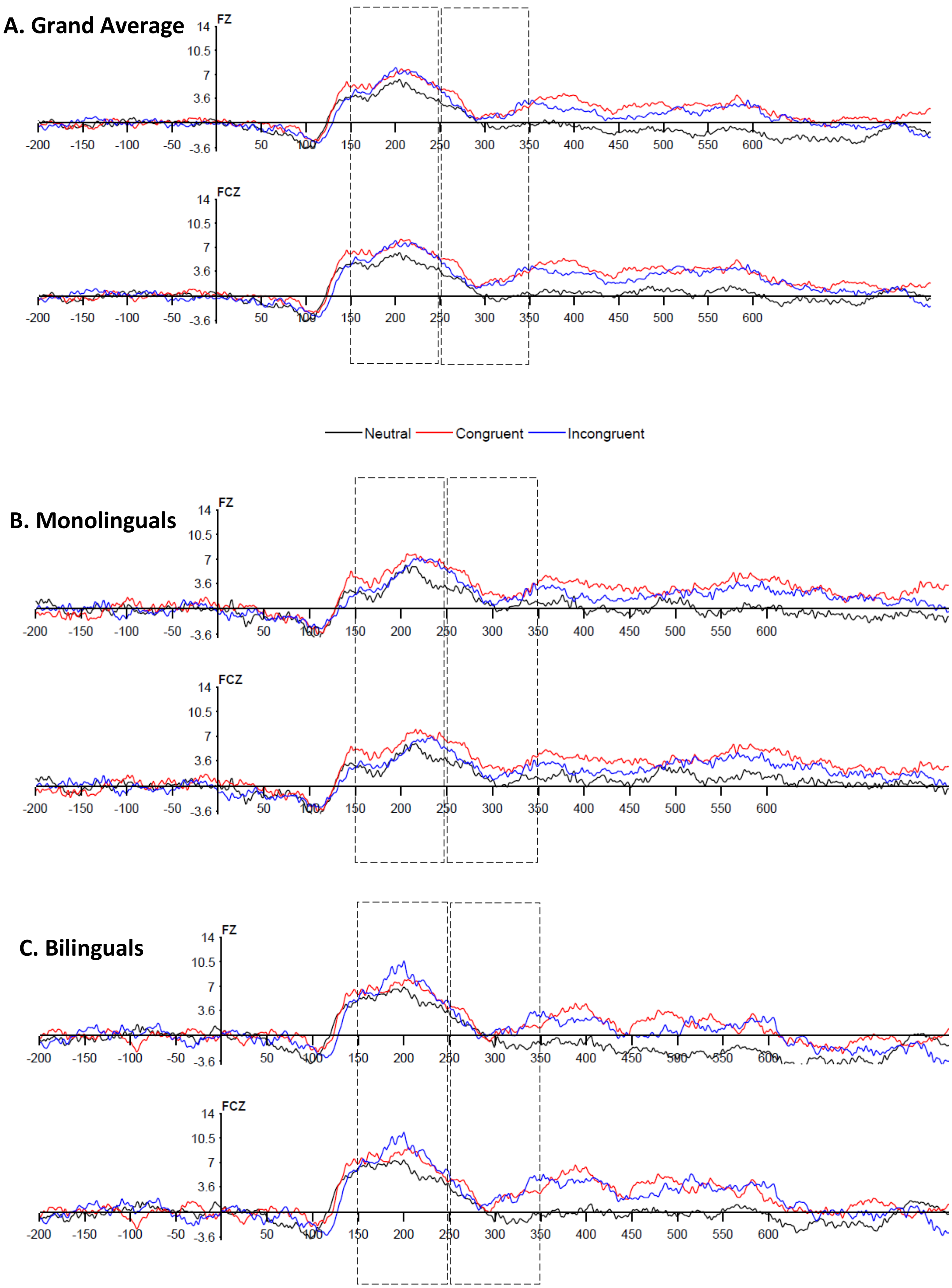

Figure 5.6. N200 in the Mixed-Language English Stroop Task. Waveforms for each congruency are shown, with time in milliseconds (ms) on the x-axis and amplitude in microvolts (µV) on the y-axis and negative plotted down. The dotted rectangles indicate the two time windows of interest, 150-249ms and 250-350ms. Panel A shows the overall waveform for each congruency, Panel B shows the Monolingual group, and Panel C shows the Bilingual group.

Because of differences found between single-language and mixed-language conditions in the behavioural Stroop task in Chapter 4, possible differences for the N200 in the single-language and mixed-language were also explored at Fz and FCz in both time windows. Visual inspection of the waveforms does not indicate any differences between the single-language and mixed-language conditions, and statistical analyses confirm these observations.

A Congruency (Neutral, Congruent, Incongruent) x Condition (Single-language, Mixed-language) x Group (Monolingual, Bilingual) ANOVA analysis was conducted for both time windows. For the 150-249ms time window at electrode site Fz, there was an effect of Congruency ($F(2,34)=8.36$, $p=.001$), but no effect of Condition ($F(1,17)=1.58$, $p=.225$), and neither interactions with group ($F(2,34)=.331$, $p=.717$) nor between Congruency, Condition, and Group ($F(2,34)=.378$, $p=.678$). There were also no differences between the two groups (M=1.41, SE=1.66, $p=.408$). Similarly, at FCz, there was only an effect of Congruency ($F(2,34)=9.11$, $p=.001$), but no effect of Condition ($F(1,17)=4.70$, $p=.336$, or any interactions with Group. There were also no differences between the two groups (M=2.24, SE=1.84, $p=.240$).

For the 250-350ms time window at electrode site Fz, there was an effect of Congruency ($F(2,34)=5.53$, $p=.011$), and a trend towards differences between Conditions ($F(1,17)=4.12$, $p=.058$), with lower amplitude (i.e, greater negativity) for the mixed-language compared to single-language condition (Mean difference=1.16, SE=.569). However, there were no interactions between Congruency, Condition, and Group ($F(2,34)=.041$, $p=.946$), and no differences between the two groups (M=1.42, SE=2.23, $p=.535$). At FCz, there was an effect of Congruency ($F(2,34)=9.29$, $p=.001$), but no effect of Condition ($F(1,17)=2.64$, $p=.123$), or any interactions with Group. There were also no differences between the two groups (M=.876, SE=2.42, p=.721). Because there were no significant differences, only difference waves for the conditions overall are shown in Figure 5.7. Difference waves, calculated as mixed-language subtracted from single-language conditions, show slightly greater amplitudes for the single-language condition, which is seen as a small positivity in the waveform in both time windows. This difference suggests greater attentional resource allocation for the mixed-language condition, and will be further discussed in Section 5.5.

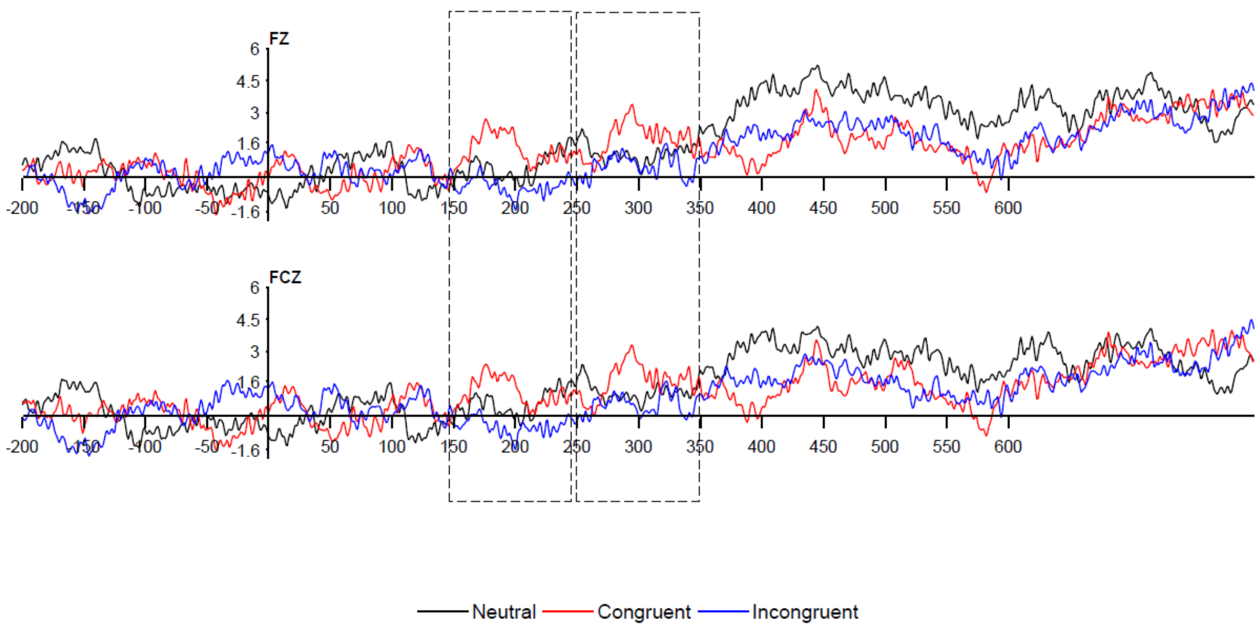

Figure 5.7. N200 Difference Waves for the Single- and Mixed-Language Conditions. Difference waves for each congruency are shown, with time in milliseconds (ms) on the x-axis and amplitude in microvolts (μV) on the y-axis and negative plotted down. The dotted rectangle indicates the time window of interest, 200-350ms.

5.4.3 The N450

Based on previous literature, the 400-500ms time window and the central Cz and centroparietal CPz and Pz electrodes were selected for analysis of the N450, and the mean amplitude was examined at each site. In the single-language condition, visual inspection of the waveforms in Figure 5.6 on the following page suggests slightly reduced amplitude for the neutral relative to congruent and incongruent stimuli, but no differences between congruent and incongruent stimuli, or between Monolingual and Bilingual groups at any of the electrode sites. A Congruency (Neutral, Congruent, Incongruent) ANOVA confirms this observation, finding neither significant main effects nor trends for Congruency, Group, or interactions between the two. The waveforms shown in Figure 5.8 are included for consistency and completeness.

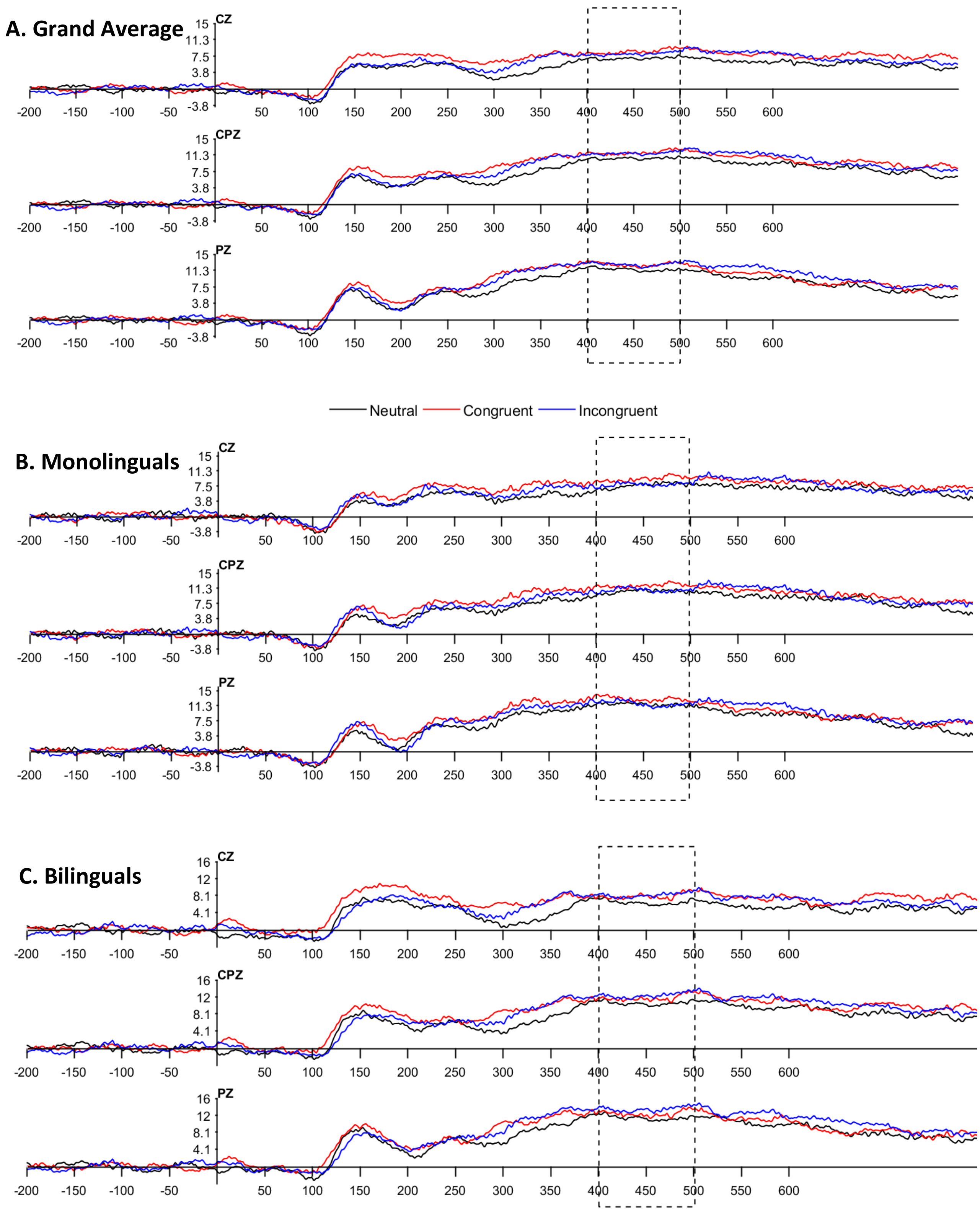

Figure 5.8. N450 in the Single-Language English Stroop Task. Waveforms for each congruency are shown, with time in milliseconds (ms) on the x-axis and amplitude in microvolts (µV) on the y-axis and negative plotted down. The dotted rectangle indicates the time window of interest, 400-500ms Panel A shows the overall waveform for each congruency, Panel B shows the Monolingual group, and Panel C shows the Bilingual group.

In the mixed-language condition, visual inspection of the waveforms suggests overall smaller amplitude for the incongruent and neutral trials relative to the congruent ones, but this is only seen at the Cz electrode. With respect to groups, this difference between congruencies appears larger for the Monolingual group at all sites, but there do not appear to be differences between the different congruencies for Bilinguals.

Statistical analysis confirmed a weak trend of Congruency ($F(2, 34)=2.78$, $p=.088$), showing a 2.34μV (SE=.970) decrease in amplitude for the neutral relative to congruent trials ($p=.067$) at the Cz electrode, but there were no interactions or differences between groups ($p=.923$), or any other trends of significant main effects at any other sites. The waveforms are shown in Figure 5.9 on the following page.

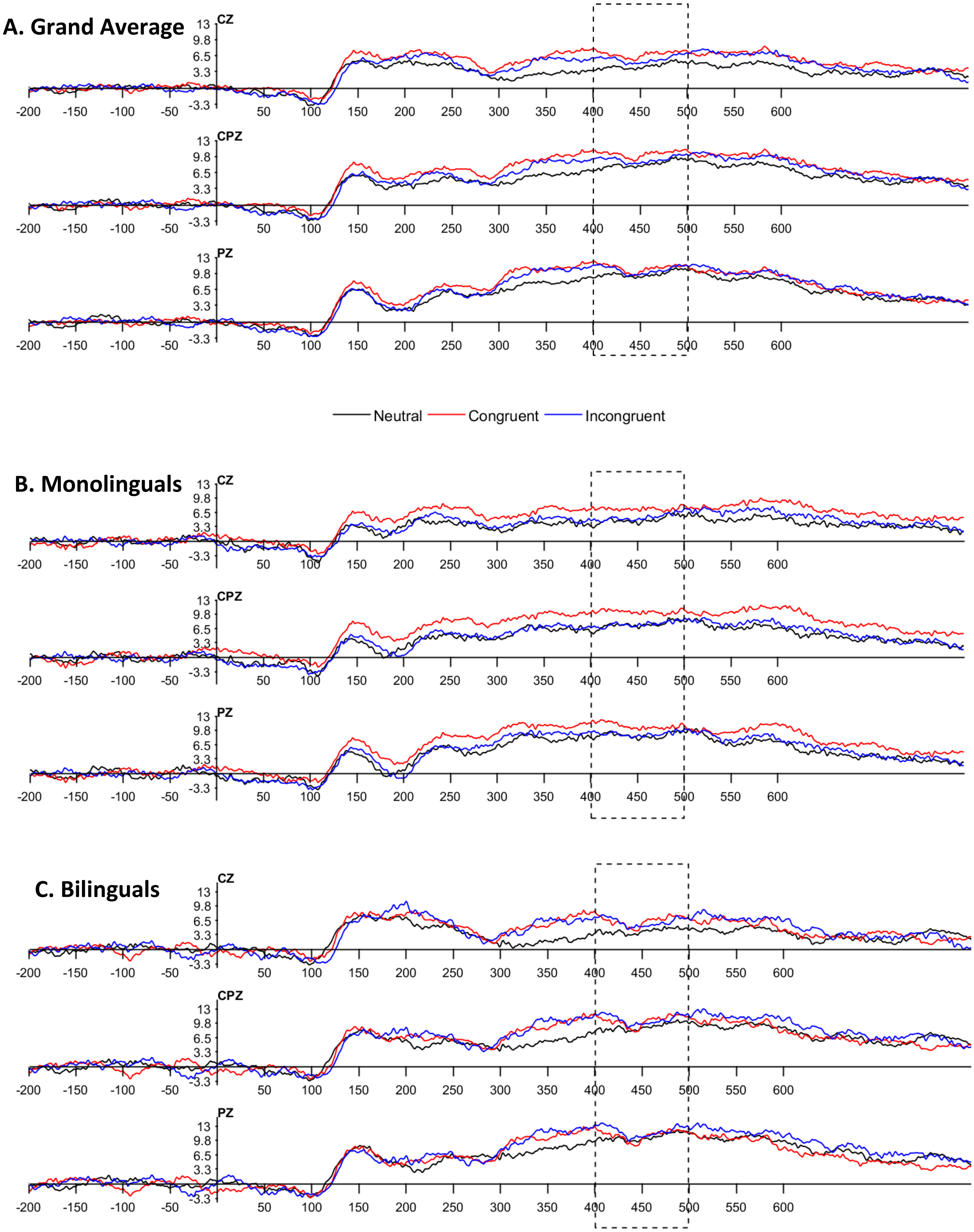

Figure 5.9. N450 in the Mixed-Language English Stroop Task. Waveforms for each congruency are shown, with time in milliseconds (ms) on the x-axis and amplitude in microvolts (µV) on the y-axis and negative plotted down. The dotted rectangle indicates the time window of interest, 400-500ms. Panel A shows the overall waveform for each congruency, Panel B shows the Monolingual group, and Panel C shows the Bilingual group.

Comparing amplitudes between the single-language and mixed-language conditions, no differences between Monolingual and Bilingual groups were found at the Cz, CPz, and Pz sites (*p*=.805, *p*=.719, and *p*=.712, respectively), but differences were found between the two conditions. At Cz, there was an effect of Condition ($F(1,17)=10.63$, $p=.005$), with greater amplitude (i.e., less negativity) for the single- compared to mixed- language condition (7.88µV vs. 5.71µV, mean difference=2.17, SE=.668). The same was found at CPz ($F(1,17)=11.84$, $p=.003$), with a 2.14µV (SE=.662) decrease in amplitude for the mixed- vs. single-language conditions, and at Pz ($F(1,17)=4.56$, $p=.048$), with a 1.99µV (SE=.931) decrease in amplitude for the mixed- vs. single-language conditions. No other effects or interactions were found at the Cz, CPz, and Pz sites. Difference waves, calculated as mixed-language subtracted from single-language conditions, are presented in Figure 5.10. Visually, the larger amplitude for the single-language condition is seen as a positive waveform in the 400-500ms time window. This difference suggests greater conflict in the mixed-language condition, and will be further discussed in Section 5.5.

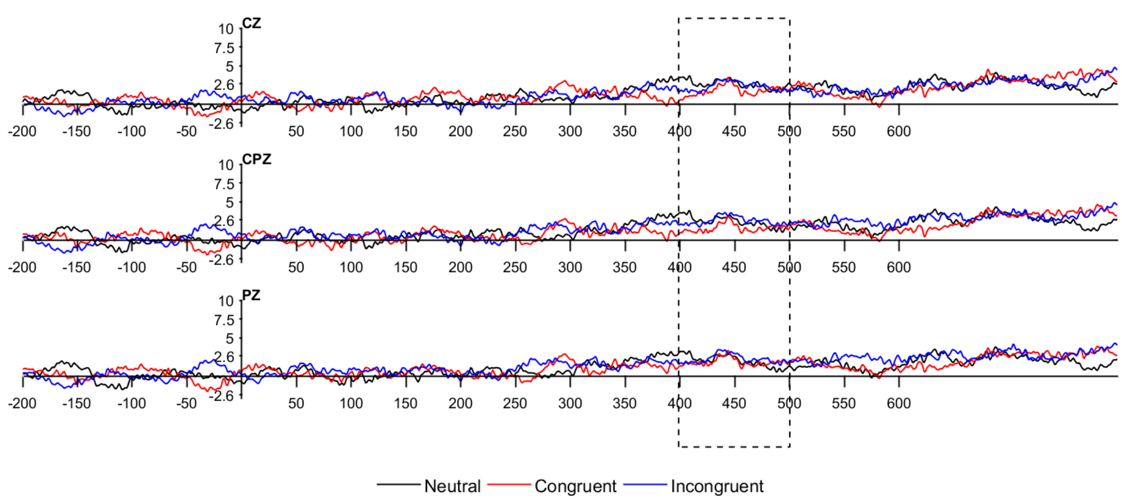

Figure 5.10. N450 Difference Waves for the Single- and Mixed-Language Conditions. Difference waves for each congruency are shown, with time in milliseconds (ms) on the x-axis and amplitude in microvolts (µV) on the y-axis and negative plotted down. The dotted rectangle indicates the time window of interest, 400-500ms.

5.5 Discussion

This chapter presented a pilot study exploring the N200 and N450 in a bilingual Stroop task, and hypothesized that bilinguals would show an advantage in attention allocation and conflict monitoring as shown by decreased amplitudes of the N200 and N450 waves relative to monolinguals. Contrary to predictions, this bilingual advantage hypothesis was not supported in the current study, and there were no significant differences between the groups for either component. However, there were some unexpected patterns in the data, and these will be the focus of this discussion.

Looking at the N200 and N450 components themselves, as expected, an N200 in the form of a negative peak was found, but at approximately 300ms post-stimulus. While this peak is not at 200ms, it is in line with Luck's (2014) discussion of ERP components, in which he concludes that although the N200 effect is seen considerably later in the Stroop task, it likely reflects the same process as its non-linguistic flanker task counterpart. Thus, while unable to make conclusions about the mechanisms underlying cognitive control, the presence of a N200 in the Stroop task does suggest a role of attention, at least in performing this specific task.

The N450 reported in previous studies, however, was not found. This may be due, in part, to the experimental design of this pilot study. To capture any potential late effects, a 700ms ISI was included after each trial, resulting in long delays between trials. Consequently, the slow pace of the task itself may have eliminated much of the conflict in the Stroop task. Although there were no group differences, two interesting observations were made: there was a significant difference in the size of components in the single- vs. mixed-language condition, and there was greater N200 negativity for neutral relative to both congruent and incongruent trials.

In the block where a mix of English and French stimuli appeared, the English stimuli showed larger negative N200 amplitudes compared to English stimuli in a block with English only, and a slight, but similar pattern for the N450. Although no known previous studies have examined the effect of such variation in the Stroop task on the N200 and N450, increases in the amplitude of negative components have been observed when task difficulty is increased (Fedota, McDonald, Roberts, & Parasuraman, 2012; Benikos, Johnstone, & Roodenrys, 2013). Benikos et al. (2013) looked at inhibition in the Go/No-Go task, manipulating the RT deadline (i.e., giving participants shorter or longer time limits to respond to the stimuli) to create different degrees of difficulty in the task. Results showed that in the most difficult condition, when the RT deadline was the shortest, the amplitude of the N2 component was the largest. The authors conclude that the N2 is likely related to conflict, and is positively correlated with task conflict. A similar effect was found for the N1, and this component was also investigated by Fedota et al. (2012), who used a stimulus discrimination task, including an easy and a difficult condition. Fedota et al. (2012) found that the N1 component, which indexes stimulus identification, also showed greater negativity in the more difficult condition.

In the present study, although only the English stimuli were examined, task difficulty was manipulated by presenting the English and French languages separately or together, and as in the aforementioned studies, the difference seen here may reflect the increased level of difficulty for the mixed block, where there is more conflict due to the two languages being mixed. The N200, which indexes attention allocation and conflict monitoring, is therefore larger in this condition compared to the single-language blocks, since greater attentional resources are required to not only manage the conflict from interfering colour-words, but also to do so in two different languages. While there are no differences in N450 among the different congruencies, this component also appears to be sensitive to the task manipulation, having greater negativity in the mixed vs. single-language task. Although little research exists examining the effect of task difficulty on ERP components, these results are in line with the limited literature showing that several components are sensitive to task manipulations. Such findings are particularly relevant for work with young adult participants, as they provide electrophysiological evidence of increased strain on cognitive resources when task challenge is increased. It is under these conditions that Costa et al. (2008), among others, have suggested that bilingual effects for young adults will become most apparent. Although no such differences between groups were found in this work, this may be more due to unintentional design flaws (i.e., the 700ms ISI).

With respect to the neutral trials, these have been rarely investigated in the existing literature. Kousaie and Phillips (2012b) were the first to examine this trial type, and their findings with the Simon task were similar to those reported for the current experiment: neutral trials elicited a larger N200 amplitude compared to congruent and incongruent trials. This is a rather unexpected finding, since the neutral trials are included for control, and are expected to require the least amount of attentional resources, resulting in the smallest N200. Kousaie and Phillips (2012) explain this apparent anomaly in their Simon task as the result of conflict monitoring. As the authors explain, two thirds of trials in their study either contained conflict (the incongruent trials) or had the potential to contain conflict (the congruent trials); thus, in 2/3 of the trials, the brain had to monitor for possible conflict. In 1/3 of the trials, there was no possible conflict, but conflict monitoring continued, causing a greater N200. This may be the case here, too. However, there are two other possible explanations.

In their review of the literature, Kousaie and Phillips (2012) note that some studies have interpreted larger N2 amplitudes as indicating reduced attentional focus on target-relevant features and increased processing of target-irrelevant features. In the current study, neutral trials consisted of high-frequency non-colour terms. Because these words appear to be unrelated to the task, they may have been a distraction from the target-relevant colours, and participants' focus may have shifted from focusing on the colour of the word to processing the word itself. This processing may have resulted in the greater N200 negativity.

However, the larger negativity may also be because neutral trials elicit a different kind of conflict, in the form of a mismatch between the type of stimulus expected and the type of stimulus that appears. In this sense, it may be similar to an oddball paradigm (i.e. 2/3 colour word "standards" and 1/3 neutral "deviants") and the Mismatch Negativity (MMN). However, what is observed in this study may not be an MMN. In describing ERP components, Luck (2014) describes the anterior N2 (essentially, the N200), explaining that this component is also sensitive to mismatch, but only when participants pay attention to the stimuli. He emphasizes that to observe this effect, the task need not necessarily be a deliberate mismatch one (e.g., the oddball paradigm), citing two studies (Luck & Hillyard, 1994; Suwazono, Machado, & Knight, 2000) that found larger anterior N2 effects when task stimuli had novel nontarget stimuli compared to when the task contained relatively similar stimuli. Importantly, this effect was not affected by the proportion of novel trials, was only seen when participants were paying attention, and disappeared when participants were not paying attention to the task (Luck & Hillyard, 1994).

This same type of effect may be seen here, where participants are paying attention to the stimuli in order to respond correctly, but the neutral non-colour terms do not match the rest of the task, and therefore result in a larger N200 negativity. Although the high degree of accuracy among participants and the visual presentation of stimuli makes it likely that this is an anterior N2 that's sensitive to mismatch rather than a MMN, further investigation is needed to confirm. To rule out the MMN, the proportion of neutral trials could be increased to 50% of the task, thus eliminating standards and deviants, and then examined to see whether increased negativity for neutral trials persists.

In the current study, no differences were found between the monolingual and bilingual participants. However, it cannot be concluded that there are no differences based on this data. This pilot study examined a limited number of electrodes from a small group of participants, and as is the case for most experiments in this dissertation, the monolingual group consisted of functional monolinguals who all had taken basic L2 classes in school. This latter issue will be discussed in detail in Chapter 6, but combined with measurements from a small area of electrodes from a small participant sample, it may have resulted in the lack of observed differences between groups in the current study. Furthermore, this may have been compounded by experimental design problems. Most notably, the 700ms ISI following each button press left long gaps between trials, and the slow tempo of the task may have reduced the conflict experienced by participants, resulting in no differences in the amplitude of the N450 among the neutral, congruent, and incongruent trials. This ISI will therefore be removed from the experiment, and this is expected to result in a visible N450 component as described in previous literature. Despite the flaws in the current study, effects of task difficulty were found, as was a greater negativity for neutral trials, and these will be important to consider when moving forward with larger groups of participants. Data collection is planned to resume in Fall 2018.

Chapter 6. General Discussion and Conclusions

6.1 Summary of Results

The current study investigated linguistic and non-linguistic cognitive control in young adult bilinguals, a group whose results have been particularly inconsistent in the literature, and asked two overarching questions: 1) Which, if any, cognitive control abilities are enhanced by bilingualism? and 2) Does the type of bilingual experience modulate observed effects? For the latter question, this work examined the effects of AoI and the linguistic environment. Behavioural ANT and Stroop experiments were conducted in both Canada and Japan, and one additional electrophysiological experiment using the Stroop task was conducted in Canada only. Bilinguals with different AoA's, which were operationalized as the age at which the individual became immersed in their L2, the AoI, were examined. To minimize variability, all participants in each country were from the same region and matched for age and education, and were native speakers of the same first language, English in Canada and Japanese in Japan, and had the same L2, French in Canada and English in Japan. The following subsections summarize the findings of the experiments, relating them to previous work, and discuss limitations that affected the strength of the results and conclusions that could be drawn.

6.1.1 Behavioural Results: The ANT and Stroop Tasks

A complex pattern of results emerged in the behavioural ANT and Stroop tasks, supporting decades of previous studies showing that bilingualism is not a detriment to cognitive ability (e.g., Peal & Lambert, 1962; Pelham & Abrams, 2014). Importantly, it also demonstrated that AoI, task characteristics, and the linguistic environment play a role in linguistic and non-linguistic cognitive control. In the existing literature, the AoI has rarely been explored. In addition, in studies that do examine the effects of age of acquisition, simultaneous and early sequential bilinguals are often collapsed as a single "early" group. The current work not only showed that AoI has an effect on cognitive control, but also showed differences between simultaneous and early bilinguals, suggesting that these two groups should not be collapsed.

This work also showed the importance of considering task characteristics, especially when testing young adults. In the Stroop task especially, it demonstrated that increasing the degree of difficulty of the task could reveal bilingual effects that were not apparent in the simpler version of the task. Cue characteristics in the ANT also contributed to the efficiency of the Executive Control network, with different cues revealing differences between the groups. Furthermore, this work suggested that the linguistic environment, which includes both spoken and written language, of the country in which participants learned their L2 may affect cognitive control abilities in young adult participants.

Looking at non-linguistic cognitive control using the ANT task, the bilingual advantage hypothesis was supported only for earliest bilingual participants (the Simultaneous group, who had acquired two languages from birth), who showed improved Executive Control compared to monolinguals; however, there were no significant differences between the Monolingual and the Early and Late bilingual groups. With respect to the Early and Late bilingual groups, the pattern of results suggests that the Executive Control networks of these individuals also benefit relative to the Monolingual group, although in the current study, these effects do not reach significance.

While advantages for earlier groups are in line with the findings of Luk et al. (2011), such findings are in contrast with Pelham and Abrams (2014), who found advantages for both Early and Late bilinguals. Still, these findings are not entirely incompatible. While the participants in Pelham and Abrams's (2014) study were all proficient in the L2 and the authors noted that proficiency and balanced use confer cognitive advantages, the proficiency varied in the current study, as well as that of Luk et al. (2011). Therefore, it is likely that late bilingualism only improves cognitive control for individuals who become proficient in their L2. Interestingly, despite little proficiency in L2 English, the Late Short-Immersed bilinguals in Japan did show an Alerting advantage in the ANT; although, whether this is truly a result of bilingualism or other factors is unclear due to various possible confounding factors (e.g., motivation, additional English classes at cram schools or conversational schools).

Results for the linguistic Stroop task were less clear with respect to showing a bilingual advantage, but do support improvements for earlier bilinguals. Particularly noteworthy is the finding that the pattern of results also differs for two of the earliest AoI groups: while the Early bilinguals show only facilitation in English and interference in French, Simultaneous bilinguals show only interference in English and facilitation in French. The English-dominant Early bilinguals thus show a strong ability to manage the interference in their native language, while being able to use facilitating cues to speed performance. Although highly skilled in French, they are unable to control the interference from stimuli in their L2. For the linguistically-balanced Simultaneous group[16], their greater experience with French allows them to use facilitating cues to boost performance in French, while their experience of living in an English-dominant Ottawa

[16] Based on self-report, participants were exposed each language 40%+ of the time during their childhood.

environment may result in greater interference from this language. It is important to note that in the case of the Simultaneous bilinguals, these differences cannot be attributed to differences between the first and the second language, as Simultaneous bilinguals acquire both languages at the same time, making both languages the L1.

Such findings demonstrate that although both groups acquire the L2 before the end of the sensitive period, a span of time (usually in childhood) during which an individual is more sensitive to environmental stimuli such as language and when brain plasticity is highest (for more on the sensitive or critical period, see Birdsong, 2018), there may still be differences between them. Pelham and Abrams (2014) suggest that the source of bilingual advantages for early vs. late bilinguals may differ, and previous work in our lab (Sabourin & Vīnerte, 2015) discusses possible differences for simultaneous vs. early sequential bilinguals as well. Specifically, while early sequential bilinguals acquire one language followed by the other, simultaneous bilinguals acquire two languages from birth, with no language preceding the other; thus, rather than having an L1 and an L2, they essentially have two L1s. This may result in only one language system that includes both languages from the beginning, while early sequential bilinguals develop (at least partially) one language system before the next system is developed. Although the result may be that representations are shared in the bilingual mental lexicon for both simultaneous and early bilinguals (Sabourin, Brien & Burkholder, 2014), there are still differences in how the language systems develop. What these differences are, exactly, and how they are linked with cognitive control development remains to be explored, but the possibility does advocate against simultaneous and early sequential bilinguals being grouped together in studies of bilingual cognitive control. In particular, the facilitation effect seen in early bilinguals and the inhibition seen in simultaneous bilinguals in English may cancel each other out if the two groups are combined and contribute to the inconsistency seen in the literature.

It might be argued that there is a monolingual advantage, with functional monolingual English and Japanese groups showing reduced interference in their L2 French and English respectively, but it is unlikely that this reflects improved cognitive control abilities. Although these groups have had some exposure to their L2, their proficiency in the language is low. Thus, it is more likely that the faster RTs reflect a lack of familiarity with the L2 that leads to the monolingual group not processing L2 stimuli as language, but as simple colour items (e.g., the colour blocks in Stroop's original study). Although these groups show some interference, this is considerably smaller than their bilingual counterparts, suggesting that the monolingual group's processing of the L2 is not automatic. Therefore, with respect to AoI, results support the bilingual advantage hypothesis for bilinguals who are immersed earlier in life.

This work also found differences in bilingual performance when task demands were considered. In the ANT task, the interactions between Cue and Congruency that have been found by other studies (e.g., Costa et al., 2008; MacLeod et al., 2010; McConnell & Shore, 2011) were replicated, and different degrees of interference were observed under different cues. The least amount of interference was seen when task demands were arguably the lowest and no cue preceded the target. This condition was also where groups performed similarly, regardless of bilingual status, and differences among groups in each country only became noticeable when the task difficulty was increased by the addition of attentional cues. Similarly, in the Stroop task, there were no differences between groups when languages were presented separately. Such results are consistent with previous findings demonstrating no bilingual effects in the Stroop task (Kousaie & Phillips, 2012). However, group differences did became apparent when the L1 and L2 were mixed, thus increasing the level of difficulty.

Such findings are in line with previous reports (e.g., Costa, 2009; Wu & Thierry, 2013; Friesen et al., 2015), and have been attributed to young adults already being at their cognitive prime. This leaves little room for improvement caused by bilingualism, and may contribute to the lack of observed bilingual effects when looking at performance in simple task conditions (i.e., the single language blocks) such as those included here. As Costa et al. (2009) and Wu and Thierry (2013) show, bilingual effects become more apparent when the task difficulty is increased. Friesen et al. (2015) agree, demonstrating that bilinguals show advantages in a visual search task only in the more challenging version that includes interference from two conflicting information sources, and emphasizing that task difficulty must be considered when working with young adult participants, who have a wealth of cognitive resources available. Furthermore, as discussed by Kroll and Bialystok (2013), it is only when these cognitive resources are under maximal strain that any advantages become apparent for young adults. Taken together, these studies and the current one show the importance of task characteristics on performance by young adult participants.

Finally, although confounded with AoI, differences reflecting the linguistic environment were also found. In the ANT, Canadian and Japanese bilinguals differed in the efficiency of the Executive Control network, with Canadian bilinguals benefitting more from attentional cues. In addition, even the Canadian monolinguals appeared to have better interference suppression compared to Japanese groups. In the Stroop task, different patterns emerged for Canadian participants, but there were no apparent differences between the Japanese groups. Together, these findings may be due to Canadian participants having more exposure to the L2 in their environment than Japanese participants, which may allow them to better detect salient cues, as well as engage and disengage attention, as predicted by the ACH for bilinguals in dual-language environments compared to ones in single-language environments. Thus, these patterns suggests that different environments (i.e., different countries in the current study) may also play a role in the development of cognitive control; however, because environments were identified based on apparent community norms, and not objectively assessed for each participant, this interpretation is made with caution, and should be more rigorously explored in the future, which would allow predictions put forth by Green and Abutalebi's (2013) ACH to be tested more systematically.

Considering writing systems as part of the linguistic environment, this work indirectly examined the effects of same vs. different writing systems in the bilinguals' languages on cognitive control. Such an investigation was conducted by Coderre et al. (2014)[17] using a Stroop and a Simon task, and although different-script bilinguals showed better interference suppression in the Stroop task, they showed overall longer RTs. In their study, it was the same-script bilinguals whose faster RTs and better interference suppression in the Simon task lead Coderre et al. (2014) to conclude that the need to control two languages with similar writing systems leads to improvements in cognitive control. Similarly, in examining bilinguals with alphabetic and logographic writing systems here, while bilinguals with a logographic system

[17] Paap et al. (2014) also looked at script, but did so in a composite database that contained various language pairs, and where other confounds also existed. Since the variation was not controlled, it is difficult to attribute results to script similarity, and the study will therefore not be discussed here.

show less interference in the Stroop task, it is the bilinguals with an alphabetic writing system that show better interference suppression in the domain-general ANT. Thus, the current results are in line with previous work, and as discussed, it may be the nature of logograph processing that accounts for less interference in the Stroop task.

6.1.2 Electrophysiological Results: The Stroop Task

While behavioural data shows the end-point of processing, it is not sensitive to the underlying mechanisms throughout processing. Thus, any possible underlying differences are obscured. While the two groups look similar on the surface, the neural pathways that allow each group to arrive at the response may be vastly different, and even if the cognitive resources used are similar, there may be differences in how and when each of these resources is employed. Indeed, when behavioural measures have shown no between-group differences, an examination of neural processes reveals the opposite (e.g., Kousaie & Phillips, 2012). Therefore, the current work included a pilot study in which monolingual and early bilingual participants were tested using the aforementioned Stroop task (with timing adapted for ERPs of interest).

No group differences emerged, however. This may have been due to the participant sample and the experimental design (see Limitations). Furthermore, not all expected ERP components were observed, which may have been due to the aforementioned task design issues. Despite this, there were two interesting findings. The first was a difference in amplitude for mixed vs. single language trials, with larger N200 negativities in the mixed condition, likely as a result of increased task challenge. The N200, while not confirming the underlying mechanisms of cognitive control, does suggest a role of attention in the task. The second was larger negativities in general for neutral stimuli. These may have stemmed from continued monitoring over the course of the neutral trials, but may also reflect a subconscious awareness of the mismatch between the colour-terms and non-colour-related control items. Despite such limited findings, the current pilot study provided the groundwork for further study of bilingual cognitive control through more sensitive ERP measures.

Although it was not possible to do so in the current work due to the lack of simultaneous bilinguals in the participant sample, the increased sensitivity of ERP measures will be particularly relevant for interpreting the behavioural similarities and differences between simultaneous vs. early sequential bilinguals. The results of the behavioural Stroop task in Chapter 4 revealed similar performance by simultaneous and early sequential bilinguals in the single-language task, while revealing differences in the mixed-language task. It is possible that differences exist even in the simpler single-language task, but that RTs are not sufficiently sensitive to capture them. Therefore, ERP data will be important for the interpretation of the behavioural results, and may provide an insight into both language and cognitive processing in these two groups.

6.1.3 Contributions

This work demonstrates benefits of earlier L2 immersion in an environment where two languages are used frequently. Although the outcomes of the experiments presented were not consistent in showing a bilingual advantage, this itself echoes previous literature showing inconsistency for young adult bilinguals. Importantly, the work here shows that this inconsistency occurs not only across studies, where experimental designs and participant populations vary greatly, but also within a tightly controlled population performing identical tasks. It thus generates questions for ongoing research, and suggests possible directions for future research.

Two important contributions that this dissertation makes to the field of bilingual cognitive control research are the data itself and the findings with respect to the research methodology. Reaction time data from the non-linguistic ANT and the linguistic Stroop task from a Canadian and a Japanese population were collected, along with a variety of detailed participant background information, including biographical information, formative and current language use, objective and subjective proficiency, and the manner of acquisition. This detailed participant information combined with different measures of cognitive control provides a rich dataset that can be explored in many ways and with respect to research questions other than the ones posed here.

A more direct contribution to the field is the demonstration that methodological manipulations can have a significant impact on the results obtained, particularly when looking at young adult participants, as shown by the different results in the single-language and the mixed-language Stroop task. Considering the impact of even subtle design manipulations is particularly important in tasks such as the Stroop, where no one, standard design exists. Although it is likely not possible to standardize many of the paradigms used in cognitive control research, this work suggests a need for more transparency when reporting the methodology used, with particular attention to the design of the task.

6.1.4 Limitations

There were several limitations of the current work that weaken the conclusions that can be drawn; specifically, these come from the participant sample, the confound between AoI and environment, categorical participant grouping, and the statistical approaches used. First and foremost is the participant sample. Monolingual participants were functional monolinguals- individuals who had low objective and subjective proficiency in their L2, but had nonetheless received classroom-based training in the language. As a result, they do have some experience with two languages, and especially with high-frequency words such as those used in the Stroop task. Thus, the comparison made in this work is not between monolinguals and various bilingual groups, but rather, a comparison of groups of bilinguals.

This grouping issue affected the experiments in both Canada and in Japan, and in addition, because of the highly standardized education system in Japan, the Japanese late bilingual group did not differ greatly from the Japanese monolingual group. In fact, written proficiency scores overlapped between the groups (see Appendix E), and it was therefore necessary to use the self-reported percentage of immersion to separate monolinguals from late-immersed bilinguals. Therefore, it is unclear whether an absence of advantages in all experiments indicates no effect of bilingualism, or simply the fact that there was no true monolingual group for comparison. To be able to conclusively state that the findings are or are not the result of bilingual experience, it would be necessary to test an age- and education-matched truly monolingual control group. This, however, proves challenging in an increasingly multilingual world.

The second limitation of this work is the confound between AoI and environment. Because simultaneous and early bilingualism is not common in Japan, these groups were not found for Experiments 2 and 4. Furthermore, the age of 1st exposure is also considerably earlier for Canadian compared to Japanese bilinguals, resulting in differences even among the late-immersed groups. While Canadian late-immersed participants were immersed as part of the late immersion program in elementary school, Japanese late-immersed bilinguals were immersed in university, during adulthood[18], making the Canadian group more a case of middle immersion, rather than late. In essence, the order of AoI from earliest to latest was Simultaneous (Canadians) < Early (Canadians) < Late (Canadians) < Late (Japanese), and for age of 1st exposure to the L2 of the monolingual groups, Monolingual (Canadians) < Monolingual (Japanese). Thus, similar groups were not tested in both countries, and AoI and environment were confounded in this study.

Furthermore, no consistent assessment of the bilingual environment for each participant was included in this study, making it difficult to classify individuals correctly according to the ACH. The initial phase of this work included only Canadian participants and aimed to examine AoI; it evolved to include a Japanese sample and an exploration of the environment. However, when the language switching questionnaire shown in Appendix F was added, the Canadian participants had already been tested, and the questionnaire was therefore completed only by the Japanese groups. As a result, the ACH environment groups mentioned here are based on qualitative observations of the environment of the participants and preliminary findings from

[18] In addition, most of these individuals were enrolled in an English program, and were therefore active L2 learners at the time of testing. This was not examined in this dissertation, but may have had an effect on their performance in both the linguistic and non-linguistic tasks.

Burkholder's (2018) work, which examines French-English bilinguals in the Ottawa-Gatineau area. To make conclusions about the impact of the bilingual environment, it would be necessary to disentangle it from AoI (and AoA in the broader sense), and meticulously match participants based on thorough language background questionnaires, proficiency, and language switching questionnaires, and to rule out any confounding factors.

Another limitation was the categorical grouping of participants. Luk and Bialystok (2013) suggest that this may not accurately reflect the bilingual experience and recommend examining bilinguals on a continuum. The current work, while certainly agreeing that bilingualism is not a categorical variable, has a small sample size which did not allow the data to be examined on a continuum. In order to examine the data on a continuum, a much larger sample size which includes a larger range of AoIs would be required. Additionally, because of the education system in Canada, where immersion programs start in specific grades, the participants here formed natural groups of AoIs (i.e., there was little variation in AoI within groups). The standardized Japanese education system created a similar situation. Thus, points on the spectrum which best represented the linguistic situation of participants were chosen, and participants were grouped categorically. It is fully acknowledged that future studies would benefit from addressing the full continuum.

A final limitation of this study is the statistical approach taken. The participants here were grouped categorically, and their data was analysed using ANOVAs. Although broadly used, ANOVAs necessarily limit analysis to group means of a few categorical variables, making it impossible to account for all the individual variability of a bilingual sample, and of the monolingual one too. For example, it is possible that the results obtained here reflect a mix of

AoI, proficiency, environment, among other individual factors, but ANOVAs are unable to tease these separate variables apart. Baum and Titone (2014) and van Heuven and Coderre (2015) therefore call for reconsideration of current statistical approaches such as ANOVAs, and as Baum and Titone (2014) observe, researchers are indeed moving more towards regression analyses and mixed effects modelling. Although ANOVAs remain a valid and used statistical analysis method in the literature, mixed effects modelling is likely a superior statistical approach as it can account for individual differences among participants, and to tease apart variables such as AoI and proficiency. The data used in this work is therefore currently being reformatted for future analyses using mixed-effects modelling, which are better able to disentangle the effects of several variables (e.g., AoI, proficiency, environment) and include both participant- and item-level analyses. This approach will allow me to determine which factor has the greatest contribution to the effects observed. In addition, it will allow me to include the trial as a factor, which will permit an examination of the timecourse of RTs throughout the tasks. Such a statistical approach will likely allow me to answer some of the questions generated by the current work.

6.2 Taken Together: A Complicated Picture of Bilingual Cognitive Control

Although this work shows some advantages of bilingualism, these patterns are complex and inconsistent, agreeing with Hilchey and Klein's (2011) assessment of young adult bilinguals showing the least noticeable effects of bilingual experience. It therefore does not appear to support the GCA hypothesis, which predicts that the impact of bilingualism will be holistic in nature and that bilinguals will outperform monolinguals on a variety of tasks. However, this work does not refute the hypothesis either, as results are in line with Valian's (2015) observation that when found, bilingual effects tend to be positive. In no condition were monolinguals at a true advantage over bilinguals. Simultaneous bilinguals in particular appeared to show the greatest effects in both the ANT and the Stroop task, which is in line with findings showing benefits for proficient and balanced bilinguals (Zied et al., 2004; Yow & Li, 2015) who have acquired both languages early in life (e.g.,Taoet al., 2011), and use their L2 frequently (De Leeuw & Bogulski, 2016).

Interestingly, not only frequent use of the L2, but also the type of use, may be important. Although Japanese bilinguals in this study do use English in their schoolwork, this is largely restricted to written language, and rarely spoken. The lack of effects seen for this bilingual group may in a sense be compatible with Emmorey, Luk, Pyers, and Bialystok's (2008) conclusions that unimodal bilinguals (ones who verbally speak both languages) benefit most due to their need to control interference from two spoken languages, but bimodal bilinguals (who speak one language and sign the other) and monolinguals do not differ. Japanese bilinguals may present a different case of bimodalism: one where one language is spoken and the other is written, and the requisite cognitive control processes for managing interference when producing language are therefore not trained. But this is, at this point, only conjecture.

Returning to balanced, proficient, early AoA bilinguals, the advantage for the Simultaneous group is also compatible with Stocco and Prat's (2014) predictions of the conditional routing model: Flexible linguistic rule application results in a better ability to adapt behaviour to novel stimuli, enhances selection abilities, improves overriding habitual responses (i.e., inhibition), shifting between task sets, and maintaining top-down goals despite distractors.

Although the authors do not specify the type of bilingual that engages in flexible linguistic rule application, Simultaneous bilinguals appear to fit the description, since they regularly use both of their languages, often even code-switching between the two. Because conditional routing requires one set of information to be prioritized over another, and this is what is suggested to lead to benefits, the model is also compatible with Green and Abutalebi's (2013) dual-language environment, where strong goal maintenance and interference suppression are particularly important, as are task engagement and task disengagement processes and conflict monitoring and selective response inhibition, to keep two languages distinct in a single environment.

Although, because of their frequent code-switching, Simultaneous bilinguals do not seem to fit into a dual-language category at first glance, it is likely that the Ottawa environment constrains their switches. Not everyone in the city or at the university is equally fluent in both English and French, and Simultaneous bilinguals are therefore required to prioritize one language over another, in the same environment, when speaking with different people. Despite being fluent code-switchers, they cannot actually switch freely in their environment. Thus, these balanced, highly-proficient bilinguals may receive additional benefits from their switch-constraining environment. However, these neurophysiological theories are still quite new, and although their claims (and compatibility) remain largely untested, the current results suggest interesting possibilities.

Looking at the experiments together, increasing the task difficulty in the behavioural Stroop experiments lead to more observable effects for the young adults tested here. This was likely due to the greater strain placed on a cognitive system that is functioning most efficiently at the time of testing, and this greater strain in the more challenging condition is confirmed by increased negativity of ERP components. Such findings are particularly relevant for work with young adults, who show the greatest inconsistency in cognitive control advantages. Furthermore, the interaction between condition and cue in the ANT task and the presence the presence of the N200 ERP component provide some evidence that attentional mechanisms play a large role in bilingual cognitive control (e.g., Bialystok et al., 2017). Thus, to see fine-grained differences between monolingual and bilingual groups, a multi-task and multi-method approach involving both behavioural and neurophysiological methods may be required. As it stands, the nature of the bilingual cognitive advantage, the exact control processes involved and affected, and the role of the bilingual linguistic experience are still debated, and thus, remain an open and interesting question in research.

6.3 Implications for Cognitive Control Research and L2 Education

The findings of the present series of studies have implications for both cognitive control research and for L2 education. Implications for research have been discussed throughout, and the most notable are the effect of task manipulation, particularly in the Stroop task. While “the Stroop task” is often used generally to describe a task in which there is interference between the colour term written and the colour of the font, there is no one, standard design in this task. This work showed that simple manipulations such as the difficulty of the task or the language pairs used have considerable consequences for performance in the task. Thus, Miyake and Friedman’s (2012) discussion of unity and diversity among tasks could also be applied to the Stroop task alone. Ideally, a single version of the Stroop task could be designed and implemented in all studies, but given the variety of research questions and participant samples, this is not feasible. Thus, awareness of the effect of various manipulations and their possible consequences for cognitive control outcomes is encouraged.

The findings of this work also have implications for L2 education, both in Canada and in Japan. Most notably, it offers support from a psycholinguistic perspective for teaching students a foreign language at an early age. This is already common practice in Canada, and particularly in Ontario, where Core French is mandatory from grade 4 to grade 8, but many schools begin offering French classes as early as kindergarten. Students also have the option of Extended French Programs, where they spend 25% of the day immersed in French in elementary school, or Early Immersion, where 50% of the day consists of instruction in French (Ontario Ministry of Education, 2018).

However, as previously discussed, foreign language education is quite different in Japan. As of 2008, the Ministry of Education, Culture, Sports, Science, and Technology (MEXT; the government body responsible for education) introduced 1 English class a week for 5th and 6th grade students, or approximately 35 English classes per school. This limited, late English exposure, as Ikegashira, Matsumoto, and Morita (2009) explain, has lead to low proficiency and poor communication abilities in the L2. In addition, the results of Experiment 4 also show that the minimal English in the environment leads to students not reading English automatically. In response to the low English proficiency, MEXT will introduce English as a subject from the 3rd grade starting in 2020. Despite these findings and upcoming changes, one concern that I commonly heard during my three years working for a board of education in Japan and later as a visiting researcher was that teaching an L2 at an early age will lead to incomplete acquisition of the L1 and mental confusion for the child- indeed, some of the very same concerns that were raised before Peal and Lambert's (1962) study (Hakuta & Diaz, 1985). The results of the current work support research conducted in Europe (e.g., de Bot, 2014), showing that early L2 acquisition has no negative consequences for cognition. In fact, as seen with the Canadian participants, not only do such early French programs improve L2 proficiency, but they can also provide some cognitive benefits. The current work therefore helps to dispel the myth that bilinguals (despite slowed lexical retrieval as shown by studies such as Pelham & Abrams, 2014), are at a cognitive disadvantage due to their two languages.

6.4 Considering the Big Picture

The present work follows the apparent trend in the literature, reporting some advantages for young adult bilinguals, but not finding them consistently or across multiple tasks. Because robust effects have been found for children and older adults, findings for young adults cannot be simply dismissed, and should be interpreted in light of the wider research field. Interpretations of this inconsistency have ranged from considering the bilingual advantage hypothesis refuted and contentious calls to end investigation altogether to more cautious acknowledgments of issues in the field and productive discussions of how to move forward. As the former position does little to explain why the inconsistency exists, the focus of this discussion will be the latter end of the spectrum.

As previously mentioned, publication biases have been found in bilingual cognitive control literature (de Bruin et al., 2014), and this has likely contributed to the significance of early positive findings being inflated. However, such publication biases exist in many fields (indeed, a quick search of the term "publication bias" turns up articles from the field of education, policy, dentistry, and clinical neuroscience, e.g., Joober, Schmitz, Annable, & Boksa, 2012), and as de Bruin and Della Sala (2015) note, the pattern of strong initial findings followed by "the decline effect" is common, and does not necessarily mean that the phenomenon investigated is not real. Instead, they recommend careful evaluation of the literature over time, and publication of all results.

One method that allows for this type of careful evaluation is meta-analyses[19]. A recent excellent meta-analysis by Lehtonen, Soveri, Laine, Järvenpää, de Bruin, and Antfolk (2018) examined 152 studies, using various factors (e.g., AoA) that have been investigated as moderators. Their results, although initially showing slight bilingual advantages, did not show any differences between monolinguals and bilinguals when the data were corrected for publication bias. However, because of the large scale of the study, it included a wide variety of linguistic and non-linguistic tasks, which, as has been seen in the current work too, do not always correlate (see Miyake and Friedman's, 2012, discussion of task unity and diversity). Thus, with combining many uncorrelated tasks, there is a chance of obscuring any bilingual effects, and it may be interesting to consider each task individually in such work. Still, although they do not fully resolve the bilingual cognitive control debate, meta-analyses such as Lehtonen et al.'s (2018) are highly valuable, since they give an excellent empirical overview of the field.

With respect to the lack of correlation between tasks, some have taken it as evidence against bilingual advantages; although, it is possible that there is no correlation between tasks, even ones that supposedly measure the same component, because the task context taps different cognitive control and non-control processes. As Kroll and Bialystok (2013) point out,

[19] It must be noted that, because they source existing data, even meta-analyses are not immune to the publication bias. However, some do include unpublished data, and there are statistical methods to account for biases.

attempting to break complex tasks down into simple components only may be counterproductive because there is no one-to-one mapping between tasks and bilingual cognitive processes. Green (2013) also questions the logic of expecting simple correlations between the complex tasks used in cognitive control studies. These researchers suggest that rather, it may be more beneficial to take a general view, as bilingual effects have been seen at a more holistic level. This, however, comes with its own set of challenges.

There still remain many challenges for researchers investigating bilingual cognitive control. Despite not finding any significant effects of bilingualism in their meta-analysis, the authors, rather than dismissing the possibility of bilingual effects, use it as an opportunity to discuss current issues and future directions in the field, including improving participant grouping, research design (Laine & Lehtonen, 2018). These two issues have often been mentioned in the literature and in conferences (e.g., the 2013 International Workshop on Bilingualism and Cognitive Control identified participant grouping and task design as two of the big issues in the field). In addition, the need to consider individual variation among both monolingual and bilingual participants has also been identified as a necessity, and has been noted in both psychological and neurophysiological research (e.g., Baum & Titone, 2014; MacFarland, 2017).

Bilinguals are often examined based on group characteristics such as AoA, proficiency, or balance, but this does not account for the considerable variation and individual differences within each group of bilinguals, and even among monolinguals. Even in the present study, where bilinguals were classified according to AoI, these were not the only differences among them. Some participants had learned other languages in school (although none had been immersed in these languages or reported anything other than “very low” proficiency), some had taken additional classes in their L2, some were proficient video game players (a factor that has also been linked to improved cognitive control; see Valian, 2015), and some were actively in the process of learning the L2. All of these factors contribute to the overall individual experiences, and no two participants are identical. Thus, even if considering bilingualism on a holistic level, one must still acknowledge the variety of bilingual (and monolingual) experiences, as well as individual differences in processing.

Laine and Lehtonen (2018) discuss the lack of a "well-specified, dynamic learning model of the putative changes in cognitive control following L2 exposure" (p. 4) as one of the current limitations in research, and suggest that moving forward, there should be more focus on testing such a theory. The present work agrees with the increasing view that one way to go about establishing and testing a concrete theory would be to examine bilingual cognitive control for a neuropsychological perspective. This would give the field concrete neruobiologically-based theories such as Green and Abutalebi's (2013) ACH and Stocco et al.'s (2014) conditional routing model as a foundation for empirical work. The former identifies eight mechanisms that may be altered by bilingualism, specifying what situations would alter them and how, and providing clear, testable predictions for both behavioural and neuroimaging work. The latter also outlines possible mechanisms and makes testable predictions, with testing already begun by the Stocco research group. However, both would benefit from further testing by other investigators, which would, in turn, provide supporting or refuting evidence for these theories, thereby also shedding light on the currently-debated mechanisms by which cognitive control may be improved in bilinguals. In addition, a neuropsychological perspective may help to reconcile the different behavioural findings and to examine individual. And whether looking at groups, at a continuum, or at individuals, Green (2013) recommends making use of variety, not throwing it away.

Finally, with respect to the bilingual advantage hypothesis and the current debate, rather than just debating the existence of advantages, it may be worthwhile to also consider the differences between monolinguals and bilinguals, not only behaviourally, but also in terms of brain organization. As Berroir et al.'s (2017) work showed, functional connectivitiy in a single region was increased for bilinguals, while, multiple regions were recruited to carry out the same task by monolinguals, demonstrating that bilinguals required less resources to complete the task. The authors also concluded that bilinguals allocate fewer resources more strategically, demonstrating different bilingual brain organization and efficiency. In addition, such neurophysiological examinations may reveal differences in neuroplasticity (i.e., the brain's ability to adapt and form new connections). In his talk, Green (2013) particularly discussed neuroplasticity from trial to trial, showing that the brain is able to adapt to a task over the course of a single experiment. How bilingualism affects this is a fascinating topic, but it is beyond the scope of the current work. Nevertheless, it is worthwhile considering the contributions of bilingualism to keeping the brain flexible throughout life (see Baum and Titone, 2014 for discussion). While not everyone may agree that increased efficiency in the absence of behavioural effects shows an advantage, it *is* a difference between monolinguals and bilinguals, and one which may demonstrate greater neural flexibility in the latter group, which is itself a considerable benefit.

6.5 Future Directions

Continuing the line of inquiry started in this work, in addition to addressing the aforementioned limitations, future research could investigate the role of language switching on attention and interference control, systematically explore different environments with the same language pairs, and most importantly, collaborate with multiple fields. With respect to language switching, although examinations of language switching are increasing, these largely focus on switch costs, with one notable exception being Verreyt et al.'s (2016) excellent study of different cognitive control abilities. Such studies, combined with a careful and methodical assessment of the linguistic environment would not only inform the bilingual cognitive control debate, but also test Green and Abutalebi's (2013) ACH model, which remains largely theoretical.

In addition, it would be interesting to extend the research here to include other language pairs in other linguistic environments. Language switching practices and cultural norms vary among countries, and even within countries (e.g., for social and political reasons, acceptance or stigmatization of switching varies from province to province in Canada), and this creates variations of the different linguistic environments proposed by the Adaptive Control Hypothesis, but such regional practices are underexplored. In particular, one possible avenue would be to investigate how the same language pairs and associated cognitive control processes develop in different environments (e.g., Japanese-English bilingualism in Japan vs. Eastern Canada vs. Western Canada), eventually extending this to look at lesser-explored language pairs such as Japanese-Russian (a pair which would also permit an examination of logographic-Cyrillic writing systems). Including relatively understudied pairs would allow the obtained result to be generalized beyond just the frequently-studied European languages.

Finally, regardless of the specific research question and factors explored, future studies would greatly benefit from more collaboration among fields. Currently, bilingualism is investigated by the various subfields of linguistics, psychology, and sociology, but communication among them appears limited. The question of bilingual benefits is a broad and multifaceted one, and determining when, where, and why bilingualism makes a difference may require more large-scale investigations from multiple perspectives.

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The Bilingual Mental Lexicon: The Role of Age of Acquisition and Proficiency Measures of Cognitive Control

Researcher
Laura Sabourin, Assistant Professor
Department of Linguistics, University of Ottawa
Office: 70 Laurier Ave. E. Room 439, Ottawa, ON K1N 6N5

Invitation to participate: I am invited to participate in a study conducted by Laura Sabourin, Assistant Professor in the Department of Linguistics.

Purpose of the study: The purpose of the study is to investigate cognitive control in monolingual and bilingual participants. The study will look at the extent to which I am able to ignore information that is provided but is not necessary to conduct the task at hand.

Participation: The experiment will be conducted in one session. During this session I will perform two tasks. In the first task I will judge the colour that presented words are written it while in the second task I will determine the direction of a target arrow. I understand that I will be asked to respond as accurately and as quickly as possible.

Risks: There are no real risks associated with this study.

Confidentiality and anonymity: The information I will provide will remain strictly confidential. Anonymity will be ensured through the use of codes instead of names. My name or any information that could identify me will not be released to anyone or in any publication. The data will be used only for the above mentioned study.

Conservation of data: The data collected will be conserved for a period of at least 5 years past the date at which the study is published. The data and language questionnaires will be kept in a secure place in the researcher's lab in the Department of Linguistics at the U. of Ottawa. Only the researcher and research assistants will have access to the data. In addition to being used for the present study, there is a possibility that the data collected will be used for future research.

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Voluntary participation: My participation is voluntary and I have the right to decide not to participate or to withdraw from this study at any time without negative consequences. If I decide to withdraw from the study, all information related to me will be erased and completely removed from the study.

Acceptance: I, _________________________, agree to participate in this study conducted by Laura Sabourin.

If you have questions concerning the study, please contact Laura Sabourin. If you have any question regarding the ethical conduct of this study, you may contact the Protocol Officer for Ethics in Research, U. of Ottawa, Tabaret Hall, 550 Cumberland Street, Room 154, (613) 562-5387 or ethics@uottawa.ca.
Please keep a copy for your records. Thank you for your time and consideration.

____ _______________

Signature (participant) Date

☐ As was explained to me, I will receive 1 point credit for participation.

____ _______________

Signature (researcher) Date

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研究プロジェクト：バイリンガルの言語習得と認識：アルファベットと漢字両方の知識がある人の認知能力

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研究招待: 私はオタワ大学の言語学部の大学院生Santa Vinerte と教授Laura Sabourinにバイリンガル実験に参加する招待を受けています。

研究の目的: この実験の目的はバイリンガル参加者の認知能力を調べることです。実験では、その実験自体に関係のない情報を見たときに、どの程度、その情報を無視できるか調べます。また、その結果をつかって、言語習得と認識の関係を調べます。

タスク: この実験は約1時間かかります。その間に、私は三つのタスクを行います。最初に、英語と日本語の言葉をスクリーンで見て、フォントの色を指します。次に、矢印の方向を指します。最後に、スクリーンに見られる文字は正しい日本語の言葉かどうかを決めます。その他、言語背景などのアンケートに答えます。

リスク: この実験はリスクがありません。

秘密保持と匿名契約：今回提供する個人情報はこの研究のみに用いられ、氏名等いかなる情報は外に漏れることはありません。

データ保存: 集められた情報全ては5年間安全な場所に保管した後、廃棄されます。

自主的な参加: この研究へは自主的に参加します。いつやめてもいい権利があります。

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同意: 私, ____________________________, はこの研究プロジェクトの内容、目的、タスク等を理解した上で、この研究に参加することに同意します。この参加は自主的であり、いつ辞退してもいいことも理解しています。

もし、質問等あれば、この研究の監督者である教授Laura Sabourin, (613) 562-5800 ext. 1763, (Laura.Sabourin@uottawa.ca)に、連絡することを承知しています。また、倫理的な問題が生じた場合には、オタワ大学の倫理部に問い合わせることができることも承知しています。University of Ottawa, Tabaret Hall, 550 Cumberland Street, Room 154, (613) 562-5387, ethics@uottawa.ca.

参加者

サイン: ____________________ 日付け:____________________

研究者

サイン: ____________________日付け:____________________

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Examining The Bilingual Mental Lexicon Through Measures of Cognitive Control

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Santa Vīnerte, PhD Student
Department of Linguistics, University of Ottawa
Office: 70 Laurier Ave. E. Room 413, Ottawa, ON K1N 6N5

Invitation to participate: I am invited to participate in a study conducted by Laura Sabourin, Assistant Professor in the Department of Linguistics, and Santa Vīnerte, PhD student under Dr. Sabourin's supervision.

Purpose of the study: The purpose of the study is to investigate cognitive control in monolingual and bilingual participants, and to investigate the underlying neural processes of cognitive control. The study will look at the extent to which my brain is able to ignore information that is provided but is not necessary to conduct the task at hand.

Participation: The experiment will be conducted in one session which will last approximately 2 hours 15 minutes. During this session I will perform two tasks. In the first task I will judge the colour that presented words are written in, while in the second task I will determine the direction of a target arrow. I understand that I will be asked to respond as accurately and as quickly as possible. While I complete the tasks, electrophysiological measurements of my brainwave activity will be measured.
In order to record my brain waves, I will be asked to wear an elastic cap with small electrodes attached to it. The cap fits tightly, but not uncomfortably, on my head. Additional electrodes will be placed around my eyes and behind my ears. These will be attached using medical adhesive tape.

☐ As was explained to me at the beginning of the semester, my participation in this study will grant me 2 points in my class even if I choose to withdraw from the study.

Risks: There are no real risks associated with this study.

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Confidentiality and anonymity: The information I will provide will remain strictly confidential. Anonymity will be ensured through the use of codes instead of names. My name or any information that could identify me will not be released to anyone or in any publication. The data will be used only for the above mentioned study.

Conservation of data: The data collected will be conserved for a period of at least 10 years past the date at which the study is published. The data and language questionnaires will be kept in a secure place in the researcher's lab in the Department of Linguistics at the U. of Ottawa. Only the researcher and research assistant will have access to the data. In addition to being used for the present study, there is a possibility that the data collected will be used for future research.

Voluntary participation: My participation is voluntary and I have the right to decide not to participate or to withdraw from this study at any time without negative consequences. If I decide to withdraw from the study, all information related to me will be erased and completely removed from the study.

Acceptance: I, ________________________, agree to participate in this study conducted by Laura Sabourin and Santa Vīnerte.

If you have questions concerning the study, please contact Laura Sabourin. If you have any question regarding the ethical conduct of this study, you may contact the Protocol Officer for Ethics in Research, U. of Ottawa, Tabaret Hall, 550 Cumberland Street, Room 154, (613) 562-5387 or ethics@uottawa.ca.
Please keep a copy for your records. Thank you for your time and consideration.

____ _______________
Signature (participant) Date

____ _______________
Signature (researcher) Date

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Language Background Questionnaire - Short Version

ERPLing Lab

Participant information – *To be filled out by the researcher*

Project code: ____________ Today's date: ____________ Participant code: ______________

1. Biographical information

Month and year of birth: ____________________ Current Age: ________ Gender: ____________

Your native language(s)? ____
Mother's native language(s)? ____
Father's native language(s)? ____
Other caregivers' native language(s)? _____________________________________

Are you left- or right-handed? ____
Do you have any known visual impairments (including colour-blindness)? ______________
Do you have any known hearing impairments? _______________________________
Have you ever had a serious head injury? ___________________________________

What is your current profession? ____

Place of birth (city, country): ____

Please list all the places where you have lived, when you lived there, and for how long. Please list these in chronological order. ____
____
____

2. Basic language information

For an example, see page 3. Please ask if you have any questions.

In the **first row**, please list all the spoken or signed languages of which you have ANY current or previous knowledge in order of **DOMINANCE**, i.e. how comfortable you are using them.

In the **second row**, please write the age at which you were **first exposed** to this language, i.e. when it first became present in your environment.

In the **third row**, please indicate whether you were ever **IMMERSED** in this language, i.e. if you received significant exposure to this language in either a community/home setting **or** a school (greater than 20%). If so, please also indicate the age or grade at which this began.

Dominance	Most ⟷				Least
Language:	1.	2.	3.	4.	5.
Age/grade of 1st exposure:					
Immersed: Age/grade:	YES / NO ______	YES / NO ______	YES / NO ______	YES / NO ______	YES / NO ______

Language Background Questionnaire - Short Version

For each of the above-listed languages, please provide your current and highest ever attained level of proficiency. This consists of your **general** proficiency. If you feel that you are between categories, simply indicate where along the scale you feel your proficiency is best represented.

Language: ________	Current level of general proficiency very low — low — intermediate — advanced — near-native — native
	Highest level of proficiency ever attained very low — low — intermediate — advanced — near-native — native

Language: ________	Current level of general proficiency very low — low — intermediate — advanced — near-native — native
	Highest level of proficiency ever attained very low — low — intermediate — advanced — near-native — native

Language: ________	Current level of general proficiency very low — low — intermediate — advanced — near-native — native
	Highest level of proficiency ever attained very low — low — intermediate — advanced — near-native — native

Language: ________	Current level of general proficiency very low — low — intermediate — advanced — near-native — native
	Highest level of proficiency ever attained very low — low — intermediate — advanced — near-native — native

Language: ________	Current level of general proficiency very low — low — intermediate — advanced — near-native — native
	Highest level of proficiency ever attained very low — low — intermediate — advanced — near-native — native

Language Background Questionnaire - Short Version

EXAMPLE 1: Julia's mother is a native speaker of Spanish, and her father is a native speaker of English. However, Julia's mother passed away when she was four years old, and Julia therefore did not get much exposure to Spanish after that age. Julia spoke Spanish natively until the age of four (highest level of proficiency ever attained) and considers her current level of proficiency to be advanced. Her current and highest ever level of proficiency in English is native. Furthermore, Julia was in French immersion all throughout high school. When she graduated, her level of proficiency was advanced, but she now feels that it is closer to intermediate. She also took a beginner-level course in Japanese when she was in her first year of university.

Dominance:	Most ⟵			⟶	Least
Language:	1. English	2. Spanish	3. French	4. Japanese	5.
Age/grade of 1st exposure:	Birth (age=0)	Birth (age=0)	First grade (age=6)	First year univ. (age=18)	
Immersion: Age/grade:	**YES** / NO Age: Birth	**YES** / NO Age: Birth	**YES** / NO Age: 12	YES / **NO** Age: _______	YES / NO Age: _______

Language:	
English	Current level of general proficiency very low — low — intermediate — advanced — near-native — native
	Highest level of proficiency ever attained very low — low — intermediate — advanced — near-native — native

Language:	
Spanish	Current level of general proficiency very low — low — intermediate — advanced — near-native — native
	Highest level of proficiency ever attained very low — low — intermediate — advanced — near-native — native

Language:	
French	Current level of general proficiency very low — low — intermediate — advanced — near-native — native
	Highest level of proficiency ever attained very low — low — intermediate — advanced — near-native — native

Language:	
Japanese	Current level of general proficiency very low — low — intermediate — advanced — near-native — native
	Highest level of proficiency ever attained very low — low — intermediate — advanced — near-native — native

3

Language Background Questionnaire – Extended Version

ERPLing Lab

Participant information – *To be filled out by the researcher*
Project code: ____________ Today's date: ____________ Participant code: ______________

1.1 Parent/Caregivers' information

Parent/Primary caregiver (from birth to 24 months): ________________________

Native language(s): ____________________ Other language(s): ____

During your infancy, their language(s) of communication:

- with you: ____
- in the home: ____
- with other family members: ____
- with people outside the home: ____

Place of birth: ___________________________ Current residence: _____________________

Please list all places where this caregiver has lived, when they lived there, and for how long, in chronological order:

____

____

Parent/Other primary caregiver (from birth to 24 months): __________________________

Native language(s): ____________________ Other language(s): ____

During your infancy, their language(s) of communication:

- with you: ____
- in the home: ____
- with other family members: ____
- with people outside the home: ____

Place of birth: ___________________________ Current residence: _____________________

Please list all places where this caregiver has lived, when they lived there, and for how long, in chronological order:

____

____

Other caregiver(s) (from birth to 24 months): ____________________________

Native language(s): ____________________ Other language(s): ____

During your infancy, their language(s) of communication:

- with you: ____
- in the home: ____
- with other family members: ____
- with people outside the home: ____

Place of birth: ___________________________ Current residence: _____________________

Please list all places where this caregiver has lived, when they lived there, and for how long, in chronological order:

____

____

Please list these caregivers in order of amount of time you spent with them. Also indicate approximately how much time you spent with each of them during a typical week (from birth to 24 months).

1. ____________________________ Approx. time spent per week: ______________________________
2. ____________________________ Approx. time spent per week: ______________________________
3. ____________________________ Approx. time spent per week: ______________________________

Language Background Questionnaire – Extended Version

1.2 Languages in your environment during infancy (0 to 24 months of age inclusively)

Please list **all** the languages that you were exposed to **during your infancy** and, for each language, the approximate percentage of the time that you heard it on a weekly basis. Note: This should add up to 100%.

Language(s)	Percentage of the time that you heard this language on a weekly basis DURING INFANCY:

2. Current Language Proficiency

Please evaluate your **current** level of proficiency for **all** languages that you have **ever** been exposed to:

Language: ______________________

Oral comprehension:	very low	low	intermediate	advanced	near-native	native
Oral production:	very low	low	intermediate	advanced	near-native	native
Writing proficiency:	very low	low	intermediate	advanced	near-native	native
Reading proficiency:	very low	low	intermediate	advanced	near-native	native
Pronunciation:	very accented	accented	slightly accented	near-native	native	

Language: ______________________

Oral comprehension:	very low	low	intermediate	advanced	near-native	native
Oral production:	very low	low	intermediate	advanced	near-native	native
Writing proficiency:	very low	low	intermediate	advanced	near-native	native
Reading proficiency:	very low	low	intermediate	advanced	near-native	native
Pronunciation:	very accented	accented	slightly accented	near-native	native	

2

Language Background Questionnaire – Extended Version

Language: ______________________

Oral comprehension:	very low	low	intermediate	advanced	near-native	native
Oral production:	very low	low	intermediate	advanced	near-native	native
Writing proficiency:	very low	low	intermediate	advanced	near-native	native
Reading proficiency:	very low	low	intermediate	advanced	near-native	native
Pronunciation:	very accented	accented	slightly accented	near-native	native	

Language: ______________________

Oral comprehension:	very low	low	intermediate	advanced	near-native	native
Oral production:	very low	low	intermediate	advanced	near-native	native
Writing proficiency:	very low	low	intermediate	advanced	near-native	native
Reading proficiency:	very low	low	intermediate	advanced	near-native	native
Pronunciation:	very accented	accented	slightly accented	near-native	native	

Language: ______________________

Oral comprehension:	very low	low	intermediate	advanced	near-native	native
Oral production:	very low	low	intermediate	advanced	near-native	native
Writing proficiency:	very low	low	intermediate	advanced	near-native	native
Reading proficiency:	very low	low	intermediate	advanced	near-native	native
Pronunciation:	very accented	accented	slightly accented	near-native	native	

If you have been exposed to more than the above 5 languages, please list the others here and comment on your general proficiency for each:

____

____

____

Language Background Questionnaire – Extended Version

3. Evolution of Language Use

1. In the first row, fill in the ages, grades, or calendar years corresponding to the education level specified on top of each column. **Please ask the researcher if you need help.**
2. In each cell, use **percentages** to indicate your usage of/exposure to English, French, and other languages (combined) for the corresponding context and age.

Note: If your language use changed within these age groups, or if the age group is inaccurate with respect to education level, please specify by writing it inside the box or explain in the comments sections below. If you have any questions, please speak to your experimenter.

	Age 2 to kindergarten	Kindergarten	Elementary school 1	Elementary school 2
Ages/grades/calendar years				
School: i.e. language of instruction. If French immersion, please specify in comments below which grades and number of hours/week	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:
At home: interactions with immediate and extended family, significant other (if you lived with them) and roommates	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:
Friends: interactions with friends and significant other (if you did not live with them)	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:
Media use: social media, leisurely reading, television, cinema, radio, internet, music, etc.	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:
Extracurricular activities: sports, hobbies, work (if part-time), etc.	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:
Daily activities in the community: grocery store, shopping mall, restaurants, gas station, etc.	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:
Other: ______________________	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:

Comments: ____
____
____
____
____

Language Background Questionnaire – Extended Version

	High school	College/Cégep	University	Other: _______
Ages/grades/calendar years				
School: i.e. language of instruction. If French immersion, please specify in comments below which grades and number of hours/week	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:
At home: interactions with immediate and extended family, significant other (if you lived with them) and roommates	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:
Friends: interactions with friends and significant other (if you did not live with them)	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:
Media use: social media, leisurely reading, television, cinema, radio, internet, music, etc.	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:
Extracurricular activities: sports, hobbies, work (if less than 20h/week), etc.	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:
Daily activities in the community: grocery store, shopping mall, restaurants, gas station, etc.	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:
Work: (if over 20h/week)	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:
Other: ____________________	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:	Eng: Fr: other:

Comments: ____
____
____
____
____

Thank you!

5

English Cloze task: Cloze Test (Brown, 1980)

DIRECTIONS

1. Read the passage quickly to get the general meaning.
2. Write only one word in each blank next to the item number. Contractions (example: *don't*) and possessives (*John's bicycle*) are one word.
3. Check your answers.

NOTE: Spelling will not count against you as long as the scorer can read the word.
EXAMPLE: The boy walked up the street. He stepped on a piece of ice.
He fell (1) ***down*** but he didn't hurt himself.

MAN AND HIS PROGRESS

Man is the only living creature that can make and use tools. He is the most teachable of living beings, earning the name of Homo sapiens. (1) ever restless brain has used the (2) and the wisdom of his ancestors (3) improve his way of life. Since (4) is able to walk and run (5) his feet, his hands have always (6) free to carry and to use (7) **.**Man's hands have served him well (8) his life on earth. His development, (9) can be divided into three major (10) **,**is marked by several different ways (11) life.
Up to 10,000 years ago, (12) human beings lived by hunting and (13) **.**They also picked berries and fruits, (14) dug for various edible roots. Most (15) **,**the men were the hunters, and (16) women acted as food gatherers. Since (17) women were busy with the children, (18) men handled the tools. In a (19) hand, a dead branch became a (20) to knock down fruit or to (21) for tasty roots. Sometimes, an animal (22) served as a club, and a (23) piece of stone, fitting comfortably into (24) hand, could be used to break (25) or to throw at an animal**.** (26) stone was chipped against another until (27) had a sharp edge. The primitive (28) who first thought of putting a (29) stone at the end of a (30) made a brilliant discovery: he (31) joined two things to make a (32) useful tool, the spear. Flint, found (33) many rocks, became a common cutting (34) in the Paleolithic period of man's (35) **.**Since no wood or bone tools (36) survived, we know of this man (37) his stone implements, with which he (38) kill animals, cut up the meat, (39) scrape the skins, as well as (40) pictures on the walls of the (41) where he lived during the winter.
(42) the warmer seasons, man wandered on (43) steppes of Europe without a fixed (44) **,** always foraging for food. Perhaps the
(45) carried nuts and berries in shells (46) skins or even in light, woven (47) **.** Wherever they camped, the primitive people (48) fires by striking flint for sparks (49) using dried seeds, moss, and rotten (50) for tinder. With fires that he kindled himself, man could keep wild animals away and could cook those that he killed, as well as provide warmth and light for himself.

French Cloze task: Tremblay (2011)

"Le taux de CO2 dans l'atmosphère augmente plus vite que prévu"

La croissance économique mondiale (1)____ provoqué un accroissement de (2)____ teneur en dioxyde de (3)____ (CO2) dans l'atmosphère beaucoup (4)____ rapidement que prévu, selon une étude (5)____ lundi dans les comptes rendus de l'Académie (6)____ des sciences des États-Unis.
Cette étude (7)____ que la concentration des émissions (8)____ gaz carbonique dans l'atmosphère a (9) ____ de 35 % en 2006, entre le début (10)____ années 1990 et les (11)____ 2000-2006, passant de 7 à 10 milliards de tonnes (12)____ an, alors que le protocole de Kyoto prévoyait (13)____ en 2012, ces émissions responsables
(14)____ réchauffement climatique devaient (15)____ baissé de 5 % par (16)_____ à 1990. « Les améliorations dans l'intensité carbonique de l'économie (17)_____ stagnent depuis 2000, après trente (18)_____ de progrès, ce qui a provoqué cette (19)_____ inattendue de la concentration de CO2 (20)_____ l'atmosphère », indique dans
(21)_____ communiqué le British Antarctic Survey, (22)____ a participé à cette étude.
(23)____ les chercheurs, les carburants polluants (24)____ responsables de 17 % de cette augmentation, (25)____ que les 18 % restant sont (26)____ à un déclin de la capacité des « puits » naturels comme (27)____ forêts ou les océans (28)____ absorber le gaz carbonique. « (29)_____ y a cinquante ans, pour chaque tonne de CO2 émise, 600 kg (30)_____ absorbés par les puits naturels. (31)______ 2006, seulement 550 kg par tonne ont été (32)______, et cette quantité continue à baisser », explique (33)____auteur principal de l'étude, Pep Canadell, du Global Carbon Project. « La baisse de l'efficacité (34)_____ puits mondiaux laisse (35)____ que la stabilisation de cette (36)____ sera encore plus (37)____ à obtenir que ce que l'on pensait jusqu'à (38)____», indique pour sa
(39)____ le British Antarctic Survey.
Ces (40)____ obligent à une révision à la hausse (41)____ prévisions du Groupe intergouvernemental d'experts (42)____ l'évolution du climat qui, dans son (43)____ de février, tablait sur l'augmentation de la température (44)____ de la terre de 1,8 °C à 4 °C (45)____ l'horizon 2100.

Japanese Cloze task: Komori and Tamaoka (2011)

Please read the following passage and fill in the (   ) with the most appropriate hiragana or katakana. Please write only one character in each blank. For each **underlined and bolded** Kanji, please write the reading above the character.

Example:むかしむか（ **し** ）、あるところ（ **に** ）、おじいさん（ **と** ）おばあさんが、

す　かわ

住んでいまし（ **た** ）。おじいさん（ **は** ）山へ木を切（ **り** ）に、おばあさんは**川**へ

洗濯に、**出**かけていき（ **ま** ）した。

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アメリカの**親**も、日本の親（　　）同じように、従順な子を高（　　）評価すると（　　）う点で、かわ（　　）が無い。親の**言**いつけを素直に聞き、親に**反**抗しない子が、**良**い子とされる（　　）はアメリカも**同**様である。（　　）かし、“従順”（　　）いう言葉は（　　）もかく、その**内**容となると、少少問題があ（　　）。

アメリカの**場**合、“従順”とは、親と子の間に**取**り決めたル（　　）ルを忠実に**守**るということ（　　）である。これ（　　）のルールは、（　　）もすれば、親（　　）側から一方**的**に押し付け（　　）れがちであ（　　）が、それでも不服そうな顔を（　　）ず、忠実に従（　　）ていくこと（　　）ある。

日本で（　　）、この点で少（　　）違う。前にも**述**べたように、親と子の間で、（　　）らかじめ何（　　）を取り決め（　　）おくという**考**え方がない。悪く言えば、出たと（　　）勝負のやり**方**で親と子の（　　）きあいが行（　　）れている。こ（　　）ような、行き（　　）たりばった（　　）のやり方で、親が安心して（　　）られるのは、**結**局、親の側に、「**私**がこれだけ（　　）わいがった**子**供が、私にそ（　　）くはずがない。」（　　）いう信念が（　　）るからだ。母（　　）子の相互依**存**関係が深く、日夜、子供のこ（　　）に気を配っ（　　）いる母親の場合、特にこの**傾**向が強い。子**供**を思うあま（　　）、自分と子供（　　）を区別して考える余裕がな（　　）なってしま（　　）、「自分の子供（　　）から自分と**同**じように考（　　）ている。」などと**錯**覚してしま（　　）母親も出て（　　）る。「うちの子に**限**ってそんな（　　）とをする（　　）ずはない。」とい（　　）、日本でよく**聞**かれる言葉は、（　　）のあたりの**事**情をよく物**語**っている。
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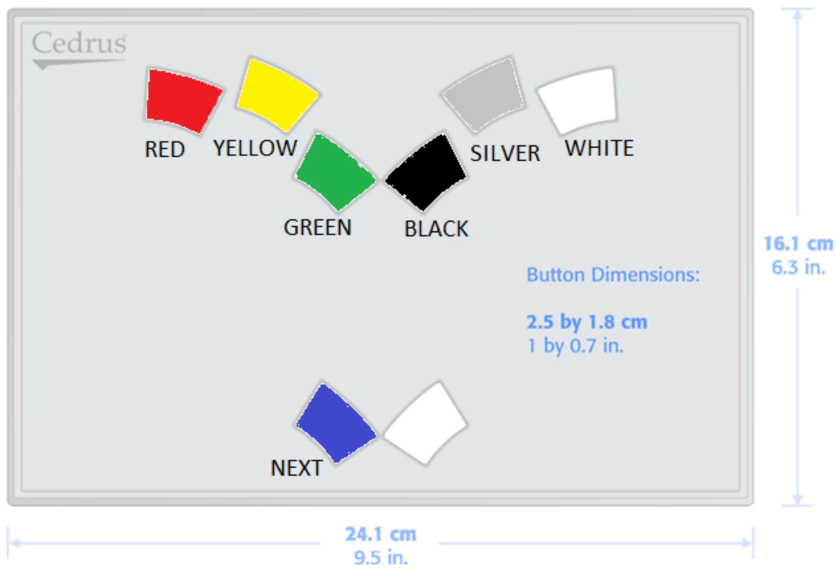
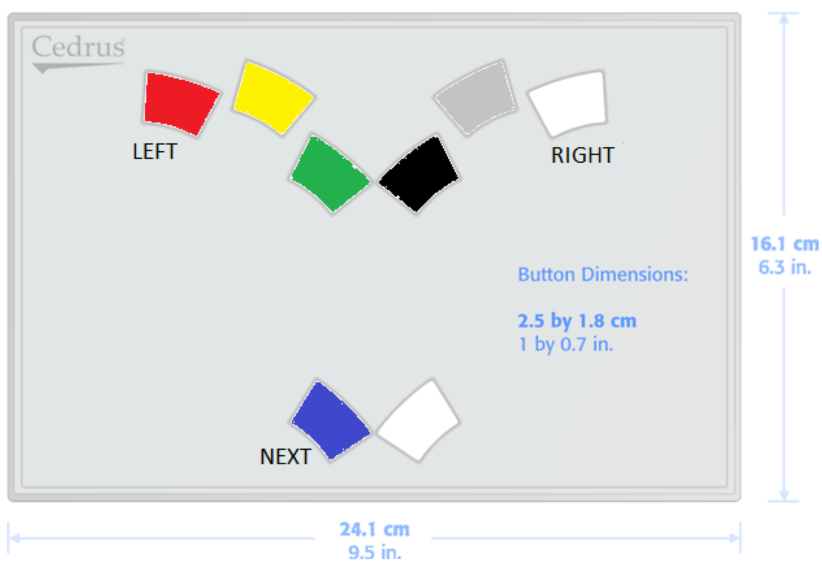


Cedrus RB-830 Button Box- Stroop Set-Up
Layout of response buttons on the button box for the Stroop task. Image taken from www.cedrus.com. Buttons labelled with colour names only for purpose of explanation of layout. For experiment, buttons were simply colours, with no labels.



Cedrus RB-830 Button Box-ANT Set-Up
Layout of response buttons on the button box. Image taken from www.cedrus.com. Buttons labelled only for purpose of explanation of layout. For experiment, the left button was red and the right button was white.

Participants in Behavioural Experiments. Participants marked with * were excluded from the indicated task, **, participants marked with ** did not complete the ANT task, and participants marked with *** did not complete the Stroop task.

Country	Participant	List	Age	Gender	L1	L2	Age of Immersion	Age of 1st L2 Exposure	Self-Rated Proficiency (/20)	English Proficiency (%)	French Proficiency (%)	Japanese Proficiency (%)
Canada	C032SR*Stroop	M	22	F	EF	EF	Simultaneous	0	17	84	58	
Canada	C006LS	E	18	F	EF	Spanish	Simultaneous	0	18	86	56	
Canada	C015AL	E	18	F	EF	Spanish	Simultaneous	0	16	68	56	
Canada	C016CE	F	18	F	EF	Arabic	Simultaneous	0	18	92	69	
Canada	C019AD	F	19	F	EF	Spanish	Simultaneous	0	19	82	84	
Canada	C025ML	F	18	F	EF	EF	Simultaneous	0	20	90	76	
Canada	C030GC	E	20	F	EF	EF	Simultaneous	0	18	80	69	
Canada	C038DP	F	18	F	EF	EF	Simultaneous	0	20	80	76	
Canada	C049AG	E	21	F	EF	EF	Simultaneous	0	20	88	82	
Canada	C056CD	F	18	F	EF	EF	Simultaneous	0	18	62	40	
Canada	C074CW	F	18	F	EF	EF	Simultaneous	0	20	82	62	
Canada	C081AB	M	18	F	EF	Spanish	Simultaneous	0	20	88	73	
Canada	C100VR*ANT	E	18	F	EF	EF	Simultaneous	0	16	84	31	
Canada	C102RC	M	19	M	EF	EF	Simultaneous	0	16	90	22	
Canada	C104DB	F	18	F	EF	EF	Simultaneous	0	20	74	49	
Canada	C106MD	M	19	F	EF	EF	Simultaneous	0	18	88	89	
Canada	C107ED	F	18	F	EF	EF	Simultaneous	0	20	86	62	
Canada	C110TL	F	18	F	EF	Spanish	Simultaneous	0	18	70	53	
Canada	C115ET	E	19	F	EF	EF	Simultaneous	0	20	80	51	
Canada	C125BL	F	18	F	EF	EF	Simultaneous	0	20	96	73	
Canada	C127MM	E	20	F	EF	Spanish	Simultaneous	0	18	84	47	
Canada	D002VB	F	18	F	EF	EF	Simultaneous	0	17	88	93	
Canada	D004GS	E	18	F	EF	EF	Simultaneous	0	17	68	18	
Canada	D008EM	F	18	F	EF	EF	Simultaneous	0	19	64	56	
Canada	C012RL	F	19	M	English	French	Early	5	12	90	18	
Canada	C033AF	E	18	M	English	French	Early	4	15	58	47	
Canada	C034JT	M	24	M	English	French	Early	4	15	92	58	

Country	Participant	List	Age	Gender	L1	L2	Age of Immersion	Age of 1st L2 Exposure	Self-Rated Proficiency (/20)	English Proficiency (%)	French Proficiency (%)	Japanese Proficiency (%)
Canada	C036SP	M	22	M	English	French	Early	5	12	86	49	
Canada	C041CM	F	18	F	English	French	Early	6	15	68	20	
Canada	C042KS	M	18	F	English	French	Early	4	12	78	47	
Canada	C043KM	E	20	F	English	French	Early	4	12	72	29	
Canada	C047AM	F	18	F	English	French	Early	4	16	70	22	
Canada	C057LA	M	22	F	English	French	Early	5	15	72	31	
Canada	C060JH	M	18	F	English	French	Early	5	18	86	60	
Canada	C061CL	E	18	F	English	French	Early	4	17	80	60	
Canada	C078TG	M	19	F	English	French	Early	5	19	86	53	
Canada	C090AS	M	18	F	English	French	Early	5	17	90	62	
Canada	C093SP	M	19	F	English	French	Early	4	19	98	82	
Canada	C114BS	M	18	F	English	French	Early	3	20	78	49	
Canada	C129AS	F	18	F	English	French	Early	6	12	86	44	
Canada	C131MC	E	19	F	English	French	Early	5	12	86	36	
Canada	D003EG	M	19	F	English	French	Early	4	12	78	47	
Canada	D005EL	F	19	F	English	French	Early	1	10	62	31	
Canada	E024JD	F	18	F	English	French	Early	5	16	92	60	
Canada	C045BQ*[ANT/Stroop]	M	18	F	English	French	Early	2	10	79	29	
Canada	C021CD	M	18	F	English	French	Late	9	13	74	29	
Canada	C059TH	F	18	F	English	French	Late	9	12	80	16	
Canada	C080EM	F	18	F	English	French	Late	8	11	78	4	
Canada	C091MM	E	18	F	English	French	Late	6	11	88	16	
Canada	E006SV	F	18	F	English	French	Late	10	8	68	20	
Canada	E007SK	M	19	F	English	French	Late	7	9	90	29	
Canada	E008TC	E	18	F	English	French	Late	6	10	98	62	
Canada	E010MP	M	20	F	English	French	Late	5	12	96	76	
Canada	E011IG	E	18	F	English	French	Late	9	10	90	38	
Canada	E013AR	M	19	F	English	French	Late	7	6	94	60	
Canada	E015SE	F	18	F	English	French	Late	8	10	86	53	

Country	Participant	List	Age	Gender	L1	L2	Age of Immersion	Age of 1st L2 Exposure	Self-Rated Proficiency (/20)	English Proficiency (%)	French Proficiency (%)	Japanese Proficiency (%)
Canada	E018DC	F	19	F	English	French	Late	9	6	62	13	
Canada	E020SH	E	18	F	English	French	Late	10	6	78	0	
Canada	E025AA	M	19	F	English	French	Late	6	12	98	71	
Canada	E026KN	M	18	F	English	French	Late	9	7	78	36	
Canada	E027DB	F	18	F	English	French	Late	6	11	82	0	
Canada	E028MF	M	20	F	English	French	Late	5	10	62	7	
Canada	E031CO	M	18	F	English	French	Late	11				
Canada	E032AC	E	17	F	English	French	Late	11	10	100	71	
Canada	E033CM	E	19	F	English	French	Late	9	8	90	73	
Canada	C007JM	E	18	F	English	French	Monolingual	9	4	82	0	
Canada	C009TD	E	19	F	English	French	Monolingual	6	4	90	0	
Canada	C023SM	M	18	F	English	French	Monolingual	9	8	88	0	
Canada	C026SM	M	18	F	English	French	Monolingual	9	11	90	4	
Canada	C040ND	E	18	F	English	French	Monolingual	9	10	78	0	
Canada	C075AH	M	18	M	English	French	Monolingual	9	6	88	11	
Canada	C086CK	E	19	F	English	French	Monolingual	10	10	74	7	
Canada	C095JP	E	27	F	English	French	Monolingual	9	8			
Canada	C121MB	E	18	F	English	French	Monolingual	6	5	90	0	
Canada	C126DS*[Stroop]	M	19	F	English	French	Monolingual	6	7	70	0	
Canada	C130SW	M	18	F	English	French	Monolingual	6	6	56	0	
Canada	E001JH	M	19	F	English	French	Monolingual	8	6	76	0	
Canada	E003SS	F	19	F	English	French	Monolingual	11	0	96	0	
Canada	E004JB	M	18	F	English	French	Monolingual	15	0	82	0	
Canada	E009MM	F	18	F	English	French	Monolingual	15	2	90	0	
Canada	E012KK	F	20	F	English	French	Monolingual	8	2	94	0	
Canada	E014AV	E	20	F	English	French	Monolingual	7	5	94	7	
Canada	E016ES	E	18	F	English	French	Monolingual	9	0	90	0	
Canada	E017HP	E	18	F	English	French	Monolingual	8	1	86	0	
Canada	E019CJ	M	19	F	English	French	Monolingual	9	2	66	0	

Country	Participant	List	Age	Gender	L1	L2	Age of Immersion	Age of 1st L2 Exposure	Self-Rated Proficiency (/20)	English Proficiency (%)	French Proficiency (%)	Japanese Proficiency (%)
Canada	E021GO	F	10	F	English	French	Monolingual	9	5	96	0	
Canada	C018SC*[ANT]	F	19	F	English	French	Monolingual	8	9	86	16	
Japan	K012MM	M	19	F	Japanese	English	Late	12	8	32		92
Japan	K013MS***	E	19	F	Japanese	English	Late	7	10	36		95
Japan	K014SK**	J	19	F	Japanese	English	Late	13	8	26		96
Japan	K015MA**	M	21	F	Japanese	English	Late	13	8	48		97
Japan	K017YT	M	21	F	Japanese	English	Late	6	11	42		96
Japan	K018SS	M	20	F	Japanese	English	Late	13	9	34		95
Japan	K040AN***	J	26	F	Japanese	English	Late	11	9	44		96
Japan	K055SK	M	19	F	Japanese	English	Late	6	7	29		98
Japan	K058RI*[ANT]	M	19	F	Japanese	English	Late	7	12	56		92
Japan	K064NK**	M	19	F	Japanese	English	Late	12	13	27		94
Japan	K067HH**	M	19	F	Japanese	English	Late	11	4	40		94
Japan	K068MW**	E	21	F	Japanese	English	Late	4	10	24		96
Japan	K073MM*[Stroop]	M	19	F	Japanese	English	Late	11	8	36		92
Japan	K075ST	J	20	F	Japanese	English	Late	6	7	40		92
Japan	K077TS	E	21	M	Japanese	English	Late	7	8	42		92
Japan	K078KM	J	20	F	Japanese	English	Late	7	8	44		96
Japan	K079KO	M	19	M	Japanese	English	Late	13	6	33		100
Japan	K082RH	M	19	F	Japanese	English	Late	13	14	31		98
Japan	K083NN**	E	21	M	Japanese	English	Late	12	12	71		90
Japan	K084YN**	E	20	M	Japanese	English	Late	13	8	53		94
Japan	K085TK**	M	20	M	Japanese	English	Late	13	9	44		90
Japan	K086RS	J	19	M	Japanese	English	Late	13	11	42		88
Japan	K087MU	E	20	F	Japanese	English	Late	12	5	38		98
Japan	K088SI	J	19	F	Japanese	English	Late	8	7	27		94
Japan	K089RM	M	20	F	Japanese	English	Late	12	8	38		96
Japan	K093AH	E	19	F	Japanese	English	Late	12	10	38		96
Japan	K095YT	M	19	F	Japanese	English	Late	11	10	33		94

Country	Participant	List	Age	Gender	L1	L2	Age of Immersion	Age of 1st L2 Exposure	Self-Rated Proficiency (/20)	English Proficiency (%)	French Proficiency (%)	Japanese Proficiency (%)
Japan	K096MK	E	19	F	Japanese	English	Late	6	7	40		90
Japan	K097TS	J	19	M	Japanese	English	Late	11	9	33		82
Japan	K098HW	M	20	M	Japanese	English	Late	13	8	29		90
Japan	K006NM	M	18	F	Japanese	English	Monolingual	11	3	22		95
Japan	K008MH***	J	20	F	Japanese	English	Monolingual	11	11	34		96
Japan	K010AI	E	19	F	Japanese	English	Monolingual	13	0	32		90
Japan	K022CS	E	21	F	Japanese	English	Monolingual	11	6	32		96
Japan	K023MO	J	21	F	Japanese	English	Monolingual	12	6	16		97
Japan	K024MY	J	19	M	Japanese	English	Monolingual	13	4	20		93
Japan	K025YO	E	19	M	Japanese	English	Monolingual	13	7	12		92
Japan	K026MS	M	19	F	Japanese	English	Monolingual	13	4	8		86
Japan	K031RY**	J	26	M	Japanese	English	Monolingual	12	0	4		96
Japan	K036HK	E	24	M	Japanese	English	Monolingual	12	0	0		80
Japan	K037MK	J	22	F	Japanese	English	Monolingual	12	0	6		93
Japan	K039CK	E	30	F	Japanese	English	Monolingual	12	8	32		95
Japan	K054NO	J	19	F	Japanese	English	Monolingual	12	12	13		90
Japan	K056SW*[ANT]	E	20	F	Japanese	English	Monolingual	11	9	27		96
Japan	K057MN**	J	19	F	Japanese	English	Monolingual	10	5	24		96
Japan	K060MS	J	20	F	Japanese	English	Monolingual	13	8	16		86
Japan	K062KY	E	19	F	Japanese	English	Monolingual	11	7	24		76
Japan	K066YN	J	19	F	Japanese	English	Monolingual	5	6	13		86
Japan	K070YT	M	19	F	Japanese	English	Monolingual	9	8	24		96
Japan	K076AN	M	19	F	Japanese	English	Monolingual	12	5	29		96
Japan	K090MK	E	20	M	Japanese	English	Monolingual	5	5	18		96
Japan	K091MS	J	19	F	Japanese	English	Monolingual	12	5	0		86
Japan	K002WO	J	22	M	Japanese	English	Short Late	12	12	36		95
Japan	K003MS	M	20	F	Japanese	English	Short Late	13	10	40		96
Japan	K007ET	E	21	F	Japanese	English	Short Late	6	12	14		95
Japan	K009NO	M	22	F	Japanese	English	Short Late	13	8	32		95

Country	Participant	List	Age	Gender	L1	L2	Age of Immersion	Age of 1st L2 Exposure	Self-Rated Proficiency (/20)	English Proficiency (%)	French Proficiency (%)	Japanese Proficiency (%)
Japan	K011MN	J	20	F	Japanese	English	Short Late	7	9	38		93
Japan	K016RM	E	20	F	Japanese	English	Short Late	10	10	26		99
Japan	K019AK	E	21	F	Japanese	English	Short Late	12	12	24		90
Japan	K020RM**	J	22	F	Japanese	English	Short Late	11	9	36		93
Japan	K021KT	M	22	F	Japanese	English	Short Late	5	8	54		92
Japan	K034AN	J	25	M	Japanese	English	Short Late	14	14	48		95
Japan	K043YS	J	25	F	Japanese	English	Short Late	13	10	46		93
Japan	K053MF	E	20	F	Japanese	English	Short Late	15	7	56		92
Japan	K069CT	J	21	F	Japanese	English	Short Late	13	7	9		96
Japan	K080EO	E	21	F	Japanese	English	Short Late	12	10	47		90
Japan	K092AM	M	20	F	Japanese	English	Short Late	10	12	20		94

Participants in ERP Stroop Experiment. Participants marked with * were excluded from analysis due to low percentage of accepted trials.

Participant	List	Age	Gender	L1	L2	Group	Age of 1st L2 Exposure	Self-Rated Proficiency (/20)	English Proficiency (%)	French Proficiency (%)	%Accepted Trials
SE016ST*	3	19	F	English	French	Bilingual	6	10	84	22	30.3
SE018LT*	2	21	F	English	French	Bilingual	4	17	90	62	14.2
SE020ES*	1	24	F	English	French	Bilingual	4	8	88	24	43.3
SE021AF*	2	18	F	English	French	Bilingual	4	10	76	38	
SE024JR*	2	24	M	English	French	Bilingual	6	11	98	38	0
SE026CF	1	18	F	English	French	Bilingual	5	8	88	36	89.7
SE028AH	3	23	F	English	French	Bilingual	3	8	94	18	89
SE030JP	2	18	F	English	French	Bilingual	4	10	94	47	73
SE033JT	2	18	F	English	French	Bilingual	4	13	94	0	67
SE034GS	3	21	F	English	French	Bilingual	1	10	68	40	74.3
SE035SJ	1	18	F	English	French	Bilingual		3	90	33	97
SE036CO	2	23	M	English	French	Bilingual	4	6	96	0	91
SE037DR	3	24	F	English	French	Bilingual	3	7	86	2	53
SE040SD*	3	18	F	English	French	Bilingual	4	13	80	42	44.7
SE041JB*	1	18	F	English	French	Bilingual	6	15	68	30	
SE042GB	2	18	F	English	French	Bilingual	4	13	86	60	52.3
SE044LW*	1	19	F	English	French	Bilingual	4	12	84	42	66
SE046MG	3	18	F	English	French	Bilingual	5	12	88	56	87
SE019SE	3	19	F	English	French	Monolingual	6	2	98	9	96.7
SE022CS	3	23	F	English	French	Monolingual	9	2	76	0	87.7
SE025MS	3	19	F	English	French	Monolingual	12	0	90	7	99
SE027SK	2	18	F	English	French	Monolingual	8	10	92	51	90
SE029CW	1	18	F	English	French	Monolingual	9	3	80	0	96
SE031MP*	3	18	F	English	French	Monolingual	6	10	90	13	31
SE038NM	1	19	F	English	French	Monolingual	8	9	98	40	70.3
SE043SV	3	18	F	English	French	Monolingual	10	10	96	20	98.3
SE045SP	2	18	F	English	French	Monolingual	7	4	90	0	84

SE047CG	1	19	F	English	French	Monolingual	9	6	78	0	75.6

Language-Switching Questionnaire

How often do you switch between the languages you speak? Switching between and mixing languages is a characteristic of many bilingual environments. These questions ask you to report your tendency to switch or mix languages during daily conversations with the people around you. Please answer the following questions about your use of Japanese and English.

1	In what situations do you tend to speak in English with your friends/family? (check all that apply) ☐one on one ☐at home ☐with friends ☐with family ☐at social gatherings ☐other (please specify or comment on above)___________________________________					
2	In what situations do you tend to speak in Japanese with your friends/family? (check all that apply) ☐one on one ☐at home ☐with friends ☐with family ☐at social gatherings ☐other (please specify or comment on above)___________________________________					
	Please answer the following questions, considering how you speak when interacting with your friends and family. Please check the box that best corresponds to your language use.	Always	Frequently	Occasionally	Very infrequently	Never
3	I start a sentence in English and then switch to speaking Japanese					
4	I start a sentence in Japanese and then switch to speaking English					
5	I borrow a Japanese word when speaking English					
6	I borrow an English word when speaking Japanese					
7	In general, I switch between English and Japanese					
8	When I cannot recall a word in English, I tend to immediately produce it in Japanese					
9	When I cannot recall a word in Japanese, I tend to immediately produce it in English					
10	I do not realize when I switch the language during a conversation or when I mix the two languages					
11	When I switch languages, I do it consciously					
12	It is difficult for me to control my language switches during a conversation					
13	Without intending to, I sometimes produce the English word faster when I am speaking in Japanese					
14	Without intending to, I sometimes produce the Japanese word faster when I am speaking in English					
15	There are situations in which I always switch between the two languages Please give a few examples: ____					
16	There are certain topics for which I normally switch between the two languages. Please give a few examples: ____					
17	People in my family switch between English and Japanese					
18	My friends switch between English and Japanese					
19	In general, people in my community switch between English and Japanese					
20	In general, I am surrounded by people who switch between English and Japanese					
21	I do not realize when people around me switch between English and Japanese					

Experiment 1- Attention Network Test RTs for Canadian Participant Groups

Cue	Condition	AoI Group	Mean RT (ms)	Std. Deviation
Double	Congruent	Monolingual	423.64	58.19
		Simultaneous	439.66	60.72
		Early	434.12	66.38
		Late	460.15	59.19
		Total	439.20	61.48
	Incongruent	Monolingual	503.17	59.79
		Simultaneous	494.93	59.85
		Early	500.77	72.00
		Late	544.36	66.04
		Total	510.52	66.25
	Neutral	Monolingual	427.31	54.27
		Simultaneous	439.66	57.37
		Early	433.24	72.19
		Late	453.42	53.35
		Total	438.29	59.37
None	Congruent	Monolingual	481.29	73.88
		Simultaneous	493.58	68.90
		Early	479.31	83.61
		Late	501.14	63.79
		Total	488.80	72.07
	Incongruent	Monolingual	523.14	74.38
		Simultaneous	530.30	72.72
		Early	523.04	77.04
		Late	544.66	66.49
		Total	530.20	71.96
	Neutral	Monolingual	472.01	55.51
		Simultaneous	491.64	69.64
		Early	485.02	66.63
		Late	496.15	57.67
		Total	486.10	62.17
Central	Congruent	Monolingual	427.01	49.25
		Simultaneous	448.52	69.67
		Early	448.08	69.28
		Late	465.91	56.89
		Total	447.15	62.25
	Incongruent	Monolingual	513.28	72.67
		Simultaneous	511.16	62.52
		Early	510.83	77.52
		Late	533.11	54.80
		Total	516.98	66.85
	Neutral	Monolingual	428.12	55.36
		Simultaneous	439.64	50.79
		Early	447.37	75.21
		Late	451.66	42.44
		Total	441.51	56.78

Spatial	Congruent	Monolingual	412.96	63.13
		Simultaneous	437.10	64.36
		Early	426.01	68.18
		Late	448.12	59.49
		Total	430.90	64.03
	Incongruent	Monolingual	482.85	90.02
		Simultaneous	476.02	57.58
		Early	476.64	65.57
		Late	507.59	67.98
		Total	485.62	71.25
	Neutral	Monolingual	408.59	54.50
		Simultaneous	420.71	48.19
		Early	421.12	63.25
		Late	435.72	57.37
		Total	421.37	55.77

Experiment 2- Attention Network Test RTs for Japanese Participant Groups

Cue	Condition	AoI Group	Mean RT (ms)	Std. Deviation
Double	Neutral	Monolingual	424.16	39.99
		Late	437.39	48.56
		Late-Short Immersed	467.08	65.47
		Total	440.55	52.79
	Congruent	Monolingual	431.52	47.59
		Late	452.78	61.13
		Late-Short Immersed	464.58	65.94
		Total	448.19	58.41
	Incongruent	Monolingual	503.67	54.64
		Late	518.88	59.73
		Late-Short Immersed	527.09	69.59
		Total	515.53	60.34
None	Neutral	Monolingual	470.73	52.05
		Late	488.17	49.23
		Late-Short Immersed	524.69	79.32
		Total	491.63	62.31
	Congruent	Monolingual	471.76	55.74
		Late	487.10	50.79
		Late-Short Immersed	526.50	72.20
		Total	492.10	61.83
	Incongruent	Monolingual	526.79	49.77
		Late	547.61	73.00
		Late-Short Immersed	579.73	99.17
		Total	548.65	75.53
Central	Neutral	Monolingual	433.09	49.63
		Late	449.62	56.14
		Late-Short Immersed	470.46	61.00
		Total	449.19	56.13
	Congruent	Monolingual	432.70	46.24
		Late	452.61	53.25
		Late-Short Immersed	474.77	73.61
		Total	451.30	58.46

	Incongruent	Monolingual	515.29	51.48
		Late	523.17	57.51
		Late-Short Immersed	541.08	71.20
		Total	525.11	59.18
Spatial	Neutral	Monolingual	419.63	43.26
		Late	429.25	59.59
		Late-Short Immersed	444.99	57.72
		Total	429.97	53.53
	Congruent	Monolingual	419.06	41.65
		Late	429.93	63.74
		Late-Short Immersed	457.09	57.73
		Total	433.27	55.95
	Incongruent	Monolingual	474.03	56.43
		Late	495.11	71.69
		Late-Short Immersed	513.50	79.64
		Total	492.36	69.32

Experiment 3- Stroop RTs for Canadian Participant Groups

Type	Language	Condition	AoI Group	Mean RT (ms)	Std. Deviation
Single	English	Neutral	Monolingual	785.64	137.94
			Early	717.24	87.36
			Late	736.98	85.92
			Simultaneous	726.86	87.49
			Total	742.28	103.97
		Congruent	Monolingual	737.31	126.80
			Early	690.86	112.87
			Late	692.35	80.37
			Simultaneous	683.71	103.15
			Total	701.31	107.17
		Incongruent	Monolingual	858.37	147.86
			Early	778.28	129.21
			Late	775.05	107.22
			Simultaneous	783.92	119.24
			Total	799.41	129.15
	French	Neutral	Monolingual	721.38	85.83
			Early	777.10	143.59
			Late	758.21	109.80
			Simultaneous	779.06	128.66
			Total	758.50	118.38
		Congruent	Monolingual	688.80	108.77
			Early	731.12	143.26
			Late	728.91	124.96
			Simultaneous	733.02	139.86
			Total	720.20	128.51
		Incongruent	Monolingual	737.82	115.04
			Early	832.35	184.49
			Late	793.40	145.47
			Simultaneous	852.28	186.87
			Total	803.27	163.21

Mixed	English	Neutral	Monolingual	763.38	133.66
			Early	786.85	118.58
			Late	762.99	79.97
			Simultaneous	711.02	98.48
			Total	755.31	110.83
		Congruent	Monolingual	708.15	108.91
			Early	700.55	91.69
			Late	733.40	101.52
			Simultaneous	703.84	98.68
			Total	711.75	99.59
		Incongruent	Monolingual	819.06	138.64
			Early	816.15	138.96
			Late	783.19	97.23
			Simultaneous	793.84	101.60
			Total	802.74	118.96
	French	Neutral	Monolingual	765.63	128.65
			Early	765.16	89.38
			Late	760.54	84.24
			Simultaneous	745.09	123.63
			Total	758.96	107.05
		Congruent	Monolingual	721.63	113.34
			Early	730.65	108.34
			Late	712.03	82.81
			Simultaneous	709.92	106.67
			Total	718.26	101.73
		Incongruent	Monolingual	784.52	136.38
			Early	830.03	112.12
			Late	795.05	105.20
			Simultaneous	773.39	124.51
			Total	794.91	119.93

Experiment 4- Stroop RTs for Japanese Participant Groups

Type	Language	Condition	AoI Group	Mean RT (ms)	Std. Deviation
Single	Japanese	Neutral	Monolingual	762.58	110.90
			Late	759.95	85.97
			Late-Short Immersed	758.12	61.81
			Total	760.41	89.16
		Congruent	Monolingual	726.25	80.30
			Late	713.03	81.66
			Late-Short Immersed	702.97	61.00
			Total	715.11	75.94
		Incongruent	Monolingual	766.64	70.65
			Late	781.24	116.34
			Late-Short Immersed	796.97	100.23
			Total	780.08	97.76

	English	Neutral	Monolingual	723.94	83.31
			Late	732.14	99.47
			Late-Short Immersed	737.89	86.22
			Total	730.73	89.64
		Congruent	Monolingual	691.61	76.13
			Late	709.26	78.92
			Late-Short Immersed	721.59	89.00
			Total	706.21	80.06
		Incongruent	Monolingual	728.91	89.35
			Late	749.46	111.92
			Late-Short Immersed	775.90	126.86
			Total	748.89	108.39
Mixed	Japanese	Neutral	Monolingual	757.90	66.37
			Late	757.38	70.16
			Late-Short Immersed	780.76	108.78
			Total	763.31	79.37
		Congruent	Monolingual	707.63	59.86
			Late	720.09	82.14
			Late-Short Immersed	740.65	96.63
			Total	720.86	78.94
		Incongruent	Monolingual	787.94	67.88
			Late	767.39	85.04
			Late-Short Immersed	799.49	95.89
			Total	782.36	82.17
	English	Neutral	Monolingual	761.00	54.02
			Late	756.81	84.42
			Late-Short Immersed	755.77	103.03
			Total	758.00	79.40
		Congruent	Monolingual	714.32	60.60
			Late	710.74	79.71
			Late-Short Immersed	726.34	82.01
			Total	715.81	73.31
		Incongruent	Monolingual	767.82	73.68
			Late	765.12	86.56
			Late-Short Immersed	786.30	86.74
			Total	771.26	81.48