A behavioural and electrophysiological investigation of the “bilingual advantage”

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ABSTRACT

A behavioural and electrophysiological investigation of the “bilingual advantage”

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This thesis presents research that addresses several questions with respect to findings demonstrating superior performance in bilinguals relative to monolinguals on cognitive control tasks, which has been termed the “bilingual advantage”. Chapter 2 reports a study investigating the presence of a bilingual advantage in a homogeneous sample of young and older adults using a Stroop task. The results demonstrated that, in young adults there was a general speed advantage for the bilinguals, but this did not translate to a decrease in Stroop interference as would be expected if there was an advantage for the bilinguals. There was no difference in performance between the monolingual and bilingual older adults.

Chapter 3 reports research further investigating the possibility of a bilingual advantage in young adults using an array of tasks (i.e., Stroop, Simon, and Eriksen flanker). In addition to behavioural measures, electrophysiological measures that I reasoned would be more sensitive to detecting language group differences were included. Behaviourally no differences between monolinguals and bilinguals were found, replicating the results from chapter 2. However, I found differences in electrical brain activity between the two groups suggesting differences in conflict processing. Specifically, differences were observed in N2 amplitude, which is thought to reflect conflict monitoring; P3 latency and amplitude, which is thought to reflect stimulus categorization time and resource allocation; and the amplitude of the error-related negativity, which is thought to reflect conflict on error trials. These findings were not consistent across the three tasks, and given the lack of behavioural differences between the groups the observed electrophysiological differences do not necessarily represent an advantage for the bilinguals.

The research presented in my thesis further examines and characterizes the previously observed advantage for bilinguals relative to monolinguals on tasks of cognitive control using improved methodology. I included a homogenous sample of monolingual and bilingual participants, used multiple tasks in the same participants, and included electrophysiological methodology capable of measuring brain activity during task performance. It is concluded that under certain conditions differences between monolinguals and bilinguals do emerge, but these differences do not necessarily represent an advantage.

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CONTRIBUTIONS OF AUTHORS

The studies included in the two manuscripts comprising this thesis were conceived of by Shanna Kousaie, with guidance from Dr. Natalie Phillips. Shanna Kousaie created the stimuli, recruited and tested the participants, and processed and analyzed the data under the supervision of Dr. Natalie Phillips. Shanna Kousaie and Dr. Natalie Phillips interpreted the results collaboratively, and the first draft of both manuscripts were written by Shanna Kousaie and subsequently revised by Dr. Natalie Phillips. Note that throughout this thesis "I" is used when referring to the thesis, whereas "we" is used within and when referring to the manuscripts that comprise chapters 2 and 3 of this thesis.

Chapter 1: General Introduction

More than half of the world's population speaks more than one language (Fabbro, 1999) and the effect of bilingualism on cognition has been of interest to researchers since the 1920s (e.g., Saer, 1923; Smith, 1923). Based on early studies it was believed that learning two languages had negative consequences for intelligence. For instance, Smith describes two studies, one cross-sectional and one longitudinal extending over a two year period, that were thought to provide support for the detrimental effect of bilingualism. In his cross-sectional examination, Smith included children from two age groups differing by four years (Standards III and VII). The monolingual and bilingual children were required to complete several tests, including writing an essay in a 15 minute time period and forming words from six letters, e.g., *a,e,o,b,m,t* (following Whipple, 1915). It was found that for free composition there was an advantage for monolinguals in Standard III and this advantage was even greater in Standard VII. For the word forming test there was no difference between the language groups in Standard III, but bilinguals were superior to monolinguals in Standard VII.

In his longitudinal examination Smith (1923) found that monolinguals showed greater improvement over the two year period relative to bilinguals in free composition, a task in which children had to complete a passage with omitted words (e.g., The hare met a tortoise ____ was plodding along ____), and an analogies test. Based on these results, Smith concluded that bilingualism was an intellectual disadvantage and "monoglot children, between the ages of 8 and 11, make better progress than bilingual children in their power of expression, their choice of vocabulary, and their accuracy of thought" (Smith, p. 282).

Almost simultaneously Saer (1923) conducted an extensive examination of the effect of bilingualism on intelligence. Saer included 1400 children, between the ages of 7 and 12 years old from both rural and urban districts, and had them complete the Stanford Binet-Simon scale (Binet & Simon, 1916), as well as handedness, rhythm, vocabulary and composition tests. In children from rural areas monolinguals showed considerable superiority over bilinguals on the Stanford Binet-Simon intelligence scale and monolinguals showed an increase in vocabulary at 8 or 9 years old that was delayed in bilinguals until 10 or 11 years of age. The range of vocabulary in monolinguals was also greater than that in bilinguals in either of their languages and bilinguals were much more confused with respect to handedness than monolinguals, which was thought to have been carried over from the brain area concerned with language. Interestingly, differences between monolingual and bilingual children from urban areas on the Stanford Binet-Simon intelligence scale were “inconsiderable”; however, bilinguals from urban areas were nevertheless thought to experience “mental confusion” given that they demonstrated greater confusion on the handedness test relative to their monolingual peers.

Saer (1923) also tested monolingual and bilingual university students from rural and urban areas using an intelligence test that he designed himself. In students from rural areas monolinguals showed superior performance relative to bilinguals, leading to the conclusion that the difference between monolinguals and bilinguals is permanent because it persisted throughout university. Similar to the results from children, monolingual and bilingual university students from urban areas showed similar performance.

A disadvantage for bilinguals relative to monolinguals seems consistent in the early literature. For example a comprehensive review found only two studies that demonstrated a favourable effect of bilingualism on intelligence (Darcy, 1953). However, a new trend began to emerge later. Peal and Lambert (1962) investigated the effects of bilingualism on intellectual functioning in French monolingual and French-English bilingual children at the age of 10 years. Intelligence was assessed using the Lavoie-Laurendeau Group Test of General Intelligence (Lavoie & Laurendeau; as cited in Peal & Lambert), a standardized intelligence test in French with both verbal and nonverbal components; Raven's Progressive Matrices (Raven; as cited in Peal & Lambert), which yielded a measure of basic intelligence; and Thurstone's Primary Mental Abilities (Thurstone & Thurstone; as cited in Peal & Lambert). It was found that bilinguals demonstrated superior performance on both verbal and nonverbal intelligence tests. Specifically, the bilinguals outperformed the monolinguals on all verbal measures and most nonverbal measures. For some of the nonverbal subtests there was no difference between the two language groups, but the monolinguals did not outperform the bilinguals on any of the nonverbal subtests. Peal and Lambert suggested that the bilingual's "experience with two language systems seems to have left him with a mental flexibility, a superiority in concept formation, and a more diversified set of mental abilities" (p. 20).

More recently, the effect of bilingualism on cognition has become an area of intense interest. Recent findings suggest that bilinguals outperform monolinguals on tasks of executive/cognitive control (see Bialystok, 2007, 2009; Bialystok & Craik, 2010; Craik & Bialystok, 2005). These higher-order cognitive processes include inhibition and switching, working memory, and sustained and selective attention (see Alvarez & Emory, 2006). The superior performance of bilinguals relative to monolinguals has been called the "bilingual advantage" and has also been demonstrated in older adults (Bialystok, Craik, & Luk, 2008; Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Martin, & Viswanathan, 2005; Zied et al., 2004), implying a potential benefit of bilingualism with respect to cognitive aging. Specifically, older bilinguals outperformed older monolinguals suggesting that bilingualism may provide a buffer against some of the well-documented age-related changes in cognition (e.g., Craik & Salthouse, 2008). The intent of this thesis is to further investigate the "bilingual advantage".

1.1 Thesis Overview

The two manuscripts included in this thesis were designed to further examine and characterize the "bilingual advantage". The first attempted to replicate previous findings of a bilingual advantage in a homogeneous sample of bilingual young and older adults. The second examined the neural correlates associated with cognitive control in monolingual and bilingual young adults while performing a series of tasks for which bilinguals have been found to demonstrate superior performance relative to monolinguals.

In manuscript 1 we attempted to replicate previous findings of a bilingual advantage using a color-word Stroop task. Our investigation included a homogeneous sample of English monolingual and English/French bilingual young and older adults, in order to assess the suggestion that bilingualism confers an advantage with respect to age-related changes in cognition. Many of the previous investigations comparing monolinguals and bilinguals have not used such a homogeneous sample (e.g., Bialystok, 2006; Bialystok et al., 2008), or have not included a monolingual control group (Zied et al., 2004). Thus, in manuscript 1 we investigated whether the bilingual advantage holds in our demographically controlled sample. To anticipate our findings, despite multiple analyses we were unable to detect any advantage for the bilinguals relative to the monolinguals in either age group.

Given that electrophysiological methods have the potential to reveal differences in underlying neural mechanisms where behavioural differences are not observed (see Bialystok et al., 2005) we opted to follow-up manuscript 1 with an investigation of the neural correlates of performance in young monolinguals and bilinguals. Thus, in chapter 2 participants performed three tasks on which bilinguals have previously been shown to perform better than monolinguals (i.e., Stroop, Simon, and Eriksen flanker tasks). We chose to include all three tasks given previous findings suggesting differences between these tasks in how conflict is processed (Fan, Flombaum, McCandliss, Thomas, & Posner, 2003). Furthermore, this provides the additional advantage of comparing performance across tasks within the same participants, rather than making cross-study comparisons.

We were interested in four event-related brain potential (ERP) components that have been found to be related to different aspects of cognitive and error processing: the N2, which is related to conflict monitoring (e.g., van Veen & Carter, 2002a; 2002b; Yeung, Botvinick, & Cohen, 2004); the P3, which is related to stimulus categorization time (Kutas, McCarthy, & Donchin, 1977) and the allocation of resources (see Polich, 2007); the error-related negativity (ERN), which is thought to relate to the detection of errors (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Falkenstein, Hoormann, Christ, & Hohnsbein, 2000; Gehring, Goss, Coles, Meyer, & Donchin, 1993) or post-response conflict (Yeung et al., 2004); and the error positivity (Pe), which is thought to reflect the motivational significance or saliency of errors (Leuthold & Sommer, 1999; Shalgi, Barkan, & Deouell, 2009).

In the following sections I will provide a general review of the literature pertinent to this thesis. In addition, each manuscript includes a review of the literature specific to the question that it addresses.

1.2 Bilingual Language Activation

A growing number of studies have found that a bilingual's two languages are simultaneously active (i.e., bilingual language activation is non-selective), even when the bilingual individual is only engaged in a single language. This has been found in both visual and auditory word recognition and language production. As will be illustrated below, different experimental paradigms and methodologies have been used to demonstrate non-selective language activation in bilinguals. Note that the literature reviewed here is meant to be representative rather than exhaustive.

In general, evidence from word recognition studies comes from studies using interlingual homographs/homophones; that is, words with identical orthography/phonology in two languages, but with distinct semantic features (e.g., *coin*, meaning "money" in English, and "corner" in French). One paradigm that has been used is picture identification. In this task, a participant hears the name of an object in one language (e.g., a can) and is required to identify the object among four alternatives, including one with a similar sounding name in the non-target language (e.g., a walking stick, i.e., "canne" in French), during which eye-movements are monitored. The relative number of looks that the participant makes towards the non-target language competitor is taken as a measure of activation of the non-target language. It has been found that bilingual participants make significantly more eye movements towards the competitor in the non-target language relative to control items (e.g., Blumenfeld & Marian, 2007; Marian, Spivey, & Hirsch, 2003), providing evidence for parallel access to both languages.

Others have used word identification to demonstrate non-selective language access (e.g., Dijkstra, Grainger, & van Heuven, 1999; Dijkstra, Timmermans, & Schreifers, 2000; van Heuven, Schreifers, Dijkstra, & Hagoort, 2008). It has been found that when participants are asked to identify whether a letter string is a word in a target language, and the target word also exists in the non-target language, they are influenced by the word's meaning in the non-target language. For example, in one of their experiments van Heuven et al. found that when English/Dutch bilinguals were asked to identify whether a letter string was an English word, response times were longer when the letter string was an interlingual homograph (i.e., it was also a Dutch word). This was also the case when there were no purely Dutch words included in the experiment; thus, Dutch was not required to perform the task. That is, even when task demands did not require activation of the non-target language individuals were unable to suppress the influence of the non-target language.

Translation recognition tasks have also demonstrated language non-selective access in bilinguals. In this task, participants are presented with word pairs and they must decide whether the two words are translation equivalents. Performance of this task necessarily requires the activation of both of a bilingual's two languages. de Groot, Delmaar, and Lupker (2000) found that when one of the words in the word pair was an interlingual homograph participants took longer to respond. This was assumed to be the result of interference caused by the meaning of the interlingual homograph in the other language. For example, in the French-English word pair *coin-corner*, if the meaning of the word *coin* is activated in both languages (i.e., meaning “corner” in French and “money” in English), the English meaning must be suppressed in order to respond correctly, which would increase response time.

Another paradigm that will be discussed in relation to non-selective language activation is semantic priming. Semantic priming paradigms have been used in combination with ERP measurement to further support language non-selective access. ERPs are extracted from the ongoing electroencephalogram (EEG) and can provide invaluable information regarding the strength and timing of cognitive processes during task performance. The component of interest in semantic priming paradigms is the N400, which is a negative deflection of the waveform occurring approximately 400 ms following a stimulus (Kutas & Van Petten, 1994). The amplitude of the N400 is related to the mismatch between the target stimulus and a primed or expected stimulus. Thus, a target that is preceded by a related prime will elicit a smaller amplitude N400 relative to when it is preceded by an unrelated prime. Semantic priming experiments have manipulated context to determine if a prior language context is capable of constraining language activation to the target language. In young adults, it has been found that an interlingual homograph primes its meaning in a non-target language, even in the presence of a single word language context (e.g., de Bruijn, Dijkstra, Chwilla, & Schriefers, 2001; Kousaie & Phillips, 2011). That is, the presence of a language cue did not bias the reading of the interlingual homograph to the target language. Instead, the meaning of the interlingual homograph in the non-target language was activated despite the language context, which was demonstrated by faster reaction times (RT) and smaller N400 amplitudes in response to target words related to the meaning of the interlingual homograph in the non-target language relative to an unrelated target word. Furthermore, Paulmann, Elston-Güttler, Gunter, and Kotz (2006) have found that even a global language context comprised of a first- or second-language film presented prior to the experiment was not sufficient to suppress the influence of a native language on performance of a second language task. In their experiment, they found both behavioural and N400 priming for targets related to the native language meaning of interlingual homograph primes despite the global second language context. Finally, Kerkhofs, Dijkstra, Chwilla, and de Bruijn (2006) examined whether a word exclusive to a single language would prime an interlingual homograph and eliminate activation of its meaning in the non-target language. It was found that both behavioural and N400 priming were influenced by the meaning of the interlingual homograph in the non-target language.

Similar evidence for interference from a non-target language has been demonstrated in language production tasks. Hermans, Bongaerts, De Bot, and Schreuder (1998) used a picture-word interference task to demonstrate the interference of a native language on picture naming in bilinguals' second language. For this task participants were required to name pictures (e.g., *dog*) as quickly and accurately as possible, and to ignore an interfering stimulus. The interfering stimulus could be related to the picture semantically (e.g., *cat*) or phonologically (e.g., *doll*), or it could be unrelated (e.g., *bed*) to the picture. The standard finding is that a phonologically related distractor facilitates picture naming, whereas a semantically related distractor causes interference resulting in longer naming times (see Hermans et al.). In two experiments, Hermans et al. asked bilingual participants to name pictures in their second language (English) in the presence of spoken word distractors. In one experiment, the distractors included English words that were phonologically related, semantically related, or unrelated to the name of the picture, and phonologically related to the name of the picture in the participant's native language (Dutch). In a second experiment, the distractors included words in the participant's native language (Dutch) that were phonologically related, semantically related or unrelated to the English name of the picture, and phonologically related to the Dutch name of the picture. It was found that the name of the picture in participants' first language was activated during initial lexical access of the translation equivalent in their second language, demonstrating interference from a native language.

Previous studies using picture-word identification have also found interference resulting from distractors in a bilingual's two languages, regardless of the language of naming (e.g., Ehri & Ryan, 1980). However in this case the distractors were words in the bilingual's native language that represented a noun other than the picture, the translation of the picture in the participant's second language, or a string of "X"s. Both types of word distractors resulted in increased naming latencies relative to a string of "X"s when participants named the pictures in either their native language or their second language.

Costa, Caramazza, and Sebastián-Gallés (2000) also used a picture naming paradigm to demonstrate simultaneous activation of a bilingual's two languages at the phonological level. In their experiments, the stimuli were cognates; words with similar orthography, phonology and semantic features in two languages (e.g., *gat* – *gato* meaning "cat" in Catalan and Spanish, respectively). Given that cognates share phonology across languages and noncognates do not, faster naming latency for cognates relative to noncognates would demonstrate activation of both languages. Furthermore, faster naming of cognates should only be observed in bilinguals because monolinguals possess a single representation regardless of cognate status. In two experiments, Costa et al. found a cognate effect when bilinguals named pictures in both their dominant and non-dominant language, although the effect was larger for naming in the non-dominant language. There was no cognate effect in the monolinguals. A cognate effect has also been found for languages that do not share a script (i.e., Japanese and English), suggesting that shared phonology alone can produce the facilitatory effect (Hoshino & Kroll, 2008). These findings further support the non-selectivity of language activation in production.

This review provides considerable evidence in support of the simultaneous activation of a bilingual's two languages, both receptive and productive. However, despite the constant competition between their two languages, bilingual individuals are capable of functioning in one of their languages without intrusions from their other language. The question that arises is how bilingual individuals accomplish this. There must be a means through which attention is directed to the target language and the non-target language is ignored. Furthermore, fluent bilinguals are able to switch between their two languages seemingly effortlessly, and are required to do so depending on the intended language of communication. The following section will address the question of bilingual language control, and cognitive control more generally.

1.3 Bilingual Language Control and Cognitive Control

Several models of bilingual language control have been proposed, and may provide insight into the mechanism of the observed bilingual advantage (described in more detail later). The first such model is Green's (1998) inhibitory control model.

According to this model language control is akin to action control, and is comprised of three levels. The first level involves the competition between language task schemas for control of the output. When a language schema is specified (e.g., translation or word production schema) it can be retrieved from memory and modified according to task demands. The schema regulates the outputs of the lexico-semantic system either until its goal is achieved, it is actively inhibited by another schema, or the goal is changed by higher-order control functions. The second level is that of word selection, and involves the selection of lemmas (i.e., word representations containing information about syntax and morphology) that are specified in terms of a language tag. The third level of control is at the lemma level which is inhibitory and reactive. That is, at the third level of control, lemmas linked to incorrect tags are suppressed.

Evidence for the inhibitory control model (Green, 1998) comes from language switching studies demonstrating greater costs when switching from a second language to a native language (e.g., Meuter & Allport, 1999; see also Meuter, 2005). That is, task switching involves shifting between tasks (similar to a bilingual switching between languages), and is associated with a cost; it takes longer to perform the task at hand when it is preceded by a different task relative to when it is preceded by the same task (see Monsell, 2003). In the case of language switching, Meuter and Allport found a larger cost when switching from a less dominant second language to a native language, relative to switching from a native language to a second language. This was taken as evidence for the active inhibition of a native language during naming in a second language. Specifically, given that a native language is dominant, the inhibition required to suppress it during second language speech production is greater than the inhibition required to suppress a less dominant second language, making switching from a second language to a native language more difficult. Costa, Santesteban and Ivanova (2006) also found that inhibition operates in bilinguals during language switching, although, they suggest that this is not always the case and that in highly proficient bilinguals lexical selection is language-specific.

Other models suggest that language activation is non-selective, but language production is selective (Costa, Miozzo, & Caramazza, 1999). Costa et al.'s model of lexical access proposes that there is parallel activation of lexical entries in a bilingual's two lexicons; however, only the entries in the lexicon of the target language compete for selection. Costa et al. present a series of experiments using a picture-word interference paradigm which provide support for their model.

In their review, Kroll, Bobb, and Wodniecka (2006) have argued that there is language non-selectivity at all levels of planning speech and thus the system is "fundamentally nonselective" (Kroll et al., p. 132). Their view is that there are multiple loci of language selection (e.g., at the lemma level, the phonological level, beyond the phonological level), and language selection depends on multiple factors that vary according to language proficiency, dominance, and experience, as well as task demands, and the degree of activity of the non-target language. For example, a less proficient second language speaker will require more time to plan speech in their second language, which offers more opportunity for their native language to influence speech production and the degree of competition between the two languages.

Abutalebi & Green (2007) propose the single network hypothesis, which proposes that there is a single network that mediates both of a bilingual's languages and this network is modulated by the same structures as more general cognitive control. The single network hypothesis assumes convergence between the representations in an individual’s native and their second language; specifically, that the processing of a second language will rely on the same network and control circuits in the brain as a native language. Furthermore, based on a review of a series of functional neuroimaging studies, the hypothesis posits that bilinguals require an inhibitory mechanism to manage their two languages.

Although several models have been described, the goal here is not to suggest that one model is superior. The goal is to demonstrate that all of these models imply some form of control for the management of multiple languages in the bilingual brain. Some are more explicit with respect to the mechanism of language selection; however, there does seem to be agreement that language activation is principally non-selective and there is competition between a bilingual’s two languages. Models that propose general cognitive control mechanisms are compelling, not simply for the sake of parsimony, but in light of neuroimaging data implicating similar brain structures in language control and in nonverbal control tasks (e.g., Fabbro, Skrap, & Aglioti, 2000; Fan et al., 2003; Hernandez, 2009; Hernandez, Dapretto, Mazziotta, & Bookheimer, 2001; Hernandez, Martinez & Kohnert, 2000; Rodriguez-Fornells et al., 2005; van Heuven et al., 2008).

Models of cognitive control generally agree that there is involvement of the dorsolateral prefrontal cortex (DLPFC) and the anterior cingulate cortex (ACC) in cognitive control, although the specific roles of these areas differ among models. Botvinick, Braver, Barch, Carter, and Cohen (2001; see also Botvinick, Cohen, & Carter, 2004) proposed the conflict monitoring hypothesis. According to this hypothesis there is a system that monitors for conflict and triggers centers responsible for cognitive control, which then adjust control accordingly. Botvinick, Braver, et al. advocate that the ACC acts as a conflict monitor and cite evidence from studies demonstrating increased ACC activity for tasks in which conflict occurs (e.g., Stroop and Eriksen flanker tasks). When conflict is detected by the ACC, brain centers responsible for control influence processing and behavioural adjustments, such as post-error slowing, are implemented to account for the conflict. However, the conflict monitoring hypothesis does not specify a role for the DLPFC. Kerns et al. (2004) examined the conflict monitoring hypothesis and found that an increase in ACC activity following conflict predicted an increase in activity in the prefrontal cortex (PFC). Furthermore, trials demonstrating behavioural adjustments were associated with greater ACC activity for the preceding high conflict trial. Kerns et al. suggested that the ACC acts as a conflict monitor leading to the recruitment of control, and that the PFC executes cognitive control.

Others have suggested that the DLPFC is responsible for implementing top-down attention control (e.g., MacDonald, Cohen, Stenger, & Carter, 2000; Milham, Banich, Claus, & Cohen, 2003; Milham et al., 2001; Miller & Cohen, 2001). That is, it is suggested that the ACC is sensitive to the presence of response conflict (Milham, Banich et al.; Milham et al.) or performance monitoring (MacDonald et al.), whereas the DLPFC is activated at the non-response level as well (e.g., discriminating between task-relevant and task-irrelevant information; Milham et al.) and is responsible for the implementation of top-down cognitive control (MacDonald et al.; Milham, Banich, et al.; Miller & Cohen). Additionally, Liu, Banich, Jacobson, and Tanabe, (2006) have proposed that there exists a functional distinction between response and non-response related attention selection in the PFC. Specifically, the right inferior PFC and the ACC were found to be related to attention at the response level, whereas activity in the left DLPFC was related to non-response aspects of attention control.

Finally, Carter and van Veen (2007) have proposed the conflict-control loop theory. This theory posits that the ACC monitors conflict during both correct and incorrect trials, and modulates the implementation of control by the DLPFC on a trial-by-trial basis. This trial-by-trial association between the monitoring mechanism of the ACC and control implementation by the DLPFC form the conflict-control loop.

Although the exact mechanism(s) of cognitive control are not agreed upon, it is interesting to note the similarities between the areas involved in cognitive/attention control just described and those that are involved in language control. In terms of non-verbal cognitive control, Fan et al. (2003) investigated brain activation using functional magnetic resonance imaging (fMRI) while participants performed tasks involving conflict between stimulus dimensions. Behaviourally, RT was faster when the two stimulus dimensions were congruent than when they were incongruent, demonstrating that the tasks introduced conflict. The fMRI data showed that the conflict in these tasks was associated with activation in the ACC and left PFC.

With respect to language control, Hernandez et al. (2001) investigated brain activation in highly fluent bilinguals during language switching using fMRI. In their experiment, bilingual participants named pictures in blocks in each of their languages separately, and in mixed language blocks. No differences were found between the brain areas activated during the within-language blocks, demonstrating overlapping areas for each language. However, during the mixed language blocks, Hernandez et al. found increased activation in the DLPFC relative to the within-language blocks, which they suggest demonstrates increased executive function related to language switching. Furthermore, a within-language switching condition, where the switch was between naming an object and naming an action, was not associated with the increase in DLPFC activation observed when switching between languages.

Rodriguez-Fornells et al. (2005) used both ERPs and fMRI during a picture naming go/no go task to examine interference from a non-target language while naming pictures in a target language in bilinguals. In this paradigm, monolingual and bilingual participants were asked to respond (or withhold responding) depending on whether the first letter in the name of the object was a vowel or a consonant (e.g., respond if the first letter is a consonant and do not respond if the first letter is a vowel). The bilinguals performed separate language blocks in their native and second language, and for half of the stimuli the names in both languages required the same response, while for the other half they required different responses. The monolinguals only named pictures in their native language. Rodriguez-Fornells et al. found behavioural, ERP and fMRI evidence demonstrating interference from the non-target language in bilinguals. Of interest here are the fMRI results, which showed that there was increased activation in the left PFC for bilinguals relative to monolinguals. This was taken as an indication that brain areas involved in executive function were recruited by the bilinguals to manage interference from the non-target language. Activity in the ACC was also greater for bilinguals than monolinguals, which was taken to reflect response conflict processes in the bilinguals.

More recently van Heuven et al. (2008) concluded that language processing leads to conflict in the bilingual brain during language comprehension, even when a single language is required to perform a task. The critical stimuli used here were interlingual homographs and English control words, and there were no words exclusive to the native language of the bilingual participants included in the experiment. English monolingual and Dutch/English bilingual participants were required to make a lexical decision on visually presented stimuli. There were two versions of the lexical decision paradigm intended to generate conflict at different levels. The English lexical decision task required participants from both language groups to decide whether a stimulus was an English word; given that interlingual homographs were included, this task was considered to involve response conflict in the bilinguals. Bilingual participants were not informed of the presence of interlingual homographs and the meaning of the interlingual homograph in the non-target language was irrelevant for the task, therefore, the interpretation in the target language would require a “yes”, while the interpretation in the non-target language would require a “no” response. The generalized lexical decision task required bilingual participants to decide whether the stimulus was a word, regardless of the language; no response conflict was expected to occur in this condition. Stimulus based language conflict (e.g., phonology, semantics) was expected in the bilinguals for both lexical decision tasks. Of interest here is that van Heuven et al. found increased activation in the ACC for the English lexical decision task relative to the generalized lexical decision task, suggesting a role for the ACC in response conflict. Furthermore, stimulus-based language conflict was expressed as stronger activation in the left inferior PFC for the interlingual homographs in the bilingual group only.

As was previously noted, proficient bilinguals are generally able to speak in one language without intrusions from the non-target language, as well as switch between languages at will. Pathological language switching (i.e., alternation of languages across utterances) has provided further support for the role of the ACC, prefrontal and frontal brain areas the management of two languages. Specifically, Fabbro et al. (2000) describe pathological language switching in a patient who underwent two stereotactic volumetric resections to remove tumours in the left frontal lobe and right cingulate area. Following the first surgery the patient demonstrated pathological language switching in the absence of aphasic symptoms, suggesting that the system responsible for language switching is independent of language per se.

Given the review thus far, it seems clear that: bilinguals activate their two languages in a non-selective fashion; some control mechanism is required for a bilingual to manage their two languages; there are similarities between bilingual language control and general cognitive/executive control; and similar brain areas are activated during tasks requiring general cognitive/executive control and bilingual language control. Keeping this in mind, the discussion will now turn to a potential consequence of the implications of these finding: the bilingual advantage.

1.4 The Bilingual Advantage

The bilingual advantage refers to findings showing that bilinguals demonstrate superior performance on tasks requiring executive control relative to monolinguals. Evidence for a bilingual advantage in executive control in young and older adults comes from studies using the Stroop task (e.g., Bialystok et al., 2008; Zied et al., 2004), the Simon task (e.g., Bialystok, 2006; Bialystok et al., 2005; Bialystok et al., 2004; Bialystok, Martin, et al., 2005), and the attention network test (ANT; e.g., Costa, Hernández, Costa-Faidella, & Sebastián-Gallés , 2009; Costa, Hernández, & Sebastián-

Gallés, 2008). Age-appropriate tasks have also been used to demonstrate the advantage for bilingual relative to monolingual children (Bialystok, 1986; 1988; 1999; Bialystok & Martin, 2004; Bialystok, Martin, et al.; Martin-Rhee & Bialystok, 2008), which suggests that executive control develops earlier in bilingual children. Each of these will be discussed in turn; however, prior to this it is important to acknowledge that there are also disadvantages that have been associated with speaking more than one language (see Bialystok, 2009; Michael & Gollan, 2005). That is, bilinguals have been found to have smaller vocabularies, difficulties with lexical access/retrieval (e.g., lower verbal fluency, more frequent tip-of-the-tongue states; longer picture naming latencies). Given that the focus of the research included in this thesis is the effect of bilingualism on executive control, and deficits associated with bilingualism seem to be restricted to language production and lexical retrieval, the disadvantages associated with bilingualism will not be discussed further.

With respect to the earlier development of executive control functions, Bialystok (1986) used a grammaticality judgement task in children between 5 and 9 years old to show superior performance in bilingual relative to monolingual children when problems involve high levels of control. The task required children to judge whether a sentence was grammatical or not, even if it was semantically meaningless (e.g., *Apples grow on noses*). A second task required children to correct ungrammatical sentences; however, they were not to correct the semantic anomaly (e.g., *Apples growed on noses* →*Apples grow on noses*). The judgment task was assumed to tap linguistic knowledge, whereas the correction task was assumed to tap control processes given that correcting the grammar of semantically anomalous sentences requires effort to suppress the anomaly. Not surprisingly, there was an effect of age, but more importantly for our purposes the bilingual children showed better performance on high control items relative to the monolingual children. These findings were replicated in children with varying levels of bilingualism and even partially bilingual children showed an advantage in high control conditions relative to monolinguals (Bialystok, 1988).

This advantage for bilinguals has also been demonstrated in children using nonverbal tasks (Bialystok, 1999), such as the dimensional change card sort task. For this task, children are given a card with a picture of one of two targets (e.g., a red square or a blue circle), and are then required to sort a set of cards with blue squares and red circles based on a single dimension (e.g., color). Once 10 cards have been sorted the rules change and the child must sort the cards based on the other dimension (e.g., shape). Solving the problem requires executive control in order to inhibit the more salient alternative and sort the cards based on the new rule. Bialystok found that bilingual children showed significantly more correct responses than monolinguals. Furthermore, using 80% correct responses as passing criteria 50% of monolingual children passed, whereas 76.7% of bilingual children passed. Bialystok and Martin (2004) further examined the bilingual advantage in the dimensional card sort task to ensure that the earlier findings did not result from differing representational abilities between bilingual and monolingual children. They replicated the previous results in a variation of the task that accounts for representational ability, and the source of the bilingual advantage was attributed to greater conceptual inhibition (i.e., the ability to inhibit the previously relevant sorting rule) in bilinguals than in monolinguals.

Martin-Rhee and Bialystok (2008) further demonstrated that the bilingual advantage is confined to tasks requiring control of attention to competing cues. In their first study, children performed a Simon task under three delay conditions: immediate response; short delay, where a cue occurring 500 ms post-stimulus indicated that the child could respond; and long delay, where the cue appeared 800 ms post-stimulus. The Simon task (Simon & Rudell, 1967) requires that participants inhibit information from one dimension of a stimulus (e.g., position) in order to respond to another (e.g., color); see Appendix A for sample stimuli. It was found that when children were given time to reflect on their response and resolve the competition between responses the bilingual advantage was eliminated, even in the short delay condition, indicating that the difference between language groups occurred at an early stage of processing.

In a second study (Martin-Rhee & Bialystok, 2008), two additional experiments were designed specifically to examine response inhibition, which refers to the need to inhibit a habitual response and replace it with an arbitrary, less familiar response, and interference suppression, which is the inhibition of information from an irrelevant dimension of a stimulus that conflicts with the dimension relevant to the response. In monolingual and bilingual children, response inhibition was examined using a Stroop picture naming task, where children were required to say “night” when they saw a picture of a bright sun, and say “day” when they saw a picture of a dark moonlit sky, whereas interference suppression was examined using a Simon task. It was found that the bilingual children showed faster RTs for both congruent and incongruent trials in the Simon task and no difference was found between the language groups for the Stroop task, indicating that the source of the bilingual advantage was interference suppression.

Martin-Rhee and Bilaystok replicated these findings in a third study using an arrows task, for which children were required to indicate the direction that an arrow was pointing in using left or right response keys. In one version of the task the arrow was presented at the center of the monitor and children had to indicate either the same or opposite direction of the arrow, which taps into response inhibition. In a second version of the task, responses were to indicate the direction of the arrow; however, the arrows were presented on either side of the monitor, thus introducing congruent and incongruent trials and tapping into interference suppression. Again, the bilingual children showed faster RTs for both congruent and incongruent trials relative to the monolingual children, and there were no language group differences when the arrows were presented at the center of the monitor.

These studies demonstrate that differences between monolinguals and bilinguals in controlled processing emerge early on in development. I will now review language group differences in young and older adulthood.

The color-word Stroop task (Stroop, 1935) requires an individual to name the colour of the print that colour words are presented in; see Appendix A for sample stimuli. On congruent trials the colour of the print and the word are the same, and this can result in facilitation for colour naming. On incongruent trials, the colour of the print and the word do not match and the dominant word reading response must be suppressed in order to correctly identify the colour of the print. This normally results in interference; an increase in response time (RT) to name the colour relative to a neutral condition (e.g., naming the colour of the print for a string of “x”s). The Stroop effect, which refers to the increase in RT for incongruent relative to neutral trials, is a robust and extensively studied phenomenon (see MacLeod, 1991), and has been considered “the most important task demonstrating executive control and conflict resolution” (Bialystok, 2009, p. 6).

Zied et al. (2004) investigated Stroop performance in younger and older bilinguals. Although they did not compare monolinguals and bilinguals, their two age groups were comprised of balanced bilinguals and individuals dominant in each of the languages of interest (i.e., French and Arabic). Furthermore, in addition to examining within language interference in the Stroop task, they also examined interference across languages by presenting incongruent stimuli in one language and requiring responses in the other. The key finding from this study was that the balanced bilinguals demonstrated faster RTs relative to both groups of unbalanced bilinguals in all Stroop conditions, and this was the case for both age groups. These findings were taken as evidence that manipulating two languages enhances inhibitory efficiency.

Bialystok et al. (2008) investigated the Stroop effect in young and older monolinguals and bilinguals in the context of a larger study also examining performance of a Simon task, and working memory and lexical access tasks. It was found that both young and older bilinguals demonstrated smaller interference effects relative to their monolingual counterparts. Interestingly, the older bilinguals also demonstrated larger facilitation effects relative to monolinguals.

As previously alluded to, the bilingual advantage has also been examined using the Simon task (Simon & Rudell, 1967). In the version most commonly used for recent investigations, an individual is presented with a stimulus in one of two colours on either side of a screen and each colour is associated with a response on either side of a keyboard or response box. On congruent trials the correct response and the position of the stimulus on the screen are on the same side, whereas on incongruent trials the response and the position of the stimulus are on opposite sides; see Appendix A for sample stimuli. In order to respond correctly an individual must ignore the position information and respond only to the colour information. It should be noted that there are different variations of the Simon task which will be specified where relevant. The Simon effect refers to the increase in RT for incongruent relative to congruent trials.

Bialystok, Martin, et al. (2005) examined the development, stability and decline of the cognitive control processes required for performance of the Simon task in monolingual and bilingual children, young adults, middle-aged adults, and older adults. Bilingual children were found to be faster for both congruent and incongruent trials relative to monolinguals. Although this suggests that the bilinguals simply demonstrated a speed advantage, this was ruled out by examining a control condition in which there was no conflict which demonstrated similar performance by the monolinguals and bilinguals. In contrast, results from the young adults indicated that there was no difference between the two language groups. However, when the bilingual and monolingual groups were subdivided into high and low computer video game players differences emerged, demonstrating faster responses for high players relative to low players, regardless of language group. In middle-aged and older adults the advantage for bilinguals re-emerged; that is, bilinguals in both age groups demonstrated faster responding for both congruent and incongruent trials relative to their monolinguals peers, and there was no difference between the language groups on the control condition. Bialystok, Martin et al. suggest that the observed bilingual advantage for both congruent and incongruent trials indicates that bilinguals are better able to carry out the switches between congruent and incongruent items relative to monolinguals. The absence of an advantage for the young adults was attributed to the fact that these individuals were at the height of cognitive efficiency and thus bilingualism afforded them no additional advantage. This led to the conclusion that bilingualism is advantageous during the development and decline of executive control functions.

Given the absence of a bilingual advantage in young adults (Bialystok, Martin, et al., 2005) Bialystok et al. (2005) used magneto-encephalography (MEG) to examine performance of the Simon task in monolingual and bilingual young adults. The goal was to determine if brain responses during Simon task performance differed between monolinguals and bilinguals despite similar behavioural performance. In their study, Bialysok et al. included two bilingual groups, Cantonese-English and French-English. Behaviourally it was found that the Cantonese-English bilinguals demonstrated a speed advantage relative to the French-English bilingual and the monolingual groups, which performed similarly. However, the imaging data differentiated the two bilingual groups from the monolingual group. Specifically, all three groups showed similar brain activation in the theta frequency band (4-8 Hz), which is normally associated with focused attention (e.g., Ishii et al., 1999). Whereas, partly in the alpha frequency band (8-15 Hz), which has been associated with sensory processing (e.g., Schürmann & Başar, 2001), faster responding in the bilinguals was associated with greater activation in the right temporal, and left frontal and cingulate areas. Thus, the results demonstrated that even in the absence of behavioural differences between monolinguals and bilinguals, the underlying neural processes involved in performance of the Simon task were different for the two language groups.

Following the finding that differences in performance of the Simon task emerged between high and low computer video game players (Bialystok, Martin, et al., 2005), Bialystok (2006) further examined the specific contributions of video game experience and bilingualism to an advantage on Simon task performance in young adults. The goal was to evaluate the effect of these two different experiences on the processes involved in performance of the Simon task, such as selective attention, inhibition, and response switching (see Bialystok). Given that managing two languages is thought to involve selective attention and inhibition, it was expected that the bilinguals would demonstrate superior performance relative to the monolinguals. Similarly, playing video games requires fast responding, selective attention, and rapid switching between response options; thus, experienced computer video game players may also show enhanced performance on the Simon task relative to non-players. However, the two experiences were hypothesized to have different effects on performance. Specifically, given the implication of bilingualism for executive control functions, bilingual individuals were expected to show an advantage when the task required greater inhibitory control, whereas the experienced computer video game players were expected to show an advantage when the task placed demands on working memory (which was taken by the author to be more closely related to the skills required for video games given the arbitrary stimulus-response associations required in video games).

Bialystok (2006) used two versions of the Simon task to examine performance in young monolingual and bilingual video game players and non-players. In the first version, the stimuli were comprised of coloured squares presented on either side of a monitor; the second used arrows that could be pointing in the same direction as the position on the screen (i.e., congruent), or the opposite direction (i.e., incongruent). Furthermore, there were low and high switch conditions for each version. The coloured square version was meant to tap working memory given the requirement to remember the stimulus-response association, whereas the arrows version was meant to draw on inhibitory control given the requirement to resolve the spatial conflict between the direction and position of the arrow. The high switch condition for both tasks were intended to increase demands on the monitoring and switching processes of executive control. Results showed that both language groups performed similarly on the low switch arrows version of the task but, for the high switch condition, bilinguals showed more rapid responding than monolinguals. For the squares task, video game players were faster than non-players and all participants performed the low switch condition faster than the high switch condition. These results demonstrated the specificity of the bilingual advantage; that is, video game playing resulted in an overall speed advantage whereas bilingualism resulted in an advantage only for the most demanding task.

The bilingual advantage for the Simon task has also been examined in older adults. Bialystok et al. (2004) examined performance on the Simon task in bilingual and monolingual young (30-54 years old) and older (60-88 years old) adults. Results showed that the Simon effect was larger for the older than the younger adults and for the monolinguals than the bilinguals in both age groups. The source of the bilingual advantage was further examined in young (30-58 years old) and older (60-80 years old) monolinguals and bilinguals by including a neutral condition, where the stimulus appeared at the center of the monitor and no spatial information was present to introduce response conflict, as well as two high working memory conditions, which included four colours requiring participants to maintain four rules in working memory. In the high working memory conditions, Bialystok et al. found faster RTs for younger relative to older adults and for the bilinguals relative to the monolinguals; furthermore, the age-related increase in RT for the high working memory conditions was smaller for the bilinguals relative to the monolinguals. In terms of inhibitory processes, the older adults showed larger Simon effects for both working memory conditions than the younger adults, as did monolinguals relative to bilinguals. Similar to the working memory findings, the age-related increase in the magnitude of the Simon effect was attenuated in the bilinguals. These findings suggested that the benefits associated with being bilingual may not be restricted to inhibitory control, and may in fact exert effects on executive control processes more generally.

In the previously described study for which Bialystok et al. (2008) found a bilingual advantage for the Stroop task, a similar advantage was found for the Simon effect. However, consistent with a previous study (Bialysok, Martin, et al., 2005), an advantage in terms of the Simon effect was only found for the older adults. In addition, the bilingual older adults showed no Simon effect, indicating that they responded with equivalent RTs for both congruent and incongruent trials.

A final task that will be described with respect to the bilingual advantage is the ANT (Fan, McCandliss, Sommer, Raz, & Posner, 2002). The ANT was designed to evaluate three attentional networks: alerting (i.e., achieving and maintaining alertness); orienting (i.e., selecting information from sensory input); and executive control (i.e., resolving response conflict). The ANT is comprised of a cued reaction time task (Posner, 1980) and an Eriksen flanker task (Eriksen & Eriksen, 1974). The cued reaction time task uses a cue to indicate when and/or where a stimulus is going to appear, whereas the Eriksen flanker task requires participants to respond to a central stimulus appearing above or below fixation while ignoring flanking distractors on either side of the stimulus; see Appendix A for sample stimuli of a simple Eriksen flanker task. In the ANT, the participant is required to indicate the direction of a central arrow. In the neutral condition the central arrow is flanked on either side by two lines, whereas in congruent and incongruent conditions the central arrow is flanked on either side by two arrows pointing in the same/congruent or the opposite/incongruent direction. This aspect of the task allows for the examination of the executive control network, which is engaged to resolve the conflict in the incongruent condition. In addition, there are four cue conditions: no cue, center cue, double cue, and spatial cue. The alerting effect is examined by subtracting the mean RT for the "double cue" condition from the mean RT for the "no cue" condition, which provides a measure of the decrease in RT resulting from the cue indicating the onset of the stimulus in the absence of any spatial information. Given that both the "center cue" and "spatial cue" conditions provide alerting information, but only the "spatial cue" condition provides any information regarding the location of the stimulus, the orienting effect is examined by subtracting the mean RT for the "spatial cue" condition from the mean RT for the "center cue" condition. Finally, the executive control network is examined by subtracting the mean RT for congruent trials from the mean RT for incongruent trials across all cue types.

Costa et al. (2008) used the ANT to investigate alerting, orienting and executive control networks in young monolinguals and bilinguals in order to determine which network(s) is/are influenced by bilingualism. In terms of the alerting network, bilinguals demonstrated a greater RT difference between the “no cue” and “double cue” conditions demonstrating that bilinguals benefitted from the alerting cue to a greater extent than the monolinguals. Examination of the executive control network revealed an advantage for bilinguals relative to monolinguals for both congruent and incongruent trials, as well as a larger increase in RT for incongruent relative to congruent trials in the monolinguals. Finally, the orienting network appeared to be unaffected by bilingualism given that the presence of an orienting cue produced similar reductions in RT relative to the “no cue” condition for both language groups. These results suggested that bilingualism exerts its effects on the alerting and executive control networks of attention. It should be noted that given the inconsistencies in the literature regarding the presence of the bilingual advantage in young adults (e.g., Biaystok , Martin et al., 2005 did not find an advantage in young adult bilinguals relative to monolinguals) Costa et al. used a large sample (n=200) affording them enough power to detect a small effect.

Costa et al. (2009) further examined the bilingual advantage in the ANT task by varying the proportion of congruent and incongruent stimuli. Given that bilinguals have been found to show faster responding for both congruent and incongruent trials (e.g., Bialystok, Martin et al., 2005; Costa et al., 2008), the goal of their investigation was to examine whether the overall speed advantage in bilinguals is the result of a more efficient monitoring system. Costa et al. conducted two experiments using modified versions of the ANT. In the first experiment, 92% of trials were either congruent or incongruent, thus requiring low monitoring given that there were few switches between congruent and incongruent trials. It was found that there were no differences in overall RT between monolinguals and bilinguals, and the RT difference between congruent and incongruent trials was similar for both language groups. In their second experiment, the proportion of incongruent trials was either 50% or 25%, which increased the demands on monitoring. In both the 50% and 25% versions bilinguals showed a general speed advantage relative to monolinguals. However, the conflict effect was smaller for the bilinguals in the first block of the 25% version only. This demonstrated that in young adults, the speed advantage for bilinguals only emerged when monitoring demands were high, suggesting a more efficient monitoring system in bilinguals relative to monolinguals. Furthermore, in blocks 2 and 3 of the 25% version monolinguals showed similar conflict effects to the bilinguals, demonstrating that the monolinguals were able to perform as well as the bilinguals with practice and suggesting that the bilingual advantage in young adults is limited to certain conditions.

The literature reviewed here provides evidence for differences in executive control function between monolinguals and bilinguals. The question that arises is: how does the knowledge of more than one language translate to enhanced higher-order cognitive function? It has been hypothesized that the constant management of two languages in bilinguals underlies this advantage (e.g., Bialystok, 2007). That is, given that a bilingual's two languages are activated non-selectively and current theories postulate that general cognitive control mechanisms are enlisted to manage the competition between the two languages, these mechanisms are believed to be well-practiced over the lifespan and thus enhanced in bilinguals (Bialystok, 2009). Studies demonstrating that the advantage for bilinguals emerges early on in development (e.g., Bialystok, 1986; 1988; 1999; Bialystok & Martin, 2004; Bialystok, Martin, et al., 2005; Martin-Rhee & Bialystok, 2008), and that executive function declines later in bilingual older adults relative to monolinguals (e.g., Bialystok et al., 2004, 2008; Bialystok, Martin, et al., 2005; Zied et al., 2004) support this suggestion. It should be noted that the majority of the evidence discussed here has come from a single research group.

Further support for the hypothesis that the constant management of two languages results in enhanced executive control is evidence suggesting that bilingualism may provide a buffer against age-related cognitive decline. Evidence for a bilingual advantage in older adults was summarized earlier; the following section will address normal age-related cognitive decline in greater detail, followed by evidence for bilingualism as a possible source of "cognitive reserve".

1.5 Age-related Changes in Executive Control

There are well-documented changes in cognition associated with normal aging (e.g., Craik & Salthouse, 2008; Drag & Bieliauskas, 2010; McDowd & Shaw, 2000), including executive control. Several theories have been proposed to account for these observed age-related changes, although there is no clear consensus on the exact process and/or mechanism.

The cognitive resources hypothesis (Hasher & Zacks, 1979) conceives of attention as a limited supply of resources that are available for performing cognitive functions, and these resources can be applied during different stages of processing (Kahneman; as cited in Hasher & Zacks; McDowd & Shaw, 2000). When processing is effortful, attentional resources are allocated to the task at hand and become unavailable for additional processing. Hasher and Zacks propose that aging is associated with a reduction in these available resources leading to the emergence of age-related deficits when processing demands are high.

Hasher and Zacks (1988; see also Zacks & Hasher, 1997) also proposed the more process-specific inhibition deficit hypothesis. According to this hypothesis, older adults experience a decline in the efficiency of inhibitory control, which leads to irrelevant information entering working memory and receiving sustained activation. Given that working memory is a limited-capacity system used to store and manipulate recent information (Baddeley, 1986) and according to the inhibition deficit hypothesis the inefficiency of inhibitory control associated with aging leads to a cluttering of working memory, it is not difficult to see how this could lead to observable declines in cognition in older adults (but see McDowd, 1997). Others have suggested that limitations in working memory capacity alone are responsible for age-related differences (Just & Carpenter, 1992). It is noteworthy that these mechanisms of change were proposed to account for age-related differences in language comprehension, although they have similar consequences for other tasks requiring inhibition and the maintenance of task relevant information in working memory (e.g., the Stroop task; Cohn, Dustman, & Bradford, 1984; Davidson, Zacks, and Williams, 2003; Houx, Jolles, & Vreeling, 1993).

Salthouse (1996) proposed that age-related declines in processing speed accounts for age-related differences in cognition, while others suggest that the executive control processes of switching and dividing attention are important for age-related changes in cognition (see McDowd & Shaw, 2000). Another view attributes changes in cognitive function to age-related declines in sensory function (Lindenberger & Baltes, 1994); that is, inefficient sensory function results in an increase in the resources required for stimulus identification, leaving fewer available resources for more complex cognitive processes (e.g., Pichora-Fuller, Schneider, & Daneman, 1995).

In terms of the mechanism by which age-related cognitive change occurs, the frontal aging hypothesis (see Dempster, 1992; West, 1996) proposes that age-related changes occurring in the prefrontal cortex are responsible for changes in cognition. Initially this theory was proposed to account for changes in inhibitory control (Dempster), and was later applied to memory processes (West). Given that the prefrontal cortex is particularly sensitive to aging (West) it is to be expected that the processes supported by this brain area would show signs of decline. The reviews provided by Dempster and by West cite evidence in support of the theory that age-related changes in the processes of inhibition, interference control, prospective and retrospective memory, and sustained attention can be explained by changes in the prefrontal cortex.

Interestingly, as was described in the previous section, executive control appears to decline later in bilinguals. Furthermore, there is evidence suggesting that bilingualism may actually provide a buffer against some of the declines associated with dementia. Specifically, it has been found that bilingualism may contribute to cognitive reserve, which refers to environmental factors such as life experience, education, and occupation, that mitigate age-related cognitive decline and allow an individual to maintain normal functioning in the presence of dementia-related brain pathology (see Stern, 2002). For instance, Bialystok, Craik, and Freedman (2007) examined the records of bilingual and monolingual patients diagnosed with probable Alzheimer's disease, as well as other dementias. The striking result was that the onset of symptoms of dementia was delayed by 4.1 years in bilinguals relative to monolinguals. However, it is noteworthy that 81 of the 93 bilinguals in this study were immigrants to Canada, whereas most of the monolinguals were not; thus, it is unclear whether the observed effect resulted from being bilingual, or from different life experiences associated with immigration. More recently, Chertkow et al. (2010) attempted to replicate these findings in both a group of multilingual speakers who were immigrants to Canada, as well as a group of native Canadian bilinguals. Furthermore, Chertkow et al. restricted their sample to patients who were diagnosed with probable Alzheimer’s disease. It was found that bilinguals were diagnosed with Alzheimer’s disease 5.1 years later than monolinguals in the immigrant group and a similar trend was found in the native French speaking bilingual Canadians (i.e., bilinguals diagnosed 3.2 years later than monolinguals); however, there was no protective effect for Canadian bilinguals whose native language was English. Furthermore, in the immigrant group the protective effect increased with increasing number of languages spoken such that monolinguals were diagnosed 6.4 years earlier than trilinguals, and 9.5 years earlier than patients who spoke four or more languages. Although Bialystok et al. and Chertkow et al. did not obtain entirely consistent results, there is evidence to suggest that the management of multiple languages may contribute to cognitive reserve, but more research is needed to elucidate the exact nature of this contribution.

In another study, the number of languages spoken was related to cognitive screening performance in a random sample of older adults (Kavé, Eyal, Shorek, & Cohen-Mansfield, 2008). Both Bialystok et al.(2007) and Chertkow et al. (2010) investigated clinical samples, whereas Kavé et al. examined a large random sample of older adults in a longitudinal study including three waves of testing over a period of 12 years. Their sample included bilinguals, trilinguals, and multilinguals defined as individuals who spoke four or more languages; there were no monolinguals. Their results showed that when other demographic variables were statistically controlled the three language groups differed in their performance on the cognitive screening measure, with multilinguals achieving the highest performance and bilinguals the lowest. Kavé et al. also found that in a sample of older adults who had received no formal education, an increase in the number of languages spoken was associated with superior cognitive state. Although more research is needed, taken together these studies suggest that the bilingual advantage that has been observed for attentional tasks may have implications for aging and cognitive decline; however, it may be the case that multilingualism and not bilingualism *per se* is advantageous in this respect. One caveat here is that all of these findings are correlational, thus it is possible that the characteristics necessary for a person to master multiple languages is responsible for the observed differences between language groups and that both the observed cognitive advantage and the mastery of multiple languages are consequences of some other variable such as brain structure or function.

The literature reviewed here is compelling and is the basis on which the studies included in this thesis were conceived and designed. To reiterate, the purpose of the studies included in this thesis were to: 1- replicate previous findings of a bilingual advantage in a more homogeneous sample of young and older adults using a Stroop task; 2- to evaluate the bilingual advantage using multiple tasks in the same sample of young monolingual and bilingual adults; and 3- to examine the electrophysiological correlates of performance in tasks previously found to be sensitive to the bilingual advantage in young adults. The following two manuscripts provide a detailed description of these studies.

CHAPTER 2: Manuscript 1: Aging, Bilingualism, and Stroop Interference.

Aging and bilingualism: An investigation of the “bilingual advantage” in Stroop interference.

To be submitted to *Bilingualism: Language and Cognition*

2.1 Abstract

Previous research has found an advantage for bilinguals over monolinguals on tasks of attentional control. This bilingual advantage has been found to be greater for older adults than for younger adults, suggesting that bilingualism provides a buffer against age-related declines in executive functioning. The goal of the present investigation was to replicate previous findings using a modified Stroop task in a more homogeneous sample than the samples used in previous studies. Young monolinguals (n=38), young bilinguals (n=35), older monolinguals (n=25) and older bilinguals (n=20) completed three conditions of a computerized Stroop task: word reading, colour naming, and incongruent colour naming. A bilingual advantage would be demonstrated by smaller Stroop interference (i.e., smaller increases in response time for incongruent trials relative to neutral or congruent trials) for bilinguals relative to monolinguals. Bilingual young adults showed a general speed advantage over their monolingual counterparts, but this was not associated with smaller Stroop interference. Older adults showed a larger interference effect than young adults, but there was no effect of bilingualism. Thus, the present investigation does not find evidence of a bilingual advantage in young or older adults, and raises questions regarding the robustness of this effect.

2.2 Introduction

Recent investigations suggest that the executive control processes required for manipulating two languages in lifelong bilinguals may provide them with an advantage on tasks of attentional control (Bialystok, 2006; Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Craik, & Ryan, 2006; Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Costa, Hernández, & Sebastián-Gallés, 2008; Martin-Rhee & Bialystok, 2008), such as the Stroop task (Bialystok, Craik, & Luk, 2008; Zied et al., 2004). Evidence for this comes from studies in children (e.g., Martin-Rhee & Bialystok, 2008), young adults (e.g., Bialystok, 2006; Costa et al., 2008, 2009), and older adults (e.g., Bialystok et al., 2004; Bialystok et al., 2008; Zied et al., 2004). Given the well-documented declines in cognition that have been associated with aging (Craik & Salthouse, 2008), these findings suggest that proficiency in a second language may provide a buffer against such age-related cognitive declines. Specifically, language experience may confer an advantage on non-language specific cognitive mechanisms. The goal of the present investigation was to replicate previous findings of a bilingual advantage in a homogeneous sample of highly proficient English/French young and older bilinguals.

Stroop (1935) was the first to describe what is now known as the Stroop interference effect. Stroop found that it took significantly longer for participants to name the colour of the ink that a colour word was printed in when the ink colour and the word did not match (e.g., saying “red” in response to the word *blue* printed in red ink), than to name the colour of solid squares. However, when asked to read colour words when they were printed in ink of another colour, there was no reliable increase in reaction time (RT) relative to reading the same words printed in black ink. That is, word reading was not affected by ink colour, whereas naming the colour of the print of an incongruent word stimulus was affected by the incongruent word.

Since the publication of Stroop's (1935) seminal paper, the Stroop effect has been extensively studied and has proven to be a highly robust effect (for review, see MacLeod, 1991). The Stroop paradigm has also been modified to investigate other phenomena, such as emotion (e.g., Frings, Englert, Wentura, & Bermeitinger, 2010), spatial attention (e.g., Luo, Lupiáñez, Fu, & Weng, 2010), and semantic processing (e.g., Conrad, 1974; Klein, 1964). Furthermore, the Stroop task has been used to investigate attentional control in various patient populations, for example, schizophrenia (e.g., Ungar, Nestor, Niznikiewicz,Wible, & Kubicki, 2010), depression (e.g., Markela-Lerenc, Kaiser, Fiedler, Weisbrod, & Mundt, 2006), traumatic brain injury (e.g., Larson, Kaufman, & Perlstein, 2009), and mild cognitive impairment and Alzheimer's disease (e.g., Bélanger, Belleville, & Gauthier, 2010; Belleville, Rouleau, & Van der Linden, 2006; Spieler, Balota, & Faust, 1996).

Several theories have been proposed to explain the Stroop interference effect with varying ability to account for the empirical findings (see MacLeod, 1991). For this investigation we take the position that Stroop interference results from competition between word reading and colour naming, and that the dominant skill of word reading must be suppressed/inhibited in order to correctly name the incongruent colour of the print. This process has been referred to as interference suppression; that is, the filtering out of irrelevant information in the environment (Bunge, Dudukovic, Thomason, Vaidya,

& Gabrieli, 2002; Bialystok et al., 2008). Thus, greater Stroop interference corresponds to weaker suppression/inhibition of the irrelevant stimulus dimension.

In the current study the effects of aging and bilingualism on Stroop interference were investigated. A dominant view in the cognitive aging literature is that declines in inhibition underlie age-related changes in cognition (Hasher & Zacks, 1988; Zacks & Hasher, 1997). According to this hypothesis, aging is associated with a decline in inhibitory control that allows irrelevant information to enter working memory and to receive sustained activation. Consistent with this hypothesis, the Stroop effect has been found to be greater in older adults relative to young adults. Cohn, Dustman, and Bradford (1984) found that healthy older adults demonstrated greater interference than younger adults and suggested that this was the result of older adults having difficulty inhibiting the irrelevant stimulus dimension, in this case the word, while attending to the relevant dimension, colour. Houx, Jolles, and Vreeling (1993) showed that this difference remained even when biological life events (e.g., exposure to neurotoxic factors, mild head injuries) were controlled for. Others have found that the greater interference effect in older adults is maintained despite practice with the stimuli (Davidson, Zacks, and Williams, 2003), is present when stimulus orientation is manipulated (Weir, Bruun, & Barber, 1997), and is associated with decreased activation in dorsolateral prefrontal and parietal cortices, more extensive activation of temporal cortex, and increased sensitivity of the anterior cingulate cortex to incongruent colour information (Milham et al., 2002). Although the effect is well established its cause is more controversial. Some authors have argued that age-related changes in sensory processing resulting from age-related deterioration of colour vision (Ben-David & Schneider, 2009), rather than a decline in inhibition underlie the effect.

Another influential hypothesis of the cause of age-related increases in the Stroop effect is that of general slowing, which contrasts with the specific effect of age on inhibitory processes proposed by the inhibitory deficit hypothesis. The processing speed theory (Salthouse, 1996) posits that age-related changes in cognition are the result of the slowing of general cognitive mechanisms. Several studies have investigated whether the increased interference observed in older adults can be accounted for by age-related decreases in processing speed and found that general slowing alone cannot account for the observed age-differences. For example, Troyer, Leach, and Strauss (2006) found a positive correlation between interference ratio scores and age on the Victoria Stroop Task, as well as increased errors with age. However, they did not find a significant correlation between age and baseline response speed on the colour naming component in the Stroop task, suggesting an age-related difficulty in suppressing the dominant word reading response. Furthermore, Bugg, DeLosh, Davalos, and Davis (2007) examined residual age-related differences in incongruent colour naming after statistically controlling for processing speed. They found that, although processing speed did account for a significant amount of the variability in Stroop performance, 74% of the age-related variance in incongruent colour naming was unaccounted for after statistically controlling for processing speed. The consensus of these is that age-related changes in Stroop interference go beyond that which can be explained by general cognitive slowing and thus must be the result of age-related changes in task-specific processes, such as inhibition (but see Verhaeghen & De Meersman, 1998).

Recently, there has been interest in the effect of bilingualism on Stroop performance. It has been suggested that the management of two languages in bilinguals requires general executive control processes, such as attention, inhibition, monitoring, and switching (see Bialystok, 2007). Specifically, it is well documented that the two languages of a highly proficient bilingual are simultaneously active, even when the individual is engaged in a single language (e.g., Blumenfeld & Marian, 2007; de Bruijn, Dijkstra, Chwilla, & Schriefers, 2001; de Groot, Delmaar, & Lupker, 2000; Dijkstra, Grainger, & van Heuven, 1999; Dijkstra, Timmermans, & Schriefers, 2000; Kerkhofs, Dijkstra, Chwilla, & de Bruijn, 2006; Kousaie & Phillips, 2011; Libben & Titone, 2009; Marian, Spivey, & Hirsch, 2003; Paulmann, Elston-Güttler, Gunter, & Kotz, 2006; van Heuven, Schriefers, Dijkstra, & Hagoort, 2008), creating circumstances unique to bilinguals whereby executive control is required to manage the two language systems. When a bilingual is using one language, attentional mechanisms are required to maintain focus on the target language and reduce interference from the non-target language which leads to extensive practice of these processes in bilinguals, but not monolinguals (Bialystok, 2007; Bialystok & Craik, 2010).

It has been hypothesized that the increased use of these functions in bilinguals results in executive control functions that are “more durable, more efficient and more resilient” (Bialystok, 2007, p. 220). Consequently, it has been suggested that these functions develop earlier and decline later in bilinguals than in monolinguals. The rationale is that attentional control tasks (e.g., the Stroop task) share processing demands similar to those required to manage two languages, such as selective attention to target information, inhibition of irrelevant information, and switching (Bialystok et al., 2004) and, therefore, bilinguals demonstrate an advantage relative to monolinguals on such tasks as a result of extensive practice.

The bilingual advantage was first described in attentional control tasks assumed to measure the inhibition of a prepotent response, similar to inhibition of word reading in incongruent Stroop conditions. The majority of the evidence for a bilingual advantage comes from the Simon task (Simon & Rudell, 1967). In this task participants are presented with stimuli that can vary along two dimensions; however, responses are based on one dimension while the other dimension is irrelevant for task performance. For example, participants are presented with squares that can be red or blue and presented on either side of a computer monitor (see Appendix A for sample stimuli). Responses are made based on the colour of the stimulus using two buttons, one on the left and one on the right. This creates both congruent and incongruent trials depending on whether the correct response corresponds to a button press on the same or different side as stimulus presentation. An increase in response time for trials on which the colour of the stimulus corresponds to a response that is incompatible with the position of the stimulus (i.e., incongruent trials) is known as the Simon effect. An advantage for bilinguals relative to monolinguals on performance of the Simon task has been found in children (Martin-Rhee & Bialystok, 2008), young adults (Bialystok, 2006), and older adults (Bialystok et al., 2004).

More relevant to the present investigation, the bilingual advantage has also been demonstrated in older adults using the Stroop task. Zied et al. (2004) examined age and bilingualism using a Stroop task which included versions in each of the bilingual participants' languages, as well as a between-language condition where stimuli were presented in one language and responses were made in the other language. Participants included bilingual individuals who were either equally proficient in their two languages (i.e., balanced bilinguals) or who were dominant in one language over the other. The important finding from their study is that both the young and older balanced bilinguals demonstrated faster response times for all Stroop conditions relative to the bilinguals with a dominant language. In terms of interference, Zied et al. focussed on within- and between-language interference, and found that older adults with a dominant language showed the greatest interference in between-language conditions. Although it was not reported, presumably there were no differences between the young and older balanced bilinguals. These results were taken as evidence that the manipulation of two languages by balanced bilinguals enhances inhibitory mechanisms.

Bialystok et al. (2008) have also found that Stroop interference (defined here as the difference between congruent and incongruent color naming) was greater for older and for monolingual participants. When their data were examined in terms of facilitation for congruent colour naming (i.e., the difference between neutral and congruent colour naming) and costs for incongruent colour naming (i.e., the difference between neutral and incongruent colour naming) an advantage for bilinguals relative to monolinguals became evident. That is, both older and younger bilinguals showed smaller costs relative to their monolingual counterparts.

Attentional mechanisms have also been found to be more efficient in bilingual than in monolingual young adults using the attentional network test (ANT; Costa et al., 2008, 2009), which measures three attentional networks including switching, orienting, and executive attention. Similarly, bilingual older adults outperformed their monolingual peers on a modified antisaccade task requiring manual responses (Bialystok et al., 2006), which requires the inhibition of a prepotent response and has been taken as further support for a protective role of bilingualism against age-related decline in executive function.

Based on this review it seems clear that bilingualism influences executive control processes and that this persists over the course of the lifespan. The goal of the present investigation was to replicate previous findings of a bilingual advantage using a modified version of the classic Stroop task (Stroop, 1935). The sample included here was comprised of a homogeneous group of English monolinguals and English/French bilinguals, which contrasts with the bilingual samples included in previous studies. That is, most previous studies reporting an advantage for bilinguals relative to monolinguals have used samples comprised predominantly of immigrants who varied with respect to their native and/or second language (e.g., Bialystok, 2006; Bialystok et al., 2006, 2008; Martin-Rhee & Bialystok, 2008). Others have included only bilingual participants varying in their level of proficiency in their L2, but no monolingual comparison group (Zied et al., 2004). Thus, it is important to demonstrate whether the bilingual advantage holds in a homogeneous sample comparing monolingual and bilingual young and older adults. It was hypothesized that if there is in fact an advantage for bilinguals relative to monolinguals there would be greater Stroop interference in the monolinguals relative to the bilinguals. Furthermore, it was predicted that the difference in performance between monolinguals and bilinguals would be greater in the older adults, demonstrating a positive effect of bilingualism on interference suppression/inhibitory control in aging. These findings would be consistent with the previous research reviewed here. Failure to support our hypotheses would raise questions regarding the robustness of the bilingual advantage.

2.3 Method

2.3.1 Participants

The participants for this investigation comprised individuals who had participated in studies investigating aging and/or bilingualism in the Cognitive Psychophysiology Laboratory. Participants were included in the present investigation if they met specific language criteria. The sample consisted of monolingual and English/French bilingual young and older adults. Young participants were recruited from Concordia University and McGill University and older participants were recruited from a database within the Cognitive Psychophysiology Laboratory at Concordia University. All participants were pre-screened using a self-report health and language questionnaire. Bilingual participants were all native English speakers who were highly proficient in French, or who self-reported both English and French as their native language (i.e., both languages were learned simultaneously from birth). Ethical approval for this study was obtained from the Concordia University Human Research Ethics Committee.

Table 1 provides demographic information for each participant group[1]. The group of young adults comprised 38 monolinguals (19 males) between the ages of 18 and 35 (*M* = 22.5, *SD* = 4.5) and 35 bilinguals (11 males) also between the ages of 18 and 35 (*M* = 23.7, *SD* = 4.0). The group of older participants comprised 25 monolinguals (6 males)

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[1] Given the difficulty recruiting participants that met our strict language criteria all the groups were not matched with respect to gender. Evidence for gender differences in Stroop performance is inconsistent (see Macleod, 1991; but see Baroun & Alansari, 2006). For this reason we compared males and females on the three conditions of the Stroop task for each age and language group. The only significant gender difference that was found was in the older bilinguals; females performed faster than males overall. Given that the speed advantage was a general one and we were interested in Stroop interference this was not considered further.

Table 1

Demographic Information for Participant Groups

	Young Monolinguals (n = 38)	Young Bilinguals (n = 35)	Older Monolinguals (n = 25)	Older Bilinguals (n = 20)
	M *(SD)*	M *(SD)*	M *(SD)*	M *(SD)*
Age (in years)	22.5 *(4.5)*	23.7 *(4.0)*	68.9 *(6.5)*	71.9 *(5.9)*
Education (in years)	15.1 *(1.7)*	15.5 *(1.3)*	13.9 *(2.0)*	15.9 *(2.8)*
MoCA	28.6 *(1.3)*	27.8 *(1.7)*	26.8 *(2.0)*	26.6 *(2.0)*
L1 self-reported language proficiency	5.0 *(0.0)*	4.9 *(0.3)*	5.0 *(0.0)*	4.9 *(0.2)*
L2 self-reported language proficiency	n/a	4.2 *(0.6)*	n/a	4.6 *(0.6)*
Coefficient of variability L1	n/a	.24 *(.09)*	n/a	.23 *(.11)*
Coefficient of variability L2	n/a	.26 *(.09)*	n/a	.22 *(.07)*

between the ages of 60 and 81 (*M* = 68.9, *SD* = 6.5) and 20 bilinguals (7 males) between the ages of 62 and 84 (*M* = 71.9, *SD* = 5.9). Forty-seven bilingual participants reported having English as their native language and had learned French before the age of 8. Eight bilingual participants (4 young and 4 older) reported that they had simultaneously learned English and French and had no preference for one language over the other. All bilingual participants reported using both languages on a daily basis. The bilingual participants were also asked to rate their level of proficiency for listening, reading, and speaking in each language on a scale of *1-5*, where *1* indicated "no ability at all" and *5* indicated "native-like ability", the overall means for each group are reported in Table 1. Language proficiency was additionally assessed using an animacy judgement task (Segalowitz & Frenkiel-Fishman, 2005) described below. Participants were matched on age within each age group, and all demonstrated normal cognitive functioning based on the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005). The older bilinguals had more years of education than the older monolinguals, which we controlled for statistically in our data analyses.

2.3.2 Materials and Apparatus

Participants included in this investigation completed the MoCA (Nasreddine et al., 2005), as a measure of overall cognitive functioning; an animacy judgement task (Segalowitz & Frenkiel-Fishman, 2005), to assess relative native (L1) and second (L2) language proficiency; and a modified version of the classic Stroop task (Stroop, 1935).

2.3.2.1 MoCA. The MoCA (Nasredine et al., 2005) is a 10-minute cognitive screening tool used to detect mild cognitive impairment in older adults. It assesses visuospatial ability, executive control, memory, attention, language, and orientation. The

MoCA was included to ensure that all participants demonstrated normal cognitive function. The MoCA is scored out of 30, with a score of 26 or higher indicating normal cognitive functioning[2].

2.3.2.2 Animacy Judgement Task. This task required that bilingual participants categorize, as quickly and accurately as possible, whether a noun referred to a living or nonliving object (Segalowitz & Frenkiel-Fishman, 2005). Scores on this task provided an objective measure of language proficiency. As used here, the task consisted of 72 nouns in English and 72 nouns in French divided into two language blocks. Within each language block there were 64 to-be-judged nouns preceded by 8 practice trials. The stimuli were presented in yellow 20 point Arial font on a black background. Participants used a green key corresponding to the letter “c” on the keyboard, to categorize the noun as animate, and a red key corresponding to the letter “m” on the keyboard, to categorize the noun as inanimate. The English and French blocks contained different nouns and there were no translation equivalents; furthermore, the blocks were matched in terms of the number of animate and inanimate judgements as well as the number of same/different responses relative to the previous trial. For the majority of participants stimuli were presented using Inquisit version 2.0 (Millisecond Software, Seattle, WA) on a Dell Inspiron 1521 laptop with an AMD Turion processor and Windows Vista operating system at the center of a 15.4 inch screen.

2.3.2.3 Stroop Task. A variation of the classic Stroop task (Stroop, 1935) was used to measure interference/inhibitory function and was the primary focus of the present

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[2] In total 12 older adults (5 older monolinguals and 7 older bilinguals) with scores between 23 and 25 were included in the study. Although these older adults scored below the cut-off for normal cognitive functioning, interaction with the experimenter and performance on other cognitive tasks provided no indication of impaired cognitive function. Critically, an independent samples t-test indicated no difference in MoCA scores between the two language groups (p=.68).

investigation. The task included three blocks of 52 trials each, there was a 150 ms post trial pause following each trial and a stimulus remained on the screen until the participant responded. RT was recorded at the onset of the vocal response using a headset microphone. Response latencies were obtained for each individual trial. Participants performed both the Stroop and animacy judgement tasks using the same computer and software. In the first block participants were presented with the words “red”, “green”, “yellow”, and “blue” in white 20 point Arial font on a black background and were asked to read the word aloud as quickly and accurately as possible (i.e., the word reading condition). The second block consisted of circles measuring 50 pixels high and 50 pixels wide that were coloured red (RGB: 255, 0, 0), green (RGB: 0, 128, 0), yellow (RGB: 255, 255, 0), or blue (RGB: 0, 0, 255) and participants were asked to name the colour of the circle as quickly and accurately as possible (i.e., the colour naming condition). The final block was comprised of the words “red”, “green”, “yellow”, and “blue” printed in 20 point Arial font in one of the three colours other than the colour that the word represented, and participants were asked to name the colour of the print as quickly and accurately as possible and to avoid reading the word (i.e., the incongruent colour naming condition). Each block was preceded by a series of practice trials to ensure that participants were comfortable with the stimuli and able to correctly perform the task specific to the block. Participants completed the word reading condition first, followed by the colour naming condition, and the incongruent colour naming condition was completed last

2.3.3 Procedure

Participants were seated in a comfortable chair and informed consent was obtained at the beginning of the testing session (see Appendix B for consent form). The time to complete the tasks included here was approximately 30 minutes. Participants were compensated at the end of the testing session; young adults in the psychology program at Concordia University were compensated in the form of course credit and all other participants were compensated $10 CAD per hour of participation.

2.4 Results

Statistical analyses were conducted using the statistical software package SPSS v. 11.5 (SPSS Inc., Chicago, IL, USA). Reported effects were significant at an alpha level of .05 (unless otherwise specified) and any significant interactions were decomposed with Bonferroni corrected simple effects analyses. Given the significant difference in years of education between the monolingual and bilingual older adults years of education was included as a covariate for all analyses of variance.

2.4.1 Animacy Judgement Task

Due to a technical error the data for one older bilingual were not available. The coefficient of variability (CV; a measure of cognitive efficiency based on intra-individual differences in RT variability; see Segalowitz & Segalowitz, 1993) was calculated for each participant by dividing the *SD* of each participant's RT for correct trials by his/her mean RT for correct trials. Trials for which the RT was less than 200 ms or greater than three standard deviations of the mean were excluded separately for each language prior to calculating the CV. The Pearson Correlation between the CV in L1 and L2 was examined in order to assess relative proficiency in French and English for the bilingual participants.

There was a significant correlation for both the young (r=.87, p<.001) and the older (r=.87, p<.001) bilinguals, demonstrating high relative L2 proficiency in both groups.

2.4.2 Stroop Task

Both accuracy and RT were examined. A mixed analysis of variance (ANOVA) including the between subjects variables Age (young vs. older) and Language Group (monolingual vs. bilingual), and the within subjects variable Condition (word reading, colour naming, and incongruent colour naming) was conducted with accuracy as the dependent variable; see Figure 1. There was a trend toward a main effect of Condition ($F(2,226)=2.77$, $MSE=14.97$, $p=.07$, $\eta^2_p=.02$), demonstrating more accurate responses for both the word reading and colour naming conditions relative to the incongruent colour naming condition. The effects of Age and Language Group were not significant ($F(1,113)=2.6$, $p=.11$ and $F(1,113)=0.23$, $p=.63$, respectively) .

The RT data were analyzed in an initial mixed ANOVA comparing the three conditions (word reading, colour naming, and incongruent colour naming), including the between subjects variables Age (young vs. older) and Language Group (monolingual vs. bilingual); these data are depicted in Figure 2. There was a main effect of Age ($F(1,113)=42.41$, $MSE=20636.38$, $p<.001$, $\eta^2_p=.27$), demonstrating faster responses by the young relative to older adults. An Age x Language Group interaction ($F(1,113)=6.83$, $MSE=20636.38$, $p=.01$, $\eta^2_p=.06$) indicated that the young bilinguals were faster than the young monolinguals, whereas the two older groups demonstrated no difference in RT. There was also a main effect of Condition ($F(2,226)=11.47$, $MSE=4950.52$, $p<.001$, $\eta^2_p=.09$), and an Age x Condition interaction ($F(2,226)=28.7$, $MSE=4950.52$, $p<.001$,

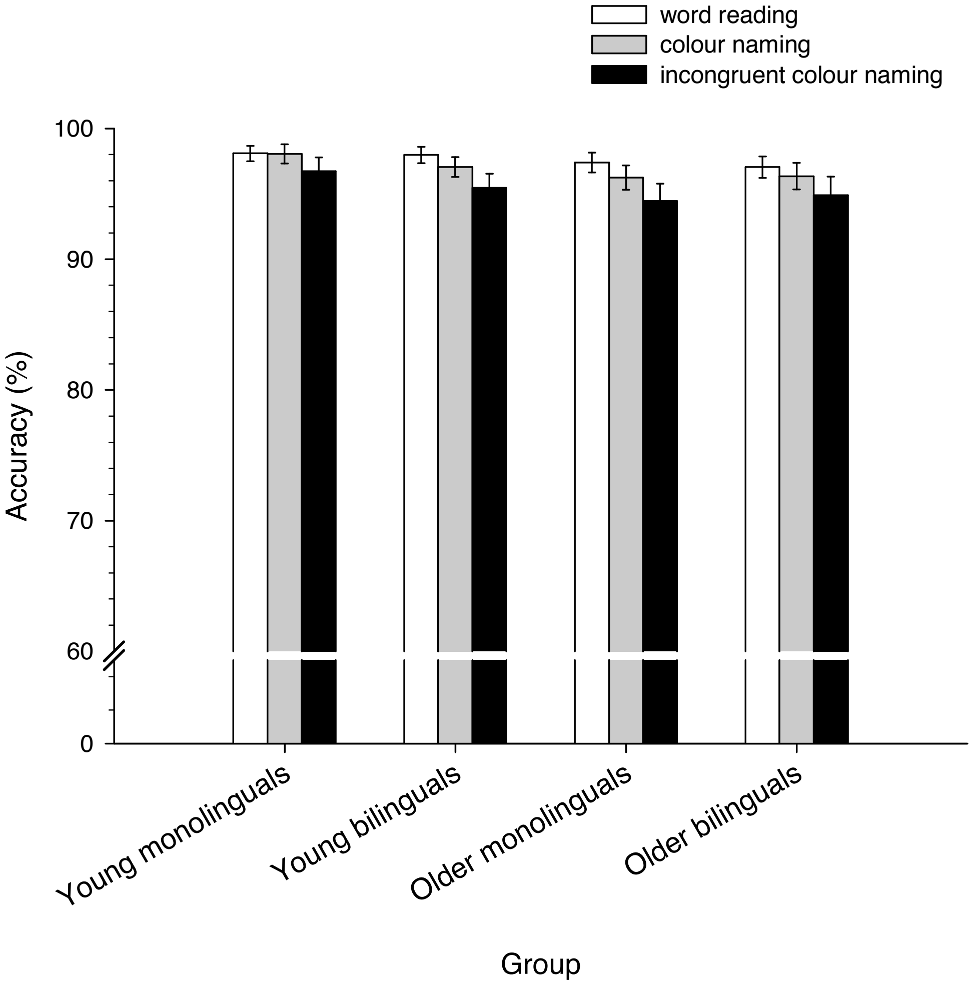

Figure 1. Mean accuracy (± *SE*) for the three Stroop conditions as a function of Age and Language Group.

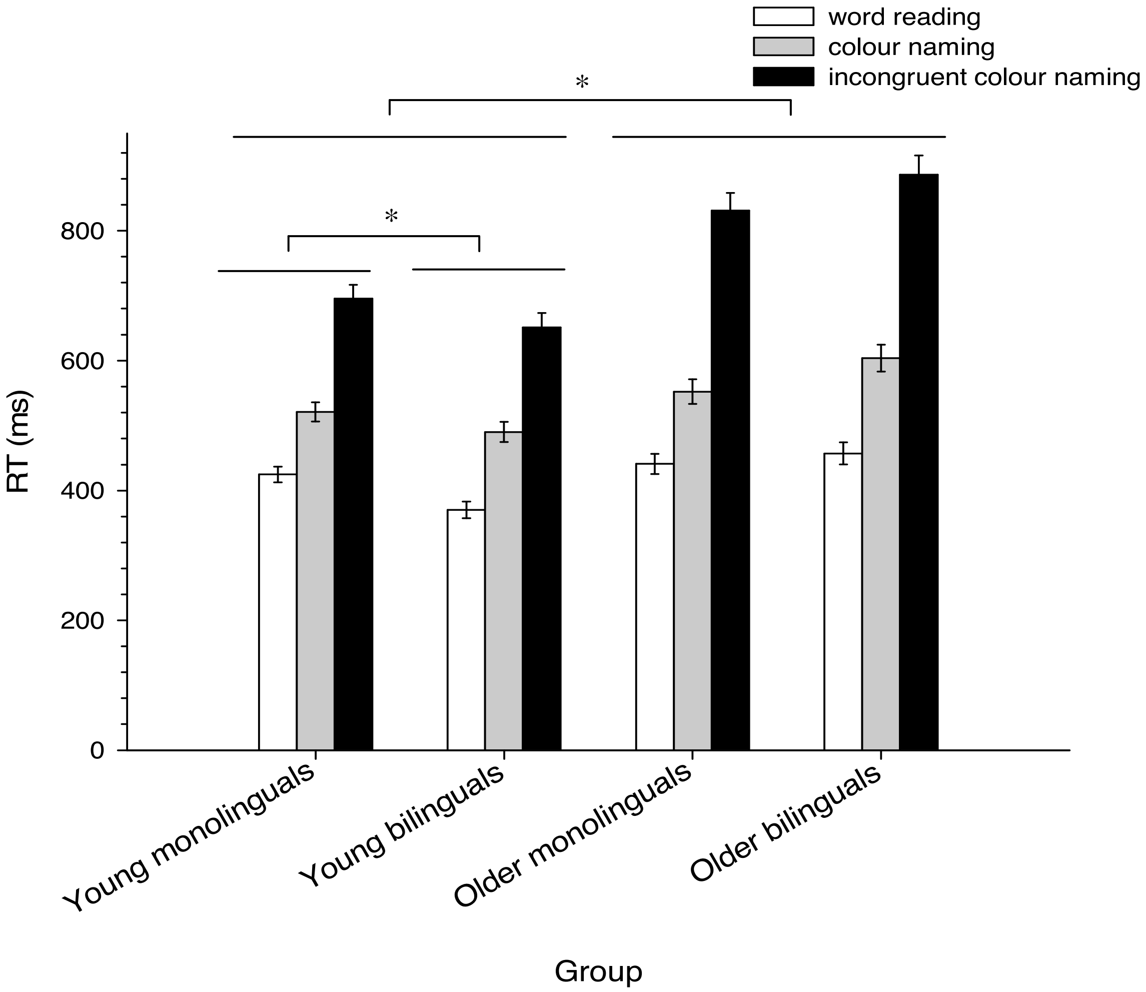

Figure 2. Mean RT (± *SE*) for each condition in the Stroop task as a function of Age and Language Group.

η^2_p=.20), which indicated that there was a significant difference between all three conditions in both age groups, with the fastest RTs for word reading and the longest RTs for incongruent colour naming. The young adults also demonstrated faster RTs relative to the older adults for all conditions. The source of this interaction was a larger RT difference between young and older adults for the incongruent colour naming condition (mean difference = 185.4 ms) than either word reading (mean difference = 51.5 ms) or colour naming (mean difference = 72.5 ms). There was no significant Age x Language Group x Condition interaction ($F(2,226)=0.28$, $p=.76$), which would be expected if the bilinguals were demonstrating an advantage relative to monolinguals.

Following analysis of the raw data for the different conditions in the Stroop task we further examined the effect of Age and Language Group on Stroop interference in a between subjects multivariate analysis of variance (MANOVA). These additional analyses were performed in order to more closely replicate the analyses in previous investigations that have found evidence for a bilingual advantage (e.g., Bialystok et al., 2008). We included several dependent variables to ensure that any effect of Language Group would be detected; furthermore, given that there were two baseline conditions (i.e., word reading and colour naming), the data were examined relative to both of these baselines, and relative to the mean of the two. Specifically, there were six dependent variables included in the MANOVA. Three of the dependent variables were based on the raw RT data (i.e., the difference between the incongruent colour naming and colour naming, the difference between incongruent colour naming and word reading, and the difference between incongruent colour naming and the mean of colour naming and word reading). The three remaining dependent variables were based on proportional increases in RT between neutral and incongruent conditions, which were calculated by dividing the difference in RT (i.e., the three dependent variables previously described) by the RT for the corresponding neutral condition. The MANOVA revealed a main effect of Age for all the dependent variables, demonstrating a smaller Stroop effect in the young adults than in the older adults (see Figure 3). Table 2 provides the relevant statistics for this analysis. There was no effect of Language Group or Age x Language Group interaction (see Table 3 for relevant statistics) demonstrating no advantage for bilinguals relative to monolinguals.

2.5 Discussion

The goal of the present investigation was to replicate previous findings of a bilingual advantage for executive control processes. Specifically, a modified version of the Stroop task was used to investigate interference suppression in young and older bilingual and monolingual participants. The most important contribution of this study is the homogeneous sample. That is, previous studies that have examined the bilingual advantage in the Stroop task have not controlled for native/second language and/or immigrant status (Bialystok et al., 2008), or have not included a monolingual comparison group (Zied et al., 2004). In the present investigation all bilingual participants were native English speakers with French as their L2, they were all born in North America and were living in the Montreal area. Thus, the present study is the first to compare a homogeneous group of younger and older monolinguals and bilinguals using a Stroop task.

The only advantage for bilinguals that was apparent in the present data was in the young group. Specifically, analysis of the raw RT for the three conditions of the Stroop task indicated that overall the young bilinguals were faster than the young monolinguals.

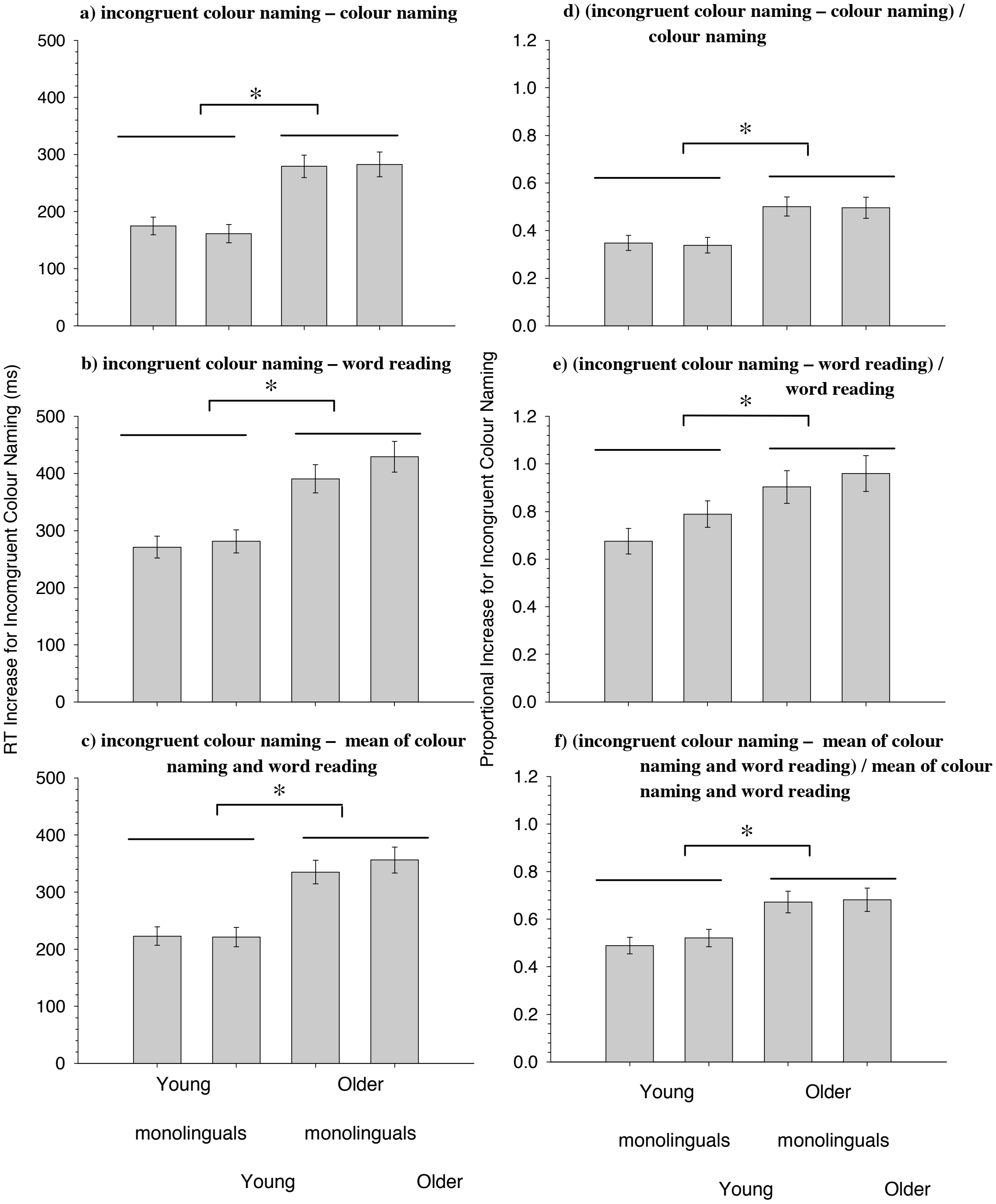

Figure 3. The left panel (a, b, and c) shows the RT increase (±*SE*) and the right panel (d, e, and f) shows the proportional increase (±*SE*) for incongruent relative to neutral conditions.

Table 2

Summary of the Main Effect of Age Revealed by MANOVA for Each Dependent Variable

Dependent Variable	*F*	*df*	*MSE*	η^2_p
Incongruent colour naming - Colour naming	38.9**	1, 113	8993.4	.26
Incongruent colour naming – Word reading	35.0**	1, 113	14052.3	.21
Incongruent colour naming – mean of Colour naming and Word reading	42.3**	1, 113	9858.5	.27
(Incongruent colour naming – Colour naming) / Colour naming	17.5**	1, 113	0.04	.13
(Incongruent colour naming – Word reading) / Word reading	9.9**	1, 113	0.11	.08
(Incongruent colour naming – mean of Colour naming and Word reading) / mean of Colour naming and Word Reading	17.6**	1, 113	.05	.14

**p<.01

Table 3

Relevant Statistics for the Main Effect of Language Group and the Age x Language Group Interaction from MANOVA

Dependent Variable	Main effect of Language Group	Age x Language Group Interaction
Incongruent colour naming - Colour naming	*F*(1,113)=0.07, *p*=.79	*F*(1,113)=0.21, *p*=.65
Incongruent colour naming – Word reading	*F*(1,113)=1.09, *p*=.30	*F*(1,113)=0.39, *p*=.54
Incongruent colour naming – mean of Colour naming and Word reading	*F*(1,113)=0.25, *p*=.62	*F*(1,113)=0.35, *p*=.56
(Incongruent colour naming – Colour naming) / Colour naming	*F*(1,113)=0.03, *p*=.86	*F*(1,113)<.01, *p*=.96
(Incongruent colour naming – Word reading) / Word reading	*F*(1,113)=1.66, *p*=.20	*F*(1,113)=0.20, *p*=.66
(Incongruent colour naming – mean of Colour naming and Word reading) / mean of Colour naming and Word Reading	*F*(1,113)=0.23, *p*=.63	*F*(1,113)=0.07, *p*=.79

This difference did not interact with condition, indicating that the bilinguals were faster across all conditions. Thus, there was no evidence for a specific advantage with respect to interference suppression. This finding is consistent with previous findings demonstrating an overall speed advantage for bilinguals relative to monolinguals in children (Martin-Rhee & Bialystok, 2008), as well as young and older adults (Bialystok et al., 2004; Costa et al., 2009; Zied et al., 2004). However, in Bialystok et al. the faster RTs for bilinguals relative to monolinguals for both congruent and incongruent conditions in the Simon task were associated with a smaller Simon effect for bilinguals than for monolinguals, in both the young and older age groups. Furthermore, the age-related increase in the Simon effect was smaller for the bilinguals than the monolinguals demonstrating attenuation of an age-related increase in the Simon effect for bilinguals. The present data do not show any differences in Stroop interference as a function of Language Group, for either the young or older age groups. It should be noted that Bialystok et al. (2008) did not find a general speed advantage for bilinguals relative to monolinguals for either the Simon task or the Stroop task.

Costa et al. (2009) have argued that a speed advantage for both congruent and incongruent trials in bilinguals relative to monolinguals reveals superior conflict monitoring in bilinguals. Specifically, using a flanker task Costa et al. showed that monolinguals and bilinguals performed similarly when 92 % of trials were congruent or incongruent and thus conflict monitoring demands were low; however, when conflict monitoring demands were higher (i.e., 50 % or 75% congruent trials) a speed advantage for bilinguals relative to monolinguals emerged for both congruent and incongruent trials. This may suggest that the general speed advantage observed in the present investigation supports a bilingual advantage in the young adults. However, given that the stimuli were presented in blocks and the trial types were not intermixed in the present design, it is unlikely that this is the case. That is, given that there was no switching there was no need to recruit conflict monitoring processes. In fact, our congruent and incongruent blocks are comparable to Costa et al.'s low-monitoring condition (except that in our case there are 100% congruent or incongruent trials), for which Costa et al. found no speed advantage for bilinguals.

In addition to examining the raw RT data, we investigated potential differences in Stroop interference. That is, the increase in RT from neutral to incongruent conditions. Given that there were two neutral conditions in the present version of the Stroop task, we examined the increase in RT relative to both neutral conditions, as well as the average of the two. Furthermore, we included proportional increases in RT in order to control for any general effects of age-related slowing. By including all six of these dependent variables we are confident that the data have been thoroughly examined and that any advantage for bilinguals over monolinguals would manifest itself in the results. However, the only significant finding was that older adults consistently demonstrated greater Stroop interference than young adults. There was no effect of being bilingual on Stroop interference. This does not replicate previous findings (Bialystok et al., 2008); however, it is noteworthy that the advantage in the Stroop task found by Bialystok et al. only became apparent when comparing facilitation for congruent conditions and costs for incongruent conditions. That is, when raw RTs were compared for congruent and incongruent conditions no advantage for bilinguals relative to monolinguals in either age group was observed; however, when both facilitation and costs were compared smaller costs for bilinguals relative to monolinguals were observed for both young and older participants. In the present investigation there was no congruent colour naming condition, therefore it was not possible to examine facilitation in our sample. Bialystok et al. also examined the percentage increase in RT for incongruent color naming relative to neutral colour naming, which was similar to our analysis of proportional increases in RT. Bialystok et al. reported smaller costs for bilinguals relative to monolinguals, a result that was not replicated in the present investigation.

The data reported here are inconsistent with previous findings, suggesting that the bilingual advantage may not be as robust as the literature suggests. There are several possible reasons why the present data may have failed to replicate previous findings, each of which will be discussed in turn.

In some cases the bilingual advantage only emerges under demanding circumstances (e.g., Bialystok, 2006; Costa et al., 2009). For instance, Costa et al. only found an advantage for bilinguals when congruent and incongruent trials were intermixed with at least 25% of trials being incongruent. In the task used here the trial types were blocked, thus the monitoring demands were low. Despite this we did find a general speed advantage for young bilinguals. If we had intermixed congruent and incongruent trials within the same block it is possible that we may have observed an effect of bilingualism on Stroop interference.

It is also possible that the sample included here was not sufficiently large to detect an effect of bilingualism. Specifically, the older group was comprised of 25 monolinguals and 20 bilinguals, which may be considered small. However, previous studies have found a bilingual advantage on the Simon task with only 15 older adults in each language group

(Bialystok et al., 2004), and on the Stroop task with 24 participants in each group (Bialystok et al., 2008). Thus, it seems likely that if there was in fact an advantage for bilinguals our sample size would provide adequate power to detect it.

Another possible explanation is that the bilingual advantage only holds for specific languages. In the present investigation all of the bilingual participants were native English speakers with French as their second language, or they reported no nominal L1 and had learned both French and English simultaneously from birth. Whereas, in Bialystok et al. (2008) the majority of older participants were immigrants (i.e., 20 of 24 participants) and English was more likely their L2, with differing L1s. Theoretically it is difficult to pinpoint why the advantage for bilinguals may be different dependent on the individual's L1; however, there is some support for this notion. Specifically, Chertkow et al. (2010) found a protective effect of speaking two or more languages against a diagnosis of Alzheimer's disease in a sample of immigrants, and a trend towards a similar finding in non-immigrants whose native language was French, but no such effect in non-immigrant bilinguals whose native language was English. Furthermore, Chertkow et al. have argued that immigrants differ from non-immigrants in many ways (e.g., diet, stress, life history) that are not normally measured. Thus, in addition to speaking two languages the bilinguals in Bialysok et al.'s study likely differ from the monolinguals on other potentially important variables.

A discussion of the sample included here is also merited. That is, all the participants were high functioning, including the older participants who were willing and able to travel to the lab for research participation. Participants were also screened using an extensive health questionnaire prior to testing to ensure that they had no history of medical conditions and were not taking medications known to affect cognitive function. This may have biased our sample resulting in such a high functioning group that differences between monolinguals and bilinguals were not detectable. However, bilingualism is hypothesized to provide protection against age-related declines in executive function that are associated with normal, healthy aging. Therefore, one would expect to see differences unless there was a systematic difference in cognitive functioning between the monolingual and bilingual groups. A comparison of the MoCA scores for the monolingual and bilingual older adults revealed no difference in global cognitive functioning between the two groups, thus reducing this possibility as an alternative explanation.

One specific demographic variable that stands out in our sample is years of education. As can be seen in Table 1, the older adults in our sample had higher than average levels of education[3]; furthermore, the bilinguals had significantly more years of education than their monolingual peers. It is possible that such a highly educated sample would not show a further benefit of bilingualism; however, the level of education in our sample of older adults was comparable to that in other studies that do find an advantage for older bilinguals relative to older monolinguals (Bialystok et al., 2006, 2008). Despite this, a question that arises is whether a bilingual advantage would be present, or even larger in a sample of older adults with average and/or below average education.

A final caveat is that we did not control for socio-economic status in the present investigation. Recent evidence suggests that socio-economic status may affect age-related changes in cognition (Czernochowski, Fabiani, & Friedman, 2008). Specifically, it was

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[3] The Public Health Agency of Canada (2002) reported that in 1996 60% of Canadian seniors never completed high school (i.e., corresponding to 11 years of education in our measurement), with one third having no secondary education.

found that higher socio-economic status was associated with the use of compensatory strategies in a source memory task. Thus, although the Stroop task is not a source memory task it remains possible that differences between our groups on socio-economic factors may have confounded the present results. We did control for education in the present investigation and all of the young adults were university students, but we did not have any information regarding occupation for the older adults. Our measures may not have been adequate to ensure that our groups were matched on socio-economic status. Future studies should consider this variable, particularly given that it has been suggested that controlling for socio-economic status can attenuate the bilingual advantage in children (Morton & Harper, 2007).

An interesting avenue for future research is to examine the bilingual advantage using neuroimaging techniques. This would allow for the investigation of more subtle differences between monolinguals and bilinguals that may not be apparent in purely behavioural measures. For example, using magneto-encephalography, Bialystok et al. (2005) found differences between monolingual and bilingual young adults in terms of the regions of brain activity associated with performance of a Simon task in the absence of RT differences.

In sum, the present investigation does not replicate previous studies demonstrating an advantage associated with being bilingual, thus raising questions with respect to the robustness of the so-called bilingual advantage and its role as a buffer against age-related declines in executive function. Future studies should take advantage of more sensitive neuroimaging techniques to further investigate whether there is an advantage too subtle to be detected behaviourally, and greater control of socio-economic factors should be applied.

CHAPTER 3: Manuscript 2: Bilingualism and Cognitive Control

Conflict monitoring and resolution: Are two languages better than one?
Evidence from reaction time and event-related brain potentials.

To be submitted to *Brain Research*

3.1 Abstract

An advantage for bilingual relative to monolingual young adults has been found for cognitive control tasks, although this finding is not consistent in the literature. The goal of the present investigation was to further examine the bilingual advantage in young adults using an array of tasks previously found to demonstrate the effect of interest. Furthermore, we included both behavioural and event-related brain potential (ERP) measures, which we reasoned would be more sensitive to differences between the language groups. Monolingual (n=17) and highly proficient bilingual (n=17) young adults completed a Stroop, Simon, and Eriksen flanker task while electrophysiological recording took place. Behaviourally we found no differences between the two language groups on any of the tasks. The ERP measures demonstrated differences between monolingual and bilingual participants with respect to conflict monitoring, resource allocation, stimulus categorization, and error-processing; however, these findings were not consistent across the three tasks. Furthermore, given the lack of behavioural differences between the groups the differences in brain responses that we observed do not necessarily represent an advantage for the bilinguals. The results are discussed with respect to previous findings of a bilingual advantage.

3.2 Introduction

Recently the effects of being bilingual on cognitive processes other than language *per se* have received an increasing amount of attention in the literature. Being bilingual has been associated with superior performance on tasks measuring executive function (see Bialystok, 2007; 2009), including the Simon task (Bialystok, 2006; Bialystok, Craik, Klein & Viswanathan, 2004), the Stroop task (Bialystok, Craik, & Luk, 2008; Zied et al., 2004), and the Attention Network Test (ANT; Costa, Hernández, Costa-Faidella & Sebastián-Gallés, 2009; Costa, Hernández & Sebastián-Gallés, 2008). Furthermore, an advantage for bilinguals over monolinguals has been found in children (Bialystok & Martin, 2004; Martin-Rhee & Bialystok, 2008), young adults (Bialystok, 2006; Costa et al., 2008, 2009), and older adults (Bialystok et al., 2004; 2008; Bialystok, Craik, & Ryan, 2006; Zied et al., 2004). The majority of the investigations examining the bilingual advantage have used behavioural measures only. The present investigation examines the bilingual advantage in a Stroop task, a Simon task, and a modified Eriksen flanker task using both behavioural (reaction time (RT) and accuracy) and electrophysiological (event-related brain potentials; ERPs) measures. The inclusion of electrophysiological measures in the present investigation permits the examination of bilingualism-related differences in the neural responses associated with the tasks that have previously demonstrated advantages for bilinguals relative to monolinguals.

It has been suggested that the source of the bilingual advantage is the constant manipulation of two languages in bilinguals (Bialystok, 2007). The simultaneous activation of both of a bilingual's two languages despite being engaged in a single language has been well documented using picture identification (e.g., Blumenfeld &

Marian, 2007; Marian, Spivey, & Hirsch, 2003), word identification (e.g., Dijkstra, Grainger, & van Heuven, 1999; Dijkstra, Timmermans, & Schriefers, 2000; van Heuven, Schriefers, Dijkstra, & Hagoort, 2008), translation recognition (e.g., de Groot, Delmaar, & Lupker, 2000), and semantic priming (e.g., de Bruijn, Dijkstra, Chwilla, & Schriefers, 2001; Kerkhofs, Dijkstra, Chwilla, & de Bruijn, 2006; Kousaie & Phillips, 2011; Paulmann, Elston-Güttler, Gunter, & Kotz, 2006), using stimuli that overlap across the languages of interest in terms of lexical and/or phonological features (e.g., interlingual homographs, which share orthography across two languages but do not share semantic features). Given that a bilingual's two languages are simultaneously activated cognitive control processes are required to prevent interference by the non-target language. The control processes engaged in the management of two languages in bilinguals may be similar to those engaged during the performance of attentional control tasks, including selective attention to target information, inhibition of irrelevant information, and switching (Bialystok et al., 2004). This creates a situation in which these control mechanisms are extensively practiced in bilinguals and could lead to more efficient control processes relative to monolinguals.

The Stroop effect was first described by J. Ridley Stroop in 1935. Stroop found that there was a significant increase in the time it took to name the colour of the print that a colour word was printed in when the print colour and the word were incongruent, relative to naming the colour of a solid square. For example, it took longer to say "red" in response to the word *blue* printed in red ink than to a red square (see Appendix A for sample stimuli) . The Stroop effect has been extensively studied since the publication of Stroop's influential paper (see Macleod, 1991), and for the present investigation we take the position that the cause of the Stroop effect is interference caused by competition between word reading and colour naming. In order to respond correctly to an incongruent stimulus an individual must suppress/inhibit the dominant word reading response in order to correctly name the colour. This has been referred to as interference suppression (Bialystok et al., 2008; Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002), and greater Stroop interference corresponds to less efficient interference suppression. Recent investigations have found that bilingualism is associated with smaller Stroop effects (Bialystok et al.; Zied et al., 2004), suggesting that bilinguals are more efficient at interference suppression relative to monolinguals.

Another task that has been investigated in relation to bilingualism is the Simon task (Simon & Rudell, 1967). In the version most widely used in recent investigations participants are presented with a stimulus in one of two colours on either side of a computer monitor, and respond to the colour of the stimulus with a left or right response key. On incongruent trials the colour and position of the stimulus provide incompatible response information. For example, the participant could be presented with a stimulus that corresponds to a left key response, but the stimulus appears on the right side of the computer monitor (see Appendix A for sample stimuli). The increase in the RT for incongruent trials relative to congruent trials, on which colour and position information correspond to the same response, is the Simon effect. Similar to results from the Stroop task, bilinguals have shown smaller Simon effects relative to monolinguals (Bialystok, 2006; Bialystok et al., 2004), which is thought to reflect better perceptual conflict resolution in bilinguals relative to monolinguals (Bialystok).

The final task included in the present investigation is an arrows version of the Eriksen flanker task, which is similar to the Stroop and Simon tasks in that it requires participants to ignore distracting information in order to correctly respond to a target (see Appendix A for sample stimuli). Eriksen and Eriksen (1974) used a letter identification task to examine the effect of noise on the speed and accuracy of identification in the absence of visual search. In their task the target letters corresponded to a lever press on one side while non-target letters corresponded to a lever press on the other side. The target letters always appeared in the same place on the monitor and were flanked on either side by three repetitions of the same letter, or distractor letters requiring either the same response or a difference response. Eriksen and Eriksen found that RT significantly increased when the distractors required a different response from the target, indicating participants were unable to avoid processing information from the flanking stimuli.

The effect of bilingualism on performance of the Eriksen flanker task itself has not been investigated; however, a variation of the task has demonstrated an advantage for bilinguals over monolinguals. Specifically, the ANT (Fan, McCandliss, Sommer, Raz, & Posner, 2002) is a combination of a cue reaction time task and a flanker task using arrow stimuli designed to explore three attentional networks: executive control, alerting and orienting. Congruent trials are comprised of a target arrow and flanking arrows pointing in the same direction, whereas incongruent trials are comprised of a target arrow pointing in one direction and flanking arrows pointing in the other direction. In terms of the flanker task in the ANT, Costa et al. (2008) found that bilinguals were faster than monolinguals overall and showed less interference from incongruent flankers than monolinguals. Furthermore, Costa et al. (2009) found that the bilingual advantage only emerged when monitoring demands were high, suggesting that the observed advantage for the bilinguals was caused by superior conflict monitoring. Given that the present investigation focuses on potential executive control differences between bilinguals and monolinguals we chose to use a simple Eriksen flanker task with arrow head stimuli rather than the ANT.

One factor common to those tasks in which bilinguals show an advantage is the need to monitor for and resolve conflict in order to maintain high accuracy. For example, in the Stroop task there is conflict between the word and the colour on incongruent trials and participants must detect this conflict and resolve it by inhibiting the dominant word reading response in order to correctly name the colour of the print. Given that bilinguals have been found to demonstrate superior performance than monolinguals on the Stroop, Simon and flanker tasks, the present investigation will examine all three tasks in the same sample using the same procedure. Until now differences between monolinguals and bilinguals in the performance of these tasks have typically been examined for each task individually. Examining all three tasks in the same sample will permit us to evaluate whether any observed effects of bilingual status vary across the tasks. Specifically, there are differences in task demands between the three tasks that may lead to differential effects of bilingualism on performance. For example, the Stroop tasks includes word stimuli and requires participants to suppress a dominant word reading response, whereas in the Simon task it is spatial information that must be ignored in order to make a correct response based on colour. Previous investigations examining the neural basis of the interference effects observed in these tasks have found that similar neural systems are involved (Fan, Flombaum, McCandliss, Thomas, & Posner, 2003; Peterson et al., 2002).

However, in a series of experiments examining the Stroop, the Simon, and a version of the flanker task Fan et al. found little evidence of a relationship between the conflict in each task despite their activation of common brain areas. That is, Fan et al. found that there was no correlation between the conflict effects produced by each of their tasks.

Several theories attempt to explain how cognitive control is implemented in performing these tasks, and there is agreement that the anterior cingulate cortex (ACC) and dorsolateral prefrontal cortex (DLPFC) are involved (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001; Carter & van Veen, 2007; Liu, Banich, Jacobson, & Tanabe, 2006; Milham, Banich, Claus, & Cohen, 2003). Although different theories postulate different roles for these brain areas (e.g., the ACC as a conflict monitor vs. the ACC being involved in conflict resolution), the previously observed behavioural differences between monolinguals and bilinguals leads to the question of whether there would be differences in brain activity, even in the absence of behavioural differences. One way to address this question is using ERPs.

ERPs are extracted from the ongoing electroencephalograph and have excellent temporal resolution, on the order of milliseconds, allowing for the measurement of cognitive processes as they unfold in time. Different components of the ERP are associated with different cognitive processes and the amplitude and latency of the component are believed to be related to the strength and timing of the underlying cognitive process (Coles & Rugg, 1995). For the purposes of the present investigation we were interested in the various ERP components that are related to executive control, including the N2, P3, error-related negativity (ERN), and error positivity (Pe).

The N2 can refer to several subcomponents, although the one that we are interested in and that has been found using tasks most similar to our own peaks 200-350 ms following the presentation of a stimulus and has a frontocentral distribution (see Folstein & Van Petten, 2008). The exact cognitive process underlying the N2 is unclear, but it is thought to be related to conflict monitoring (e.g., van Veen & Carter, 2002a; 2002b; Yeung, Botvinick, & Cohen, 2004) and has been correlated with activity in the ACC as measured by functional magnetic resonance imaging (fMRI; Mathalon, Whitfield & Ford, 2003). Using an arrows version of the Eriksen flanker task, Danielmeier, Wessel, Steinhauser and Ullsperger (2009) found that the amplitude of the N2 was modulated by pre-response conflict, which is a function of conflict between the correct response and incorrect response tendencies. The amount of pre-response and post-response conflict was manipulated by varying the distance between the central target arrow and the flanking arrows. Danielmeier et al. found that the difference between the N2 for correct incongruent and correct congruent trials was larger when pre-response conflict was high relative to when it was low. Melara, Wang, Vu and Procter (2008) also found that the N2 was modulated by conflict in a Simon task such that the N2 had significantly greater amplitude for incongruent relative to congruent stimuli, replicating previous results indicating an association between the N2 for correct trials and conflict monitoring and/or detection (van Veen & Carter, 2002a; 2002b; Yeung et al., 2004).

The P3 is a broad positive waveform with a centroparietal scalp distribution that peaks 300-600 ms following an eliciting stimulus and is thought to be related to the updating of schemas (Donchin, 1981) and the allocation of resources (see Polich, 2007). P3 latency has been found to be proportional to stimulus categorization time (Kutas, McCarthy, & Donchin, 1977) and smaller in amplitude with increasing resource allocation (see Polich). Valle-Inclán (1996) found the P3 to be smaller in amplitude and delayed in latency for correct incongruent relative to correct congruent trials in a Simon task, and more recently, Melara et al. (2008) found that P3 amplitude peaked earlier for congruent relative to incongruent stimuli in a Simon task. An effect of congruency on the P3 has not been consistently shown in studies of the Stroop and Flanker tasks; however, a reduction in P3 amplitude for congruent relative to incongruent trials has previously been observed in a flanker task (Kopp, Rist, & Mattler, 1996).

Both the N2 and the P3 are elicited following correct responses, whereas the ERN and the Pe are error-related. The ERN is a sharp negative waveform that peaks 50-100 ms following an incorrect response and is thought to reflect error-detection (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Falkenstein, Hoormann, Christ, & Hohnsbein, 2000; Gehring, Goss, Coles, Meyer, & Donchin, 1993). However, others suggest that the ERN reflects post-response conflict resulting from a comparison of the erroneously executed response and the correct response tendency (Yeung et al., 2004). Support for the latter comes from Danielmeier et al. (2009) who found that the ERN was larger in amplitude for incorrect incongruent trials in the high post-response conflict condition relative to the low post-response conflict condition.

It is important to note that dipole modeling has found that the frontocentral N2 and the ERN can be modeled by a dipole in the same area of the ACC (van Veen & Carter, 2002a). Furthermore, the amplitude of both of these components has been correlated with ACC activity measured by fMRI (Mathalon et al., 2003). Thus, it has been suggested that the ACC is activated prior to the response in correct conflict trials, which is reflected by the frontocentral N2, and immediately after the response in incorrect conflict trials, which is reflected by the ERN (Carter & van Veen, 2007).

Finally, the Pe is a sustained modulation of the ERP which occurs after the ERN, peaking approximately 200-500 ms following the response (Falkenstein et al., 2000). The functional significance of the Pe has not been well studied, but it is thought to be related to the motivational significance of errors and its amplitude has been found to be positively correlated with the saliency of the error (Leuthold & Sommer, 1999; Shalgi, Barkan, & Deouell, 2009). Furthermore, it has been suggested that the Pe may be a response-locked manifestation of the P3 (Ridderinkhof, Ramautar & Wijnen, 2009). To our knowledge no studies have explicitly compared the Pe following errors on congruent and incongruent trials, thus the present investigation was the first.

The primary goal of the present investigation was to compare the neural responses of monolinguals and bilinguals when performing the Stroop, the Simon and the modified Eriksen flanker tasks. Given that the behavioural evidence suggests an advantage for bilinguals relative to monolinguals and this advantage is believed to be the result of well-practiced control mechanisms in bilinguals, one must suspect that the neural correlates of these control mechanisms would differ between these two groups. To our knowledge there is only one imaging study that has examined this question. Bialystok et al. (2005) used magneto-encephalography (MEG) to localize the differences in brain activity between monolinguals and bilinguals in performance of the Simon task. Behaviourally there was no performance difference between monolinguals and French-English bilinguals. However, both Cantonese-English and French-English bilinguals showed systematic differences in MEG responses from monolinguals and both bilingual groups showed a relationship between faster responses and greater activity in areas of the left PFC and ACC. This pattern was similar for congruent and incongruent trials and emerged in the 8-15 Hz frequency band, which is generally associated with signal processing. These results suggest that despite similar behavioural results the monolinguals and bilinguals differed in the underlying neural processing involved in task performance, and that the management of two languages lead to changes in executive function.

The present investigation examined the neural correlates associated with the processes thought to be modified by being bilingual. Specifically, behavioural evidence from the Stroop task (Bialystok et al., 2008), the Simon task (Bialystok, 2006; Bialystok et al., 2004; Martin-Rhee & Bialystok, 2008), and the ANT (Costa et al., 2008, 2009) suggests that bilinguals are better able to monitor for and resolve conflict than their monolingual counterparts; therefore, one would expect to see differences in the brain responses leading to the observed behavioural differences. Using the Stroop, Simon and Eriksen flanker tasks, the present study examined the bilingual advantage using both behavioural and ERP measures. In terms of the behavioural measures it was expected that all participants would show differences between all three trials types (i.e., neutral, congruent and incongruent), with congruent trials having the greatest accuracy and fastest RT and the incongruent trials having the lowest accuracy and longest RT. Furthermore, bilinguals were expected to show faster RTs for both congruent and incongruent trials as well as smaller costs (i.e., increases in RT for incongruent relative to neutral trials) relative to monolinguals, as has been previously described in the literature. In terms of the ERP measures, based on previous findings it was expected that all participants would show larger N2 and smaller ERN amplitude for incongruent than congruent trials[4] (Melara et al., 2008; Danielmeier et al., 2009); and that the P3 would be delayed in latency and smaller in amplitude for incongruent relative to congruent trials (Bauer, Kaplan & Hesselbrock, 2009; Melara et al., 2008; Valle-Inclán, 1996). Given that this is the first investigation to compare the Pe for congruent and incongruent trials the expectations regarding this component are speculative; however, based on findings suggesting that the Pe is related to error salience (Leuthold & Sommer, 1999; Shalgi et al., 2009), it was expected that the Pe would be larger for congruent than incongruent trials because errors on congruent trials should be more salient. Previous investigations do not appear to have examined neutral trials therefore we cannot make specific predictions based on previous findings; however, given that conflict is not present in neutral trials we expected that relative to congruent and incongruent trials N2 amplitude would be reduced, ERN amplitude would be larger, P3 amplitude would be larger and would not be delayed, and Pe amplitude would be larger.

Central to the goals of the present investigation, we also expected language group differences. Specifically, it was hypothesized that the bilinguals would show larger N2 amplitude for incongruent trials relative to monolinguals given that reduced N2 amplitudes have been associated with reduced conflict monitoring abilities (Holmes & Pizzagalli, 2008); and that monolinguals would show greater delays in P3 latency for incongruent trials than monolinguals given that this has been associated disruptions in

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[4] This prediction for the ERN may seem counterintuitive; however, it must be considered in light of Danielmeier et al.'s (2009) findings demonstrating that the amplitude of the ERN was related to the amount of post-response conflict, and in the present investigation there was more post-error conflict in congruent relative to incongruent trials.

cognitive control[5] (Bauer et al., 2009). Predictions regarding the ERN and the Pe are less straightforward; that is, given that these two components are related to errors and the bilingual advantage has been demonstrated in RT on correct trials, the effects of bilingualism on the neural aspects of error processing are less obvious. Given that the ERN has been related to post-response conflict (Danielmeier et al., 2009) and the suggestion is that bilinguals are better at conflict monitoring/resolution it was expected that the bilinguals would show larger ERN amplitudes relative to the monolinguals. Given that the Pe has been related to the motivational significance/salience of errors, we speculated that the Pe would be larger for bilinguals as a result of superior conflict monitoring.

3.3 Method

3.3.1 Participants

Thirty-four young adults were recruited from Concordia University and McGill University to participate in this study. There were 17 monolinguals (7 males) between the ages of 18 and 35 (*M* = 22.4, *SD* = 4.5), and 17 bilinguals (4 males) between the ages of 19 and 30 (*M* = 23.8, *SD* = 3.1). All participants were pre-screened using a self-report health and language questionnaire and reported no illness, health condition, or use of medication known to affect cognitive functioning. All participants showed normal cognitive functioning based on the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005). The bilingual participants were native English speakers who were highly proficient in French. All had learned French before the age of 7 and provided high self-report ratings of L2 proficiency as well as regular use of French in their daily activities.

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[5] This is not to imply that monolinguals demonstrate disruptions in cognitive control; but rather that bilinguals show enhanced cognitive control relative to monolinguals.

In addition, they showed comparable performance on an animacy judgement task (Segalowitz & Frenkiel-Fishman, 2005), which was used as an objective measure of relative L2 proficiency.

Table 4 provides demographic information for both participant groups. The monolingual and bilingual groups were matched on age, education, and maternal and paternal education. Note that in cases where participants were excluded from an analysis (e.g., due to poor behavioural performance, or poor quality electrophysiological recordings) the groups remained matched on these demographic variables.

Ethical approval for this study was obtained from the Concordia University Human Research Ethics Committee.

3.3.2 Materials and Apparatus

Participants completed the MoCA (Nasreddine et al., 2005) to assess cognitive functioning; and three experimental tasks for which EEG recording took place. The experimental tasks included a modified Stroop task (Stroop, 1935), a modified Simon task (Simon & Rudell, 1967), and a modified Eriksen flanker task (Eriksen & Eriksen, 1974). In addition to these, the bilingual participants also completed the animacy judgment task to assess relative L1 and L2 proficiency (Segalowitz & Frenkiel-Fishman, 2005).

3.3.2.1 MoCA. The MoCA (Nasredine et al., 2005) is a 10-minute cognitive screening tool used to detect mild cognitive impairment in older adults. It assesses visuospatial/executive control, memory, attention, language, and orientation. Although the MoCA is generally used in older adult samples it was included here so that the present data could be compared to data from older adults in future studies.

Table 4

Demographic Information for Participant Groups

	Monolinguals (n = 17; 7 males)	Bilinguals (n = 17; 4 males)
	M *(SD)*	M *(SD)*
Age	22.4 *(4.5)*	23.8 *(3.1)*
Education	15.2 *(1.6)*	15.8 *(0.9)*
MoCA	28.3 *(1.4)*	28.4 *(1.3)*
L1 self-reported language proficiency	5.0 *(0.1)*	4.9 *(0.3)*
L2 self-reported language proficiency	n/a	4.3 *(0.6)*
Coefficient of variability L1	n/a	.23 *(.08)*
Coefficient of variability L2	n/a	.25 *(.08)*
Maternal Education	15.2 *(2.4)*	14.9 *(2.3)*
Paternal Education	15.7 *(3.1)*	15.6 *(2.6)*

3.3.2.2 Animacy Judgment Task. Bilingual participants categorized nouns as animate or inanimate, as quickly and accurately as possible; this produced an objective measure of language proficiency (Segalowitz & Frenkiel-Fishman, 2005). The version of the task used here consisted of 72 nouns in English and 72 nouns in French divided into two language blocks. Within each language block there were 64 nouns preceded by 8 practice trials. The stimuli were presented in yellow 20 point Arial font on a black background. Participants used a green key corresponding to the letter “c” on the keyboard, to categorize the noun as animate, and a red key corresponding to the letter “m” on the keyboard, to categorize the noun as inanimate. The English and French blocks contained different nouns and there were no translation equivalents. The blocks were matched in terms of the number of animate and inanimate judgements and the number of same/different responses relative to the previous trial. Stimuli were presented using Inquisit version 2.0 (Millisecond Software, Seattle, WA) on a Dell precision 370 desktop with a Pentium 4 processor and Windows XP operating system on a 16 inch Compaq monitor.

3.3.2.3 Experimental Tasks. All three experimental tasks were comprised of 720 experimental trials divided into 10 blocks of 72 trials and preceded by 36 practice trials. Each block comprised an equal number of intermixed neutral, congruent, and incongruent trials presented in pseudorandom order such that no more than three trials of the same type were presented consecutively. All stimuli were presented using Inquisit version 2.0 (Millisecond Software, Seattle, WA) on a Dell precision 370 desktop computer with a Pentium 4 processor and Windows XP operating system on a 16 inch Compaq monitor. Prior to each trial a blank screen was presented for 500 ms; each trial began with a fixation cross presented for 250 ms followed by the stimulus which stayed on the screen until a response was detected, or until a specified “timeout” was reached. For the Stroop task, the maximum time to respond was 1250 ms, whereas for the Simon and Eriksen tasks, the timeout was 750 ms; a longer response interval was used for the Stroop task given its greater demand on working memory (i.e., four response keys to choose from, versus two for the Simon and Eriksen tasks). Participants performed the practice block first to ensure that the instructions were understood and, in the rare case when accuracy was less than 80% for the practice block it was repeated until this minimum criterion was achieved. Note also that errors in the practice block were followed by a 250 Hz tone identifying the response as an error; however, no performance feedback was provided during the experimental blocks.

For the Stroop task, neutral trials were comprised of a series of “x”s printed in green (RGB: 0, 255, 0), red (RGB: 255, 0, 0), yellow (RGB: 255, 255, 0), or blue (RGB: 0, 0, 255), and the number of “x”s corresponded to the number of letters in the colour word name (e.g., “xxx” printed in red); congruent trials were comprised of the colour words *green*, *yellow*, *red*, and *blue* printed in the corresponding colour; and incongruent trials were comprised of the same colour words printed in one of the alternate three colours (e.g., the word *red* printed in blue). Stimuli were presented at the center of the monitor in bold 27 point Arial font on a black background. The participant responded using the index and middle finger on each hand to identify the colour of the print using the computer keyboard; the letter “z” corresponded to yellow, the letter “x” to green, the symbol “,” to red, and the symbol “.” to blue. Prior to the practice block participants performed a key acquisition task in order to familiarize themselves with the colour-response key mappings. The key acquisition task comprised 80 trials for which the stimuli were green, yellow, red, or blue circles, and the colour of the circle was to be identified. Participants were permitted to complete this task as many times as necessary until they felt comfortable with the response keys (note that most participants only completed the key acquisition task once).

For the Simon task, stimuli comprised red and blue squares (100 x 100 pixels) on black background presented at the center of the monitor, or 10% from the left or right edge of the screen. Red stimuli required a left key press (i.e., the letter “x” on the keyboard) and blue stimuli required a right key press (i.e., the symbol “.” on the keyboard). For neutral trials the stimulus was presented at the center of the monitor, for congruent trials the stimulus was presented on the same side of the monitor as the correct response (e.g., a red stimulus presented on the left of the monitor), and for incongruent trials the stimulus was presented on the opposite side of the monitor as the correct response (e.g., a red stimulus presented on the right of the monitor).

For the Eriksen task, stimuli comprised arrowheads presented at the center of the monitor in white, bold, 36 point Arial font on a black background. Neutral trials consisted of a single arrowhead; congruent trials consisted of a central arrowhead flanked on either side by three arrowheads pointing in the same direction as the target (e.g., < < < < < < <); and the incongruent condition comprised a central arrowhead flanked on either side by three arrowheads pointing in the opposite direction as the target (e.g., < < < > < < <). Participants responded to the direction of the central arrowhead by pressing a left key (i.e., the letter “x” on the keyboard) if the arrowhead was pointing to the left, and a right key (i.e., the symbol “.” on the keyboard) if the arrowhead was pointing to the right.

3.3.2.4 EEG Recording. The continuous EEG was recorded from 64 scalp locations using Ag-AgCl electrodes and an ActiveTwo nylon cap (BioSemi, Amsterdam, NL) to ensure electrode placement according to the international 10-20 system. Eight additional electrodes were used: one on each earlobe, to be used as a reference for offline processing of the data; one above and one below the left eye, to record the vertical electro-oculogram (EOG); one on the outer canthi of each eye, to record the horizontal EOG; and two corresponding to sites FT9 and FT10 according to the international 10-20 system of electrode placement. The EEG was recorded relative to Common Mode Sense and Driven Right Leg (CMS/DRL) electrodes placed at the back of the head (to the left and the right of electrode POz, respectively) and was amplified using ActiveTwo amplifiers (BioSemi, Amsterdam, NL). The EEG was acquired using ActiView version 6.05 software (BioSemi, Amsterdam, NL), time-locked to the onset of the stimulus and sampled at a rate of 512 Hz in a 104 Hz bandwidth. Polygraphic Recording Data Exchange version 1.2 (PolyRex; Kayser, 2003) software was used to convert the continuous EEG from BioSemi Data Format (.BDF) to continuous file format (.CNT) for offline processing using SCAN 4.3.1 (Compumedics USA, Charlotte, NC, USA). During conversion using PolyRex, the EEG was referenced to linked ears and a fixed gain of .5 was applied.

Offline processing of the EEG data was performed separately for each task and consisted of applying a low pass 30 Hz filter, correcting vertical EOG artefacts using a spatial filter (NeuroScan, EDIT4.3), excluding trials containing horizontal EOG artefacts exceeding ±50 μV, and excluding trials containing EEG deflections exceeding ±100 μV. The electrophysiological time window was 700 ms including a 100 ms pre-stimulus/pre-response baseline (i.e., averages were baseline corrected to a 0 μV average of the 100 ms pre-stimulus/pre-response interval) and trials were averaged based on trial type and response type resulting in six averages (i.e., neutral correct, congruent correct, incongruent correct, neutral incorrect, congruent incorrect, incongruent incorrect) per task for each participant. For correct trials, averages were stimulus-locked, and for incorrect trials, averages were response-locked.

3.3.3 Procedure

Participants were seated in a comfortable chair and informed consent was obtained at the beginning of the testing session (see Appendix C for consent form). The MoCA was completed, followed by the animacy judgement task for bilingual participants. The electrode cap was then fit to the participant's head and facial electrodes were applied. Once set-up was complete the Stroop task was performed first, followed by the Simon and Eriksen flanker tasks in counterbalanced order. The Stroop task was completed first due to its greater complexity relative to the other two experimental tasks (i.e., greater demands on working memory). Following completion of the experiment participants were debriefed and compensated for their time; participants enrolled in the psychology program at Concordia University received course credit, all other participants received $10 CAD per hour of participation.

3.4 Results

Statistical analyses were conducted using the statistical software package SPSS v. 11.5 (SPSS Inc., Chicago, IL, USA). Reported effects were significant at an alpha level of .05 (unless otherwise specified) and any significant interactions were decomposed with

Bonferroni corrected simple effects analyses. Behavioural results will be reported first followed by the electrophysiological results.

3.4.1 Behavioural Results

Several analyses were conducted for each of the three tasks in the present investigation. First, a Language Group (monolingual and bilingual) x Trial Type (neutral, congruent, and incongruent) mixed ANOVA was carried out for the dependent variables accuracy and RT. In order to more closely replicate the analyses conducted in previous studies that have found a bilingual advantage (e.g., Bialystok et al., 2008) and given that the RT data from these tasks can also be examined in terms of facilitation (the decrease in RT between neutral and congruent trials) and interference (the increase in RT between neutral and incongruent trials), we also conducted a one-way ANOVA separately for the dependent variables interference and facilitation, as well as a Language Group (monolingual vs. bilingual) x Contrast (facilitation vs. interference) mixed ANOVA (following the analysis of Bialystok et al., 2008). Interference and facilitation were defined as the difference between the two relevant trial types (i.e., facilitation = neutral – congruent; interference = incongruent – neutral). Note that for our purposes both facilitation and interference are expressed as positive values. Results will be reported for each task in turn.

3.4.1.1 Stroop task. As can be seen in the top panel of Figure 4, all participants demonstrated high accuracy on the Stroop task. The Language Group x Trial Type ANOVA revealed a main effect of Trial Type ($F(2,64)=12.47$, $MSE=7.34$, $p<.01$, η^2_p $=.28$), indicating greater accuracy for neutral and congruent trials relative to incongruent trials, and no difference between neutral and congruent trials. There was no effect of

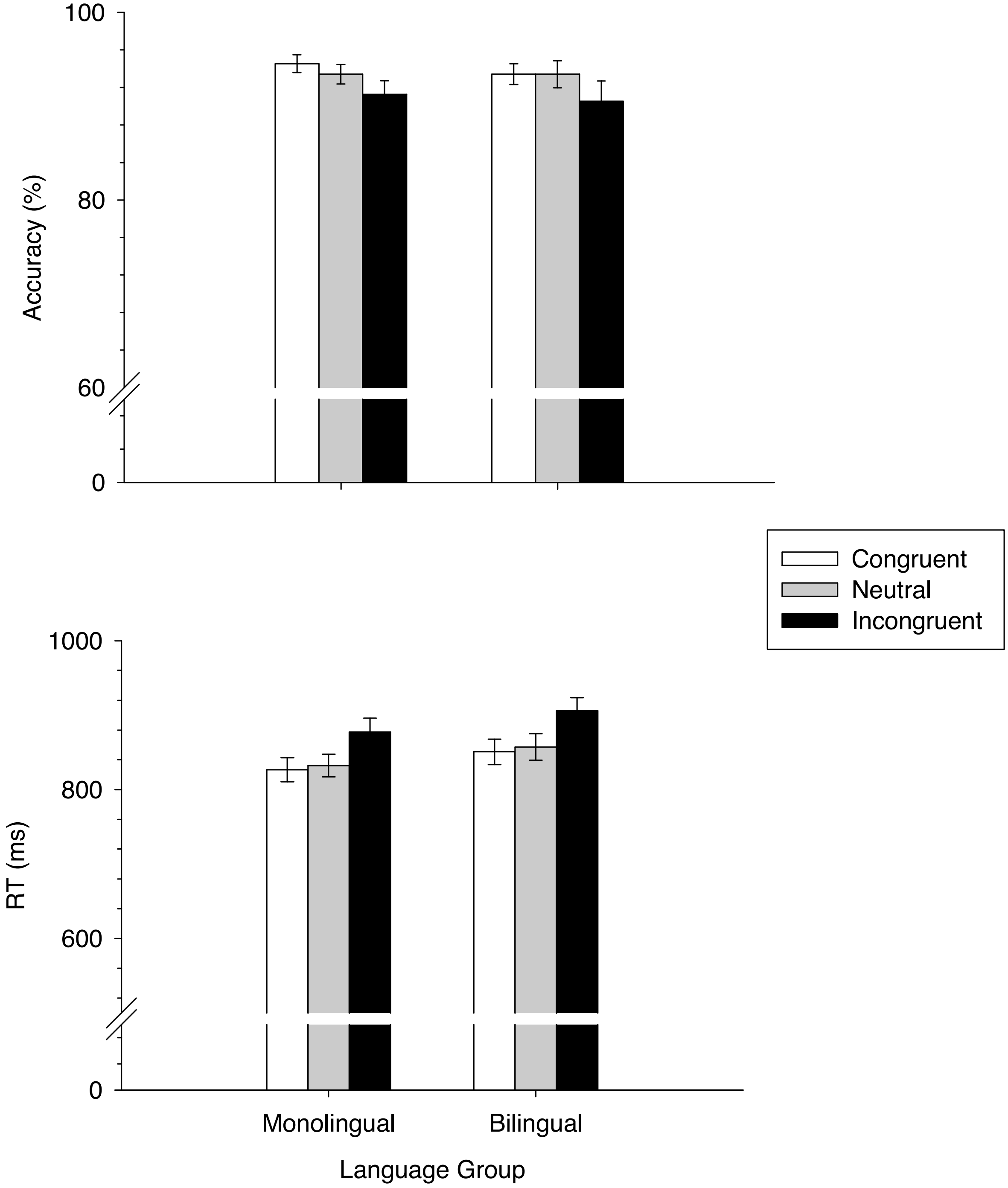

Figure 4. The top panel shows accuracy (±*SE*) and the bottom panel shows RT (±*SE*) for the Stroop task as a function of Language Group and Trial Type.

Language Group (*F*(1,32)=0.11, *p*=.74), nor a Language Group x Trial Type interaction (*F*(2,64)=0.36, *p*=.62).

The bottom panel of Figure 4 shows the RT data as a function of Language Group and Trial Type. Analysis of the RT data also revealed a main effect of Trial Type (*F*(2,64)=108.69, *MSE*=261.93, *p*<.01, η^2_p =.77), indicating a significant difference between all three trial types with congruent trials having the shortest RT and incongruent trials having the longest. There was no effect of Language Group (*F*(1,32)=1.18, *p*=.29), nor a Language Group x Trial Type interaction (*F*(2,64)=0.20, *p*=.79).

There was no effect of Language Group revealed in the analysis of facilitation (*F*(1,32)=0.02, *p*=.90), nor the analysis of interference (*F*(1,32)=0.20, *p*=.66). Finally, the Language Group x Contrast ANOVA revealed a main effect of Contrast (*F*(1,32)=46.97, *MSE*=604.03, *p*<.01, η^2_p =.60), demonstrating greater interference than facilitation. There was no effect of Language Group (*F*(1,32)=0.29, *p*=.60), nor a Language Group x Contrast interaction (*F*(1,32)=0.07, *p*=.80).

3.4.1.2 Simon task. One bilingual participant was excluded from all analyses of the Simon task due to poor accuracy (i.e., 48 – 53% accuracy). The top panel of Figure 5 shows that all remaining participants demonstrated high accuracy on the Simon task. Analysis of the accuracy data revealed a main effect of Trial Type (*F*(2,62)=49.17, *MSE*=5.78, *p*<.01, η^2_p =.61), demonstrating a significant difference between all three trial types with highest accuracy for congruent trials and lowest accuracy for incongruent trials. There was no effect of Language Group (*F*(1,31)=0.05, *p*=.83), nor a Language Group x Trial Type interaction (*F*(2,62)=0.64, *p*=.53).

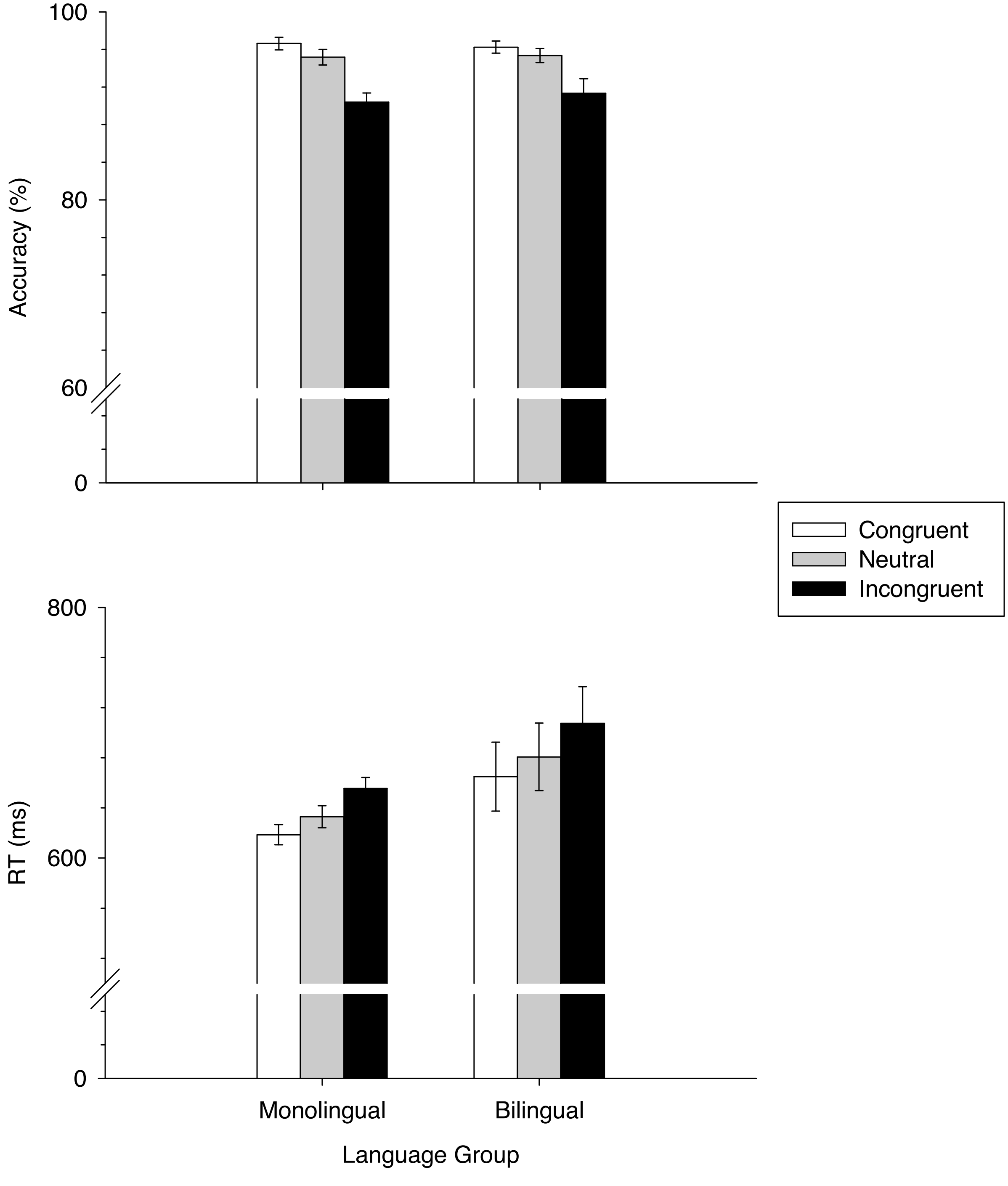

Figure 5. The top panel shows accuracy (±*SE*) and the bottom panel shows RT (±*SE*) for the Simon task as a function of Language Group and Trial Type.

The bottom panel of Figure 5 depicts the RT data as a function of Language Group and Trial Type. There was a main effect of Trial Type ($F(2,62)=235.63$, $MSE=56.10$, $p<.01$, $\eta^2_p=.88$), demonstrating a significant difference between all three trial types with the shortest RTs for congruent trials and the longest RTs for incongruent trials. There was no effect of Language Group ($F(1,31)=2.96$, $p=.10$), nor a Language Group x Trial Type interaction ($F(2,62)=1.26$, $p=.29$).

There was no effect of Language Group revealed in the analysis of facilitation ($F(1,31)=1.31$ $p=.26$), nor in the analysis of interference ($F(1,31)=0.22$, $p=.65$). Finally, the Language Group x Contrast ANOVA revealed a main effect of Contrast ($F(1,31)=14.71$, $MSE=105.07$, $p<.01$, $\eta^2_p=.32$), demonstrating greater interference than facilitation. There was no effect of Language Group ($F(1,31)=1.68$, $p=.20$), nor a Language Group x Contrast interaction ($F(1,31)=0.35$, $p=.56$).

3.4.1.3 Eriksen task. The top panel of Figure 6 shows that all participants performed the Eriksen task with high accuracy. There was a main effect of Trial Type ($F(2,64)=56.42$, $MSE=17.13$, $p<.01$, $\eta^2_p=.64$), demonstrating a significant difference between all three trial types with the most accurate responses for congruent trials and least accurate for incongruent trials. There was no effect of Language Group ($F(1,32)=0.04$, $p=.85$), nor a Language Group x Trial Type interaction ($F(2,64)=0.26$, $p=.78$).

The RT data can be seen in the bottom panel of Figure 6. Analysis of these data revealed a main effect of Trial Type ($F(2,64)=364.96$, $MSE=144.39$, $p<.01$, $\eta^2_p=.92$), demonstrating faster RTs for neutral and congruent trials (which did not differ from each other) relative to incongruent trials. There was no effect of Language Group

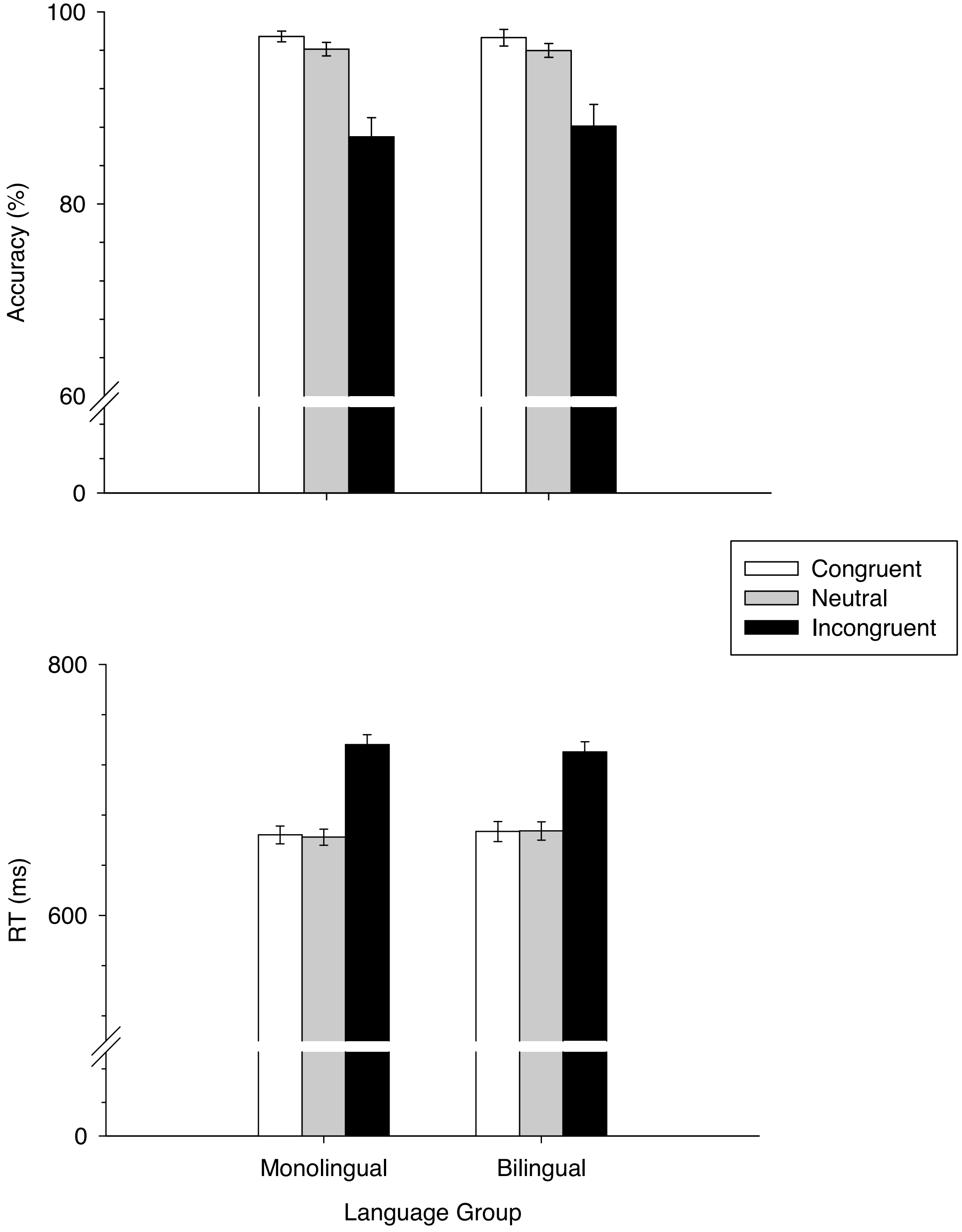

Figure 6. The top panel shows accuracy (±*SE*) and the bottom panel shows RT (±*SE*) for the Eriksen task as a function of Language Group and Trial Type.

(*F*(1,32)<0.01, *p*=.96), nor a Language Group x Trial Type interaction (*F*(2,64)=2.02, *p*=.14).

There was no effect of Language Group revealed in the analysis of facilitation (*F*(1,32)=0.69, *p*=.41), nor in the analysis of interference (*F*(1,32)=2.84, *p*=.10). The Language Group x Contrast ANOVA demonstrated an effect of Contrast, showing greater interference relative to facilitation. There was no effect of Language Group (*F*(1,32)=1.53, *p*=.23), or Language Group x Contrast interaction (*F*(1,32)=3.35, *p*=.08). Although the Language Group x Contrast interaction was a trend, analysis of the simple effects revealed no simple effect of Language Group and greater interference relative to facilitation for both monolinguals and bilinguals.

3.4.2 Electrophysiological Results

Separate analyses were conducted for each component of interest (i.e., N2, P3, ERN, and Pe) for each of the three experimental tasks, and the results will be presented for each task separately. In addition to the factors included in the behavioural analyses, the electrophysiological analyses also included the factor Site. Site refers to the scalp location of the electrode, which included a subset of midline electrodes that were selected based on previous research and inspection of the grand averaged waveforms. Specifically, the midline sites Fz, and FCz were included for analysis of the N2, and the midline sites Fz, FCz, and Cz for analysis of the ERN given the frontocentral distribution of these components (Falkenstein et al., 2000; see Folstein & Van Petten, 2008). Cz, CPz, and Pz were included for analysis of the P3 and Pe given their centroparietal scalp distribution (Falkenstein et al., 2000; Squires, Squires, & Hillyard, 1975).

For each component in each task, we conducted a primary mixed ANOVA including the between subjects factor Language Group (bilingual/monolingual) and the within subjects factors Trial Type (neutral, congruent, and incongruent) and Site. The dependent variable was the mean amplitude over a single time interval which encompassed the entire component of interest; given that the latency of the different components of interest varied across tasks the selected time intervals also varied and will be specified within the results for each task. A second set of ANOVAs were conducted in order to more closely examine the timing of observed differences. These ANOVAs included the additional within subjects factor Time, which refers to smaller 20 ms time intervals comprising the larger time interval included in the primary analysis. The dependent variable in the secondary analyses was the mean amplitude within each time interval, which allowed us to examine amplitude changes across the selected time intervals. Given that we hypothesized a latency effect in the P3 we specifically examined this by identifying the latency of maximum amplitude within the P3 time interval for each participant and conducted an additional mixed ANOVA with the between subjects factor Language Group and the within subjects factors Trial Type and Site.

For each ANOVA we conducted planned simple effects comparisons for the Language Group x Trial Type interaction to examine our hypotheses regarding Language Group differences for specific Trial Types, and our predictions for Trial Type within each Language Group. Any other significant interactions were followed with Bonferroni corrected simple effects analyses.

We first report results from the primary ANOVA including a single time interval, followed by results from the secondary analysis including multiple time windows when these provide additional information. For the P3 component, the peak latency analysis is reported last. Note that for analyses with more than one degree of freedom in the numerator, the Huynh and Feldt (1976) correction for non-sphericity was used. Following convention we report the unadjusted degrees of freedom, the corrected mean square error (*MSE*), the adjusted *p*-value, and the Huynh-Feldt epsilon value (ε).

Due to poor technical quality of the EEG recording several participants were excluded from the electrophysiological analyses (Stroop task – four monolinguals and four bilinguals; Simon task – three monolinguals and two bilinguals; Eriksen task – two monolinguals and three bilinguals). One additional bilingual was excluded from analyses of the Simon task due to poor behavioural performance, and one additional monolingual was excluded from analyses of the Eriksen task due to achieving 100 % accuracy. Thus analysis of the electrophysiological data are based on 13 participants in each language group for the Stroop task, and 14 participants in each language group for both the Simon and Eriksen tasks.

3.4.2.1 Stroop task. Figure 7 shows the stimulus-locked waveforms for correct trials as a function of Trial Type for the monolinguals (left panel) and the bilinguals (right panel). Based on the grand averaged waveforms in Figure 7, the N2 was analyzed between 220 and 360 ms and the P3 between 300 and 500 ms.

The primary analysis of the N2 revealed a trend toward a main effect of Language Group ($F(1,24)=3.90$, $MSE=32.17$, $p=.06$, $\eta^2_p=.14$), demonstrating larger N2 amplitude for monolinguals relative to bilinguals. There was also a Trial Type x Site interaction ($F(2,48)=3.68$, $MSE=0.09$, $p=.03$, $\eta^2_p=.13$, $\varepsilon=.97$), demonstrating more negative N2 amplitude for incongruent relative to congruent trials at both electrodes sites; however,

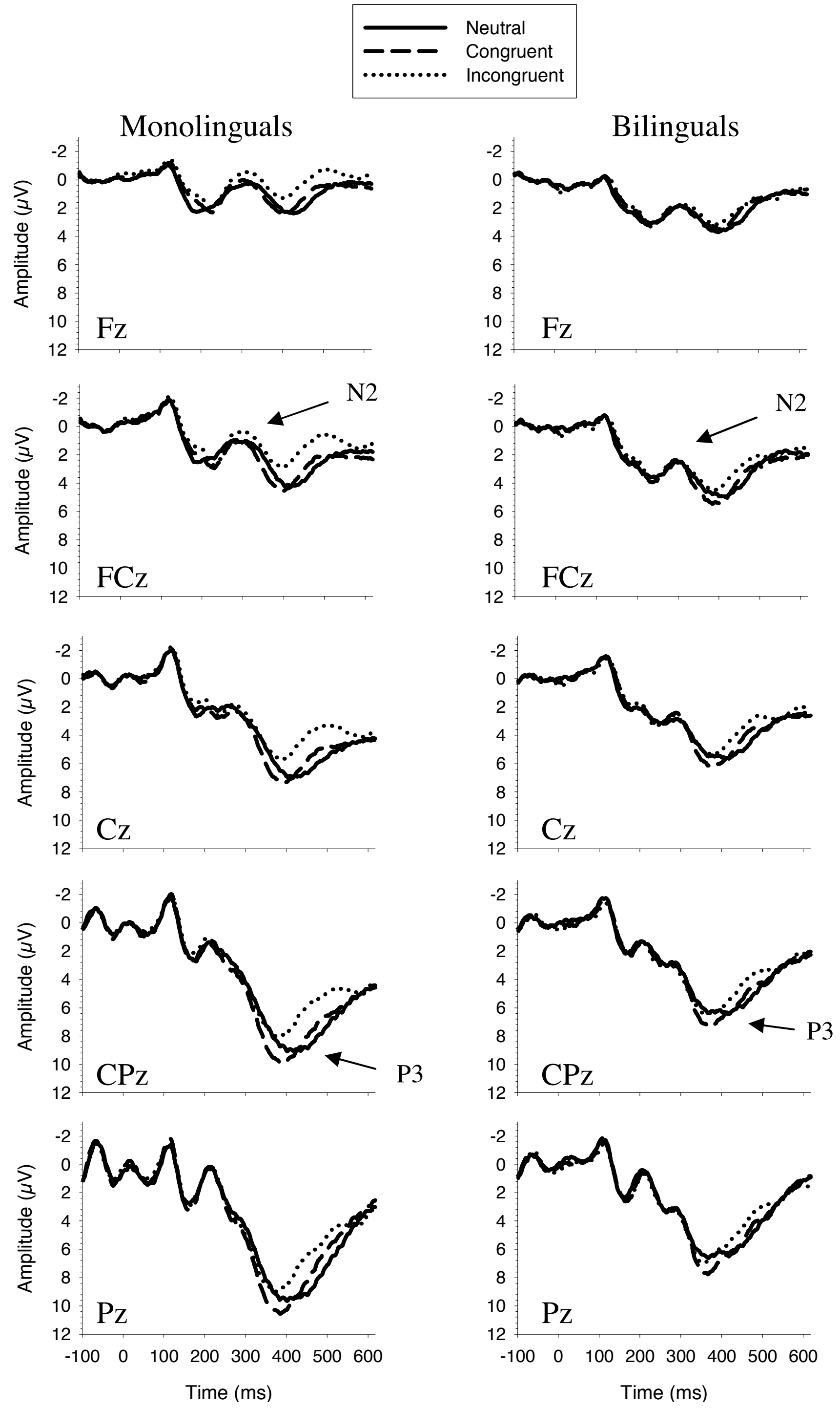

Figure 7. Stimulus-locked grand averaged waveforms (0 ms represents stimulus onset) for correct trials in the Stroop task for monolinguals (left panel) and bilinguals (right panel) as a function of Trial Type. The N2 was analyzed at sites Fz and FCz, and the P3 was analyzed at sites Cz, CPz, and Pz.

the amplitude difference between the two trial types was larger at site FCz (0.57 μV) than at site Fz (0.37 μV). The Language Group x Trial Type interaction was not significant ($F(2,48)=0.64$, $p=.52$); however, the planned comparisons showed larger N2 amplitude for the monolinguals relative to the bilinguals for incongruent trials ($p=.04$), and a similar trend for neutral ($p=.08$) and congruent ($p=.09$) trials. Furthermore, the monolinguals showed larger N2 amplitude for incongruent relative to congruent trials, whereas there was no effect of trial type in the bilinguals. The secondary ANOVA revealed a Trial Type x Site x Time interaction ($F(12,288)=3.96$, $MSE=0.11$, $p=.01$, $\eta^2_p=.14$, $\varepsilon=.24$), demonstrating larger N2 amplitude for incongruent relative to congruent trials (300-360 ms, at Fz and FCz), and relative to neutral trials (300-340 ms at Fz), which corresponds to the peak and positive going portion of the N2 (i.e., the P3).

The primary analysis of the P3 revealed a main effect of Trial Type ($F(2,48)=9.65$, $MSE=2.93$, $p<.01$, $\eta^2_p=.29$, $\varepsilon=1.0$), demonstrating smaller P3 amplitude for incongruent trials relative to both congruent and neutral trials, which did not differ from each other. The Language Group x Trial Type interaction was not significant ($F(2,48)=1.19$, $p=.31$); however, the planned comparisons revealed the same difference in Trial Type in the monolinguals as was found in the primary analysis. In the bilinguals, P3 amplitude was smaller for incongruent than congruent trials, but there was no difference between neutral trials and the other two trial types. Inspection of Figure 7 suggests that the P3 peaked later for neutral trials, and the secondary analysis indicated an interaction between Trial Type, Site, and Time ($F(36,864)=2.76$, $MSE=0.21$, $p<.01$, $\eta^2_p=.10$, $\varepsilon=.27$ reflecting this shift in latency. Analysis of the peak latency revealed a main effect of Trial Type ($F(2,48)=8.77$, $MSE=3017.34$, $p<.01$, $\eta^2_p=.27$, $\varepsilon=.59$), demonstrating a delay in the peak latency of the P3 for neutral trials relative to both congruent and incongruent trial which did not differ. The Language Group x Trial Type interaction was not significant ($F(2,48)=0.22$, $p=.61$); however, the planned comparisons revealed that the delay in P3 latency for neutral trials was significant in the monolinguals, and was only a trend in the bilinguals ($p=.08$ and $p=.07$ for congruent and incongruent trials respectively).

Figure 8 shows the response-locked waveforms for incorrect trials as a function of Trial Type for the monolinguals (left panel) and the bilinguals (right panel). Based on the grand averaged waveforms in Figure 8, the ERN was analyzed between 0-100 ms and the Pe between 100-400 ms.

The right panel of Figure 8 shows a striking difference in the amplitude of the ERN for neutral trials relative to congruent and incongruent trials (i.e., larger ERN amplitude for neutral trials) in the bilinguals. The primary analysis of the ERN time window did not reveal any significant effects; however, the planned comparisons of the Language Group x Trial Type interaction ($F(2,48)=2.38$, $p=.11$) revealed an effect of Trial Type in the bilinguals only demonstrating larger ERN amplitude for neutral trials relative to both congruent and incongruent trials, which did not differ from each other. Monolinguals also demonstrated larger ERN amplitude for congruent trials relative to bilinguals. The secondary analysis revealed an additional Language Group x Trial Type x Time interaction ($F(8,192)=111.42$, $MSE=33.0$, $p=.02$, $\eta^2_p=.12$, $\varepsilon=.47$), demonstrating that the larger ERN amplitude for monolinguals relative to bilinguals on congruent trials occurred from 20-60 ms post-response, corresponding to the peak of the ERN.

The primary analysis of the Pe time window revealed a trend for a Language Group x Trial Type interaction ($F(2,48)=2.66$, $MSE=50.23$, $p=.08$, $\eta^2_p=.10$, $\varepsilon=1.0$). The

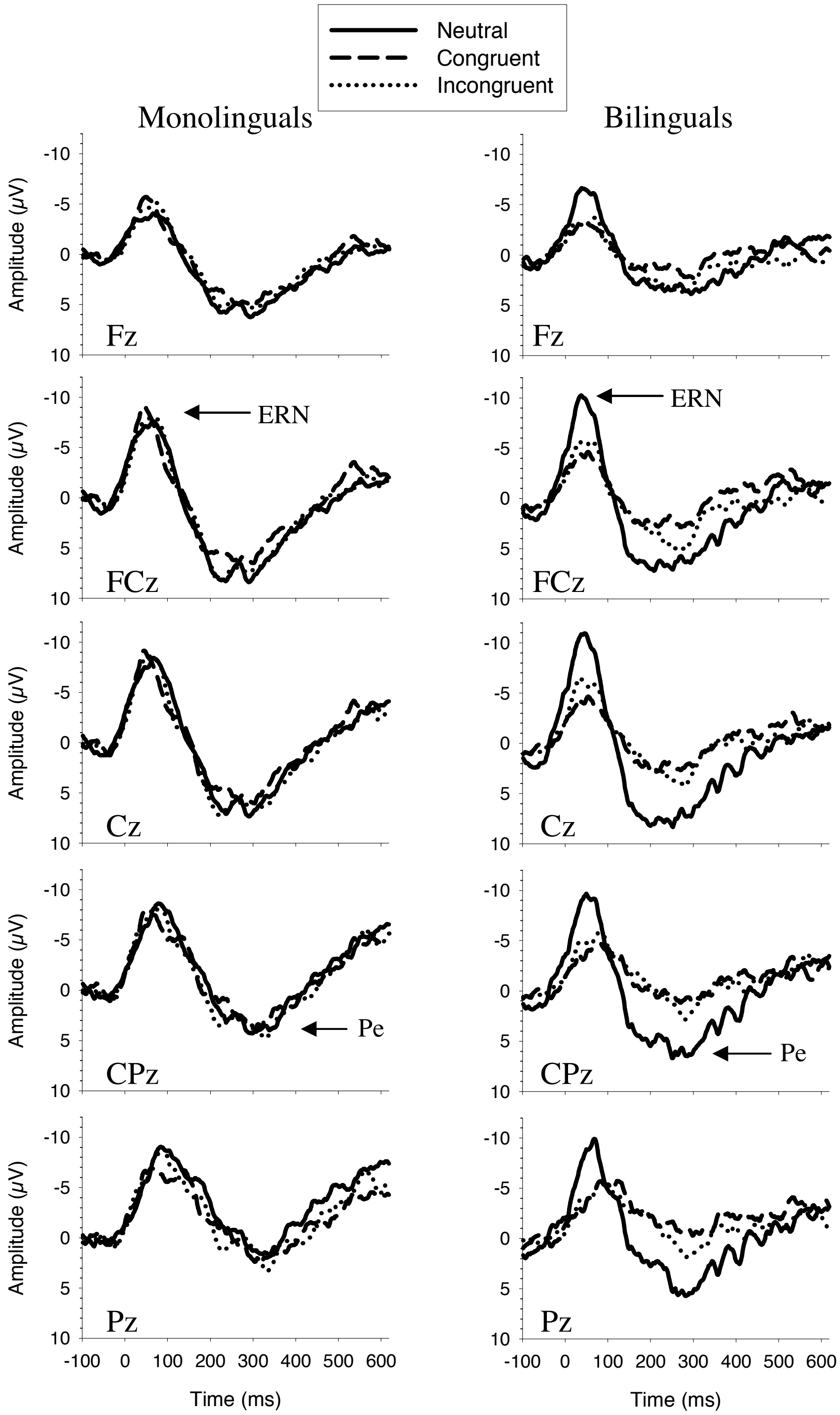

Figure 8. Response-locked grand averaged waveforms (0 ms represents response onset) for incorrect trials in the Stroop task for monolinguals (left panel) and bilinguals (right panel) as a function of Trial Type. The ERN was analyzed at sites Fz, FCz, and Cz, and the Pe was analyzed at sites Cz, CPz, and Pz.

planned comparisons revealed a simple effect of Trial Type for the bilinguals only, which indicated larger Pe amplitude for neutral trials relative to both congruent and incongruent trials, which did not differ from each other. The secondary analysis did not yield any additional information.

3.4.2.2 Simon task. Figure 9 shows the stimulus-locked waveforms for correct trials as a function of Trial Type for the monolinguals (left) and the bilinguals (right). Based on the grand averaged waveforms in Figure 9, the N2 was analyzed between 200 and 300 ms and the P3 was analyzed between 240 and 460 ms post-stimulus. It is noteworthy that inspection of the right panel of Figure 9 shows what appears to be two peaks in the N2 time interval for congruent and incongruent trials in the bilinguals; based on the timing of the N2 for neutral trials and for all three trial types in the monolinguals we have taken the first peak to be the N2 in bilinguals.

The primary analysis of the N2 revealed a main effect of Trial Type ($F(2,52)=31.5$, $MSE=1.35$, $p<.01$, $\eta^2_p=.55$, $\varepsilon=.89$), indicating a significant difference in N2 amplitude between all three trials types with the largest amplitude for neutral trials and the smallest amplitude for congruent trials. The Language Group x Trial Type interaction was not significant ($F(2,52)=.22$, $p=.78$), and the planned comparisons yielded no additional information. The secondary analysis did not yield any additional information.

The primary analysis of the P3 revealed a main effect of Language Group ($F(1,26)=10.80$, $MSE=79.43$, $p<.01$, $\eta^2_p=.29$), demonstrating larger P3 amplitudes for the monolinguals than the bilinguals. There was also a Trial Type x Site interaction ($F(4,104)=2.97$, $MSE=0.29$, $p=.04$, $\eta^2_p=.10$, $\varepsilon=.88$), demonstrating larger P3

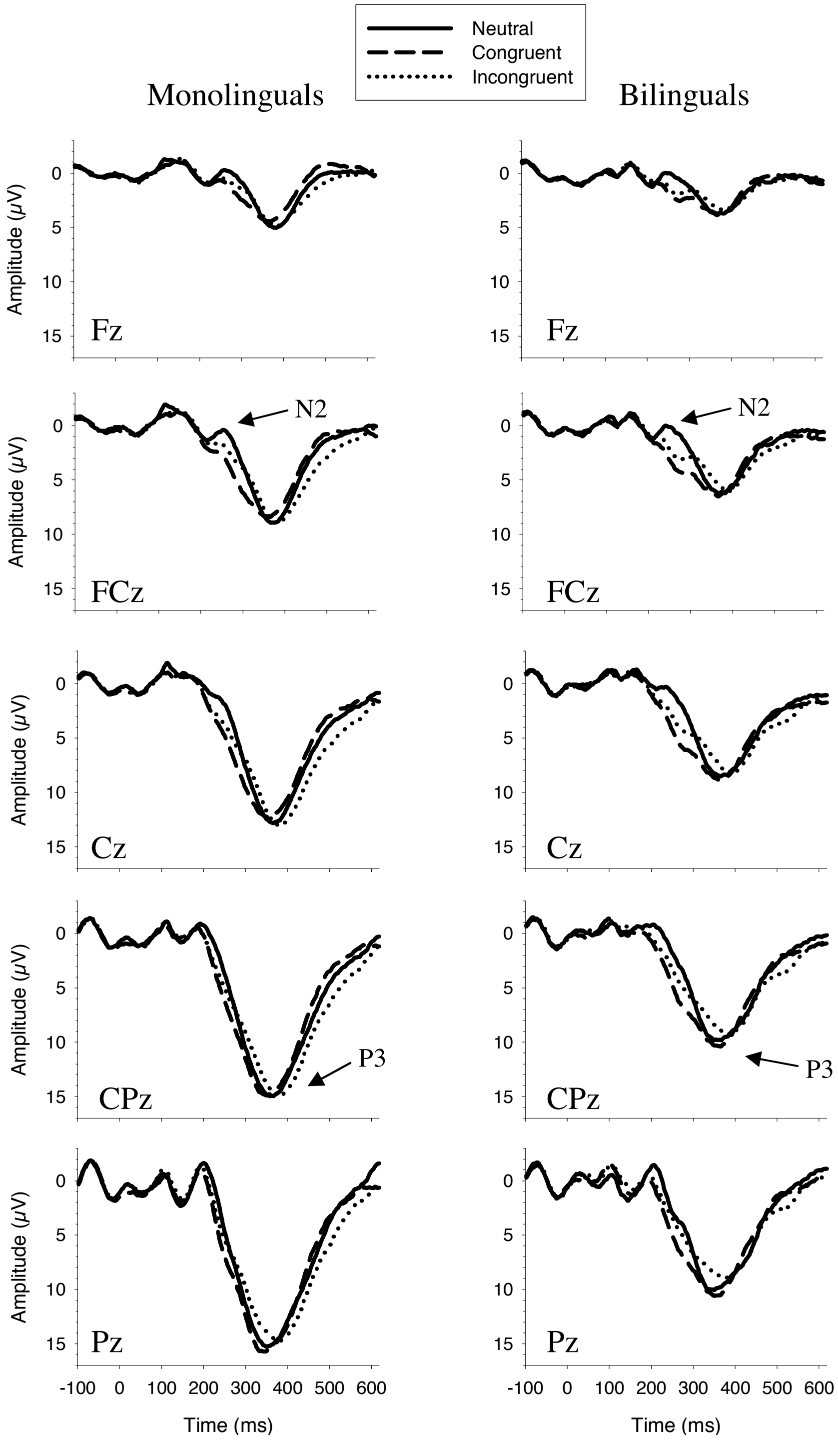

Figure 9. Stimulus-locked grand averaged waveforms (0 ms represents stimulus onset) for correct trials in the Simon task for monolinguals (left panel) and bilinguals (right panel) as a function of Trial Type. The N2 was analyzed at sites Fz and FCz, and the P3 was analyzed at sites Cz, CPz, and Pz

amplitude for congruent relative to incongruent trials at site Pz. The Language Group x Trial Type interaction was not significant ($F(2,52)=0.60$, $p=.53$); however, the simple effects analysis revealed that the monolinguals showed larger amplitude P3s relative to bilinguals for all trial types. Furthermore, there was no simple effect of Trial Type in the monolinguals, but the bilinguals showed smaller P3 amplitude for incongruent relative to congruent trials. The secondary analysis revealed a Language Group x Trial Type x Time interaction ($F(20,520)=2.23$, $MSE=8.49$, $p=.03$, $\eta^2_p=.08$, $\varepsilon=.37$). This demonstrated that monolinguals exhibited larger P3 amplitude relative to bilinguals (neutral trials: 260-380 ms; congruent trials: 240-380 ms; incongruent trials: 280-460 ms). Furthermore, the simple effect of Trial Type over the different time intervals differed for the monolinguals and bilinguals reflecting a difference in P3 latency. Analysis of the peak latency revealed a main effect of Trial Type ($F(2,52)=21.22$, $MSE=1036.60$, $p<.01$, $\eta^2_p=.32$, $\varepsilon=.94$), demonstrating later peak latency for incongruent trials relative to both neutral and congruent trials, which did not differ. The Language Group x Trial Type interaction was not significant ($F(2,52)=0.36$, $p=.69$), and the planned comparisons revealed no additional information.

Figure 10 shows the response-locked waveforms for incorrect trials as a function of Trial Type for the monolinguals (left panel) and the bilinguals (right panel). Based on the grand averaged waveforms in Figure 10, the ERN was analyzed between 0-100 ms and the Pe between 100-400 ms. The primary and secondary analyses revealed no significant effects for the ERN or the Pe.

3.4.2.3 Eriksen task. Figure 11 shows the stimulus-locked waveforms for correct trials as a function of Trial Type for the monolinguals (left panel) and the bilinguals

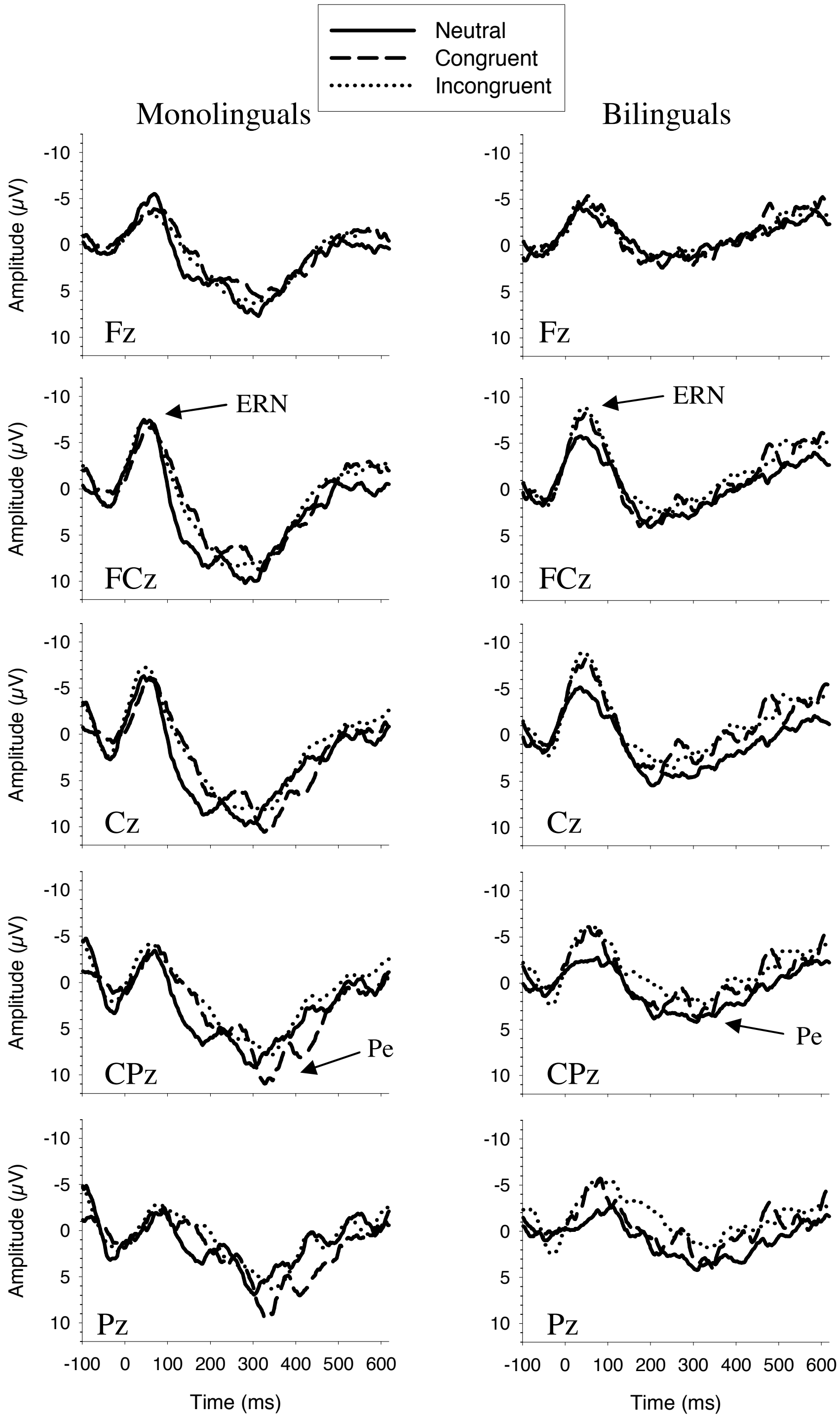

Figure 10. Response-locked grand averaged waveforms (0 ms represents response onset) for incorrect trials in the Simon task for monolinguals (left panel) and bilinguals (right panel) as a function of Trial Type. The ERN was analyzed at sites Fz, FC, and Cz, and the Pe was analyzed at sites Cz, CPz, and Pz.

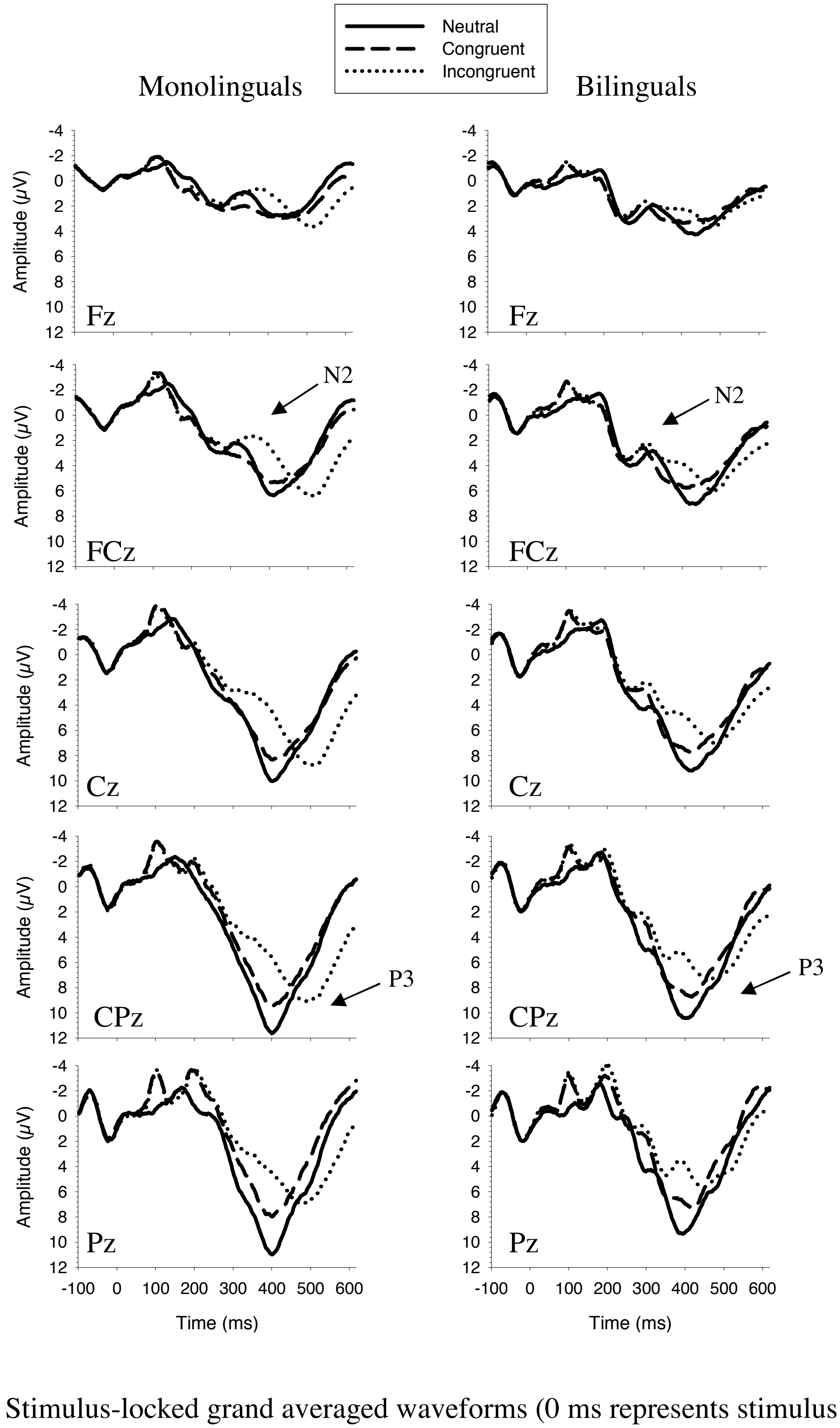

Figure 11. Stimulus-locked grand averaged waveforms (0 ms represents stimulus onset) for correct trials in the Eriksen task for monolinguals (left panel) and bilinguals (right panel) as a function of Trial Type. The N2 was analyzed at sites Fz and FCz, and the P3 was analyzed at sites Cz, CPz, and Pz.

(right panel). Based on the grand averaged waveforms in Figure 11, the N2 was analyzed between 260 and 420 ms and the P3 between 300 and 560. As can be seen in Figure 11, there is a clear latency shift in both the N2 and the P3 for the incongruent condition (i.e., the N2 and P3 peak later for the incongruent condition). For this reason we included an analysis of the peak latency of the N2 as well as the P3. We identified the peak latency of the N2 as the most negative point in the N2 time interval and conducted a mixed ANOVA similar to that for P3 peak latency.

The primary analysis of the N2 time interval revealed a main effect of Trial Type ($F(2,52)=14.70$, $MSE=1.70$, $p<.01$, $\eta^2_p=.36$, $\varepsilon=1.0$), demonstrating larger N2 amplitude for incongruent relative to congruent and neutral trials, which did not differ from each other. The Language Group x Trial Type interaction was not significant ($F(2,52)=0.38$, $p=.61$) and the planned comparisons did not yield any additional information. The secondary analysis did not reveal any additional information; however, analysis of the N2 peak latency revealed a main effect of Trial Type ($F(2,52)=10.52$, $MSE=1523.28$, $p<.01$, $\eta^2_p=.29$, $\varepsilon=1.0$), indicating that the N2 peaked earlier for congruent trials relative to both neutral and incongruent trials. The Language Group x Trial Type interaction was a trend ($F(2,52)=2.71$, $MSE=1523.28$, $p=.08$, $\eta^2_p=.10$, $\varepsilon=1.0$), and the planned comparisons showed that in the monolinguals the N2 was delayed for incongruent trials relative to both congruent and neutral trials (which did not differ), while for the bilinguals the N2 was delayed for neutral relative to congruent trials.

The primary analysis of the P3 time interval showed a main effect of Trial Type ($F(2,52)=5.62$, $MSE=6.54$, $p=.01$, $\eta^2_p=.18$, $\varepsilon=.85$), and a Trial Type x Site interaction ($F(4,104)=8.89$, $MSE=0.41$, $p<.01$, $\eta^2_p=.26$, $\varepsilon=.52$), demonstrating larger P3 amplitude for neutral relative to congruent trials at site CPz, and relative to both congruent and incongruent trials at site Pz. The Language Group x Trial Type interaction was not significant ($F(2,52)=.28$, $p=.72$); and the planned comparisons revealed that for both language groups the P3 was larger for neutral relative to congruent trials. The secondary analysis revealed a Language Group x Trial Type x Site x Time interaction ($F(48,1248)=2.15$, $MSE=0.94$, $p=.03$, $\eta^2_p=.08$, $\varepsilon=.19$), reflecting the latency shift in the P3. Analysis of the P3 peak latency revealed a main effect of Trial Type ($F(2,52)=84.36$, $MSE=5402.89$, $p<.01$, $\eta^2_p=.76$, $\varepsilon=1.0$), demonstrating that the P3 peaked later for incongruent trials relative to both congruent and neutral trials. The Language Group x Trial Type interaction was also significant ($F(2,52)=3.84$, $MSE=5402.89$, $p=.03$, $\eta^2_p=.13$, $\varepsilon=1.0$), and showed that P3 peak latency was delayed for incongruent relative to congruent and neutral trials in both language groups; however, the delay was larger in monolinguals than in bilinguals (mean difference between incongruent and neutral: 73.5 ms vs. 54.6 ms; mean difference between incongruent and congruent: 82.1 ms vs. 50.2 ms).

Figure 12 shows the response-locked waveforms for incorrect trials as a function of Trial Type for the monolinguals (left panel) and the bilinguals (right panel). Based on the grand averaged waveforms in Figure 12, the ERN was analyzed between 0 and 100 ms and the Pe between 100 and 400 ms. Inspection of Figure 12 suggests that the ERN peak for incongruent trials was broader than that for neutral trials in the bilinguals.

Analysis of the ERN time window revealed a Trial Type x Site interaction ($F(4,104)=3.25$, $MSE=3.15$, $p=.04$, $\eta^2_p=.11$, $\varepsilon=.58$), demonstrating larger ERN amplitude for incongruent relative to neutral trials at sites FCz and Cz. The Language Group x Trial

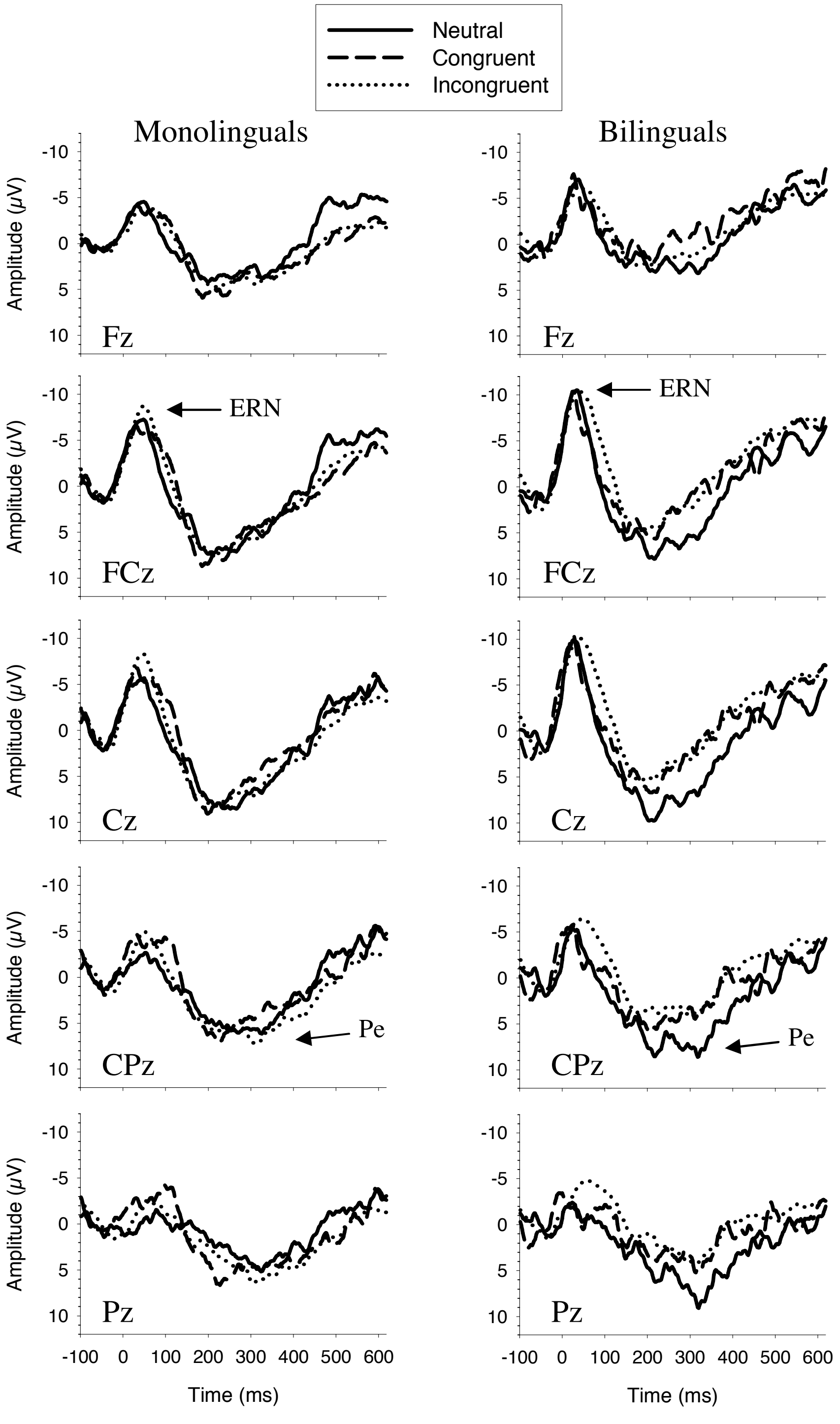

Figure 12. Response-locked grand averaged waveforms (0 ms represents response onset) for incorrect trials in the Eriksen task for monolinguals (left panel) and bilinguals (right panel) as a function of Trial Type. The ERN was analyzed at sites Fz, FC, and Cz, and the Pe was analyzed at sites Cz, CPz, and Pz.

Type interaction was not significant (*F*(2,52)=.28, *p*=.70); however, the planned comparisons revealed no effect of Trial Type in the monolinguals, and significantly larger ERN amplitude for incongruent relative to neutral trials in the bilinguals, likely reflecting the broader ERN observed in Figure 12.

Analysis of the Pe revealed no significant effects. Planned comparisons of the Language Group x Trial Type interaction (*F*(2,52)=2.29, *p*=.11) revealed larger Pe amplitude for neutral relative to incongruent trials in the bilingual group only; there was no simple effect of Trial Type in the monolinguals. Analysis of multiple time windows did not reveal any additional information.

3.5 Discussion

There were two goals of the present investigation in which monolingual and bilingual participants performed a Stroop, a Simon and a modified Eriksen flanker task while electrophysiological recording took place. First, we examined the behavioural data from the three tasks in an attempt to replicate previous findings of a bilingual advantage. Second, we examined the ERPs elicited by correct and incorrect trials on these tasks to determine if there were language group differences in the neural correlates of performance. Our inclusion of three tasks for which bilinguals have previously demonstrated an advantage relative to monolinguals within the same sample, and the combined use of behavioural and electrophysiological methods make this a unique and rigorous investigation of the bilingual advantage.

3.5.1 Behavioural Data

Based on previous findings we expected to find the classic effects for both language groups, namely greater accuracy and faster RTs for congruent relative to neutral trials, and for both congruent and neutral trials relative to incongruent trials. This hypothesis was largely confirmed by the main effect of Trial Type in the analysis of all three tasks, with significantly poorer performance on the incongruent trials. However, there were two exceptions, accuracy did not differ between congruent and neutral trials in the Stroop task, and RT did not differ between neutral and congruent conditions in the Eriksen task. Overall, however, we can conclude that the three tasks used here were introducing interference on incongruent trials and thus tapping the conflict monitoring and resolution processes required for successful performance of the task.

Of greater interest was the effect of Language Group. Analysis of the raw accuracy and RT data revealed no effect of Language Group for any of the three tasks; recall that we expected to find overall faster RTs in the bilinguals relative to the monolinguals. Nor did we find less interference for the bilinguals relative to the monolinguals as we had expected. Finally, we examined whether monolinguals and bilinguals differed in the relative facilitation and interference for each task. Once again, we found similar performance for monolinguals and bilinguals.

These findings contrast with those of others who report language group differences in young adults. Bialystok et al. (2008) found that bilinguals demonstrated smaller Stroop interference effects than monolinguals; however, there were no language group differences in the raw RTs or in the percentage increase in RT between congruent and incongruent trials. Bialystok (2006) also found an advantage for bilinguals relative to monolinguals in an arrows version of the Simon task. In that study the bilingual advantage was only present in the most demanding conditions of the experiment. Similarly, Costa et al. (2009) found that the bilingual advantage only emerged when the proportion of congruent and incongruent trials in the task created high demands on conflict monitoring processes. The present investigation used a simpler version of each of the three tasks in which there were equal proportions of each trial type and did not manipulate the difficulty of the task; it is possible that the task demands were not great enough for a bilingual advantage to be demonstrated.

Previous studies demonstrating an advantage for bilinguals relative to monolinguals have used larger samples (i.e., Bialystok, 2006: n= 40 monolinguals and 57 bilinguals; Bialystok et al., 2008: n=24 in each language group; Costa et al., 2008: n=100 in each language group; and Costa et al., 2009: n=30 in each language group), thus it is possible that they were able to detect a small effect. Given that our previous research (Kousaie & Phillips, unpublished manuscript) has not found a bilingual advantage for the Stroop task with a sample size comparable to previous studies we do not believe that the absence of a significant language group difference in the current study is a power issue.

3.5.2 Electrophysiological Data

Electrophysiological recordings were included in the present investigation in order to investigate language group differences in the neural responses to conflict, for both correct and incorrect trials. Given that we have been unable to replicate previous findings of a bilingual advantage in the Stroop task (Kousaie & Phillips, unpublished manuscript), and that Bialystok et al. (2005) found language group differences in the neural underpinnings of performance on the Simon task using MEG, we reasoned that ERPs would be a good measure of potential language group differences in the cognitive processes involved in performance of the Stroop, Simon, and Eriksen tasks, even if there were no behavioural difference in performance. Based on previous investigations, we took the N2 to be a measure of conflict monitoring (van Veen & Carter, 2002a; 2002b; Yeung et al., 2004), P3 latency as a measure stimulus categorization time (Kutas et al., 1977), and P3 amplitude as an index of resource allocation (Polich, 2007). In terms of the error-related components, we took the ERN to be a measure of conflict detection on error trials (Danielmeier et el., 2009; Yeung et al., 2004) and the Pe as an index of the saliency of errors (Leuthold & Sommer, 1999; Shalgi et al., 2009). We will discuss each component in turn, followed by a discussion of our findings for neutral trials given that our hypotheses regarding neutral trials were tentative due to a lack of previous research.

3.5.2.1 N2. Given that the N2 is thought to reflect conflict monitoring we predicted that all participants would show greater N2 amplitude for incongruent relative to congruent trials due to greater demands on conflict monitoring for these trials. Furthermore, we predicted that bilinguals would show larger N2 amplitudes relative to their monolinguals peers due to enhanced conflict monitoring in bilinguals.

For the Stroop task, we found that the monolinguals showed larger N2 amplitude for incongruent relative to congruent trials, whereas the bilinguals showed no difference in N2 amplitude between trial types. This suggests that, for the bilinguals, the degree of conflict monitoring required for incongruent trials was not significantly greater than for congruent trials, whereas in the monolinguals it was. There was also a trend showing that the monolinguals exhibited larger N2 amplitudes overall relative to the bilinguals; this was only significant for incongruent trials, although there was a similar trend for congruent trials. This result was contrary to our predictions and suggests greater conflict monitoring in the monolinguals than in the bilinguals. However, it is possible that the bilinguals required less active conflict monitoring than the monolinguals in order to perform the Stroop task. That is, if bilinguals are more efficient conflict monitors as a result of their experience with two languages then conflict monitoring in these individuals should require less activation of the ACC, thus eliciting a smaller amplitude N2. This interpretation is supported by a study demonstrating that a reduction in N2 amplitude from childhood to adolescence reflects the development of cognitive control (Lamm, Zelazo, & Lewis, 2006). Specifically, Lamm et al. found that smaller N2 amplitude during a Go/Nogo task was associated with better performance on independent measures of executive function, including a color-word Stroop task.

In both the Simon and Eriksen tasks incongruent trials elicited a larger amplitude N2 than congruent trials and this effect was the same for both language groups. This finding supports our prediction and demonstrates greater conflict monitoring for incongruent than for congruent trials. However, there were no differences between the two language groups suggesting that conflict monitoring was similar for monolinguals and bilinguals on the Simon and Eriksen tasks.

In the Eriksen task the N2 was delayed for incongruent relative to congruent trials in the monolinguals only, suggesting that conflict monitoring took longer for incongruent stimuli in the monolinguals. Given that the P3 was also delayed (as will be discussed later) the observed delay in the N2 for incongruent trials may also be the result of longer stimulus categorization time in the monolinguals. There was no delay in N2 peak latency for incongruent trials in the bilinguals.

3.5.2.2 P3. P3 latency has been associated with stimulus categorization time, thus we predicted that, for all participants, the P3 would be delayed in latency for incongruent relative to congruent trials, and this delay would be greater for monolinguals relative to bilinguals given that bilinguals are thought to profit from enhanced cognitive control mechanisms. In terms of P3 amplitude, increased resource allocation has been associated with decreased P3 amplitude, thus we predicted that the P3 would be smaller for incongruent relative to congruent trials.

For the Stroop task, there was no difference in the latency of the P3 for congruent and incongruent trials, demonstrating that stimulus categorization was similar for both types of trials in both language groups. The amplitude of the P3 was smaller for incongruent relative to congruent trials in both the monolinguals and the bilinguals. This confirms our hypothesis that there was greater resource allocation for incongruent trials; there were no differences between monolinguals and bilinguals with respect to resource allocation as indexed by P3.

For the Simon task, the P3 was delayed for incongruent trials relative to congruent trials in both monolinguals and bilinguals, demonstrating that it took longer to categorize incongruent stimuli, as predicted. This delay was not larger for the monolinguals relative to the bilinguals as expected, suggesting that stimulus categorization was similar for monolinguals and bilinguals. With respect to P3 amplitude, monolinguals demonstrated larger amplitude P3s relative to the bilinguals, suggesting greater resource allocation in the bilinguals relative to the monolinguals. This finding is surprising given the evidence for a bilingual advantage in Simon task (e.g., Bialystok, 2006; Bialystok et al., 2004). In the bilinguals, the P3 also indicated that fewer resources were allocated for congruent relative to incongruent trials, which is consistent with our hypothesis, whereas the monolinguals showed similar resource allocation irrespective of the type of trial. Taken together, these two findings with respect to P3 amplitude make an alternative explanation possible. We can speculate that the baseline levels of resource allocation differ for monolinguals and bilinguals. Following this, the finding that there was no differentiation between trial types in the monolinguals suggests that resources were not available, and the differentiation between the trial types in the bilinguals suggests a possible advantage for the bilinguals. Specifically, congruent and incongruent trials appear to be equally difficult for monolinguals, but in the bilinguals congruent trials appear to be easier relative to incongruent trials. Alternatively, the larger amplitude P3s in monolinguals could represent a floor effect (i.e., all three trial types were equally effortless); however, given that the P3 was delayed in latency for incongruent trials and the N2 indicated different degrees of conflict monitoring for the different trial types we do not believe this interpretation to be accurate.

The Eriksen task showed a delay in the latency of the P3 for incongruent relative to congruent trials, as predicted, indicating that incongruent stimuli took longer to categorize. Furthermore, the delay in P3 latency for incongruent trials was larger in the monolingual group, supporting our second hypothesis concerning the P3, and suggesting greater cognitive control in the bilinguals. There was no difference in P3 amplitude between congruent and incongruent trials, or between the monolingual and bilingual groups.

3.5.2.3 ERN. The ERN is believed to reflect error detection or post-response conflict (i.e., the conflict between an executed, erroneous, response and the intended, correct response); following this, we predicted that all participants would show reduced ERN amplitude for incongruent relative to congruent trials and that bilinguals would show larger ERN amplitudes relative to monolinguals. That is, enhanced cognitive control mechanisms in bilinguals would result in enhanced error detection.

For the Stroop task we found similar ERN amplitudes for congruent and incongruent trials in both monolinguals and bilinguals. This finding does not support our hypothesis and suggests that there was similar post-response conflict for both trials types in the version of the Stroop task used here. However, the monolinguals did show larger ERN amplitudes relative to the bilinguals for time intervals corresponding to the peak of the ERN. This suggests greater post-response conflict in monolinguals relative to bilinguals, which is contrary to our hypothesis. Given that we also found greater conflict monitoring in the monolinguals relative to the bilinguals it is possible that this greater post-response conflict is a product of greater conflict monitoring. Specifically, if the monolinguals were monitoring for conflict to a greater extent than bilinguals, the larger ERN amplitudes in response to errors may reflect this greater monitoring when errors were committed.

There were no significant differences in ERN amplitude between congruent and incongruent trials or between language groups for the Simon or the Eriksen[6] tasks.

3.5.2.4 Pe. Given a lack of previous research our hypotheses regarding the Pe were speculative. The Pe is thought to reflect the motivational significance of errors, as well as error salience. We hypothesized that for all participants the Pe would be larger for errors on congruent than on incongruent trials because errors for congruent trials would be more salient than for incongruent trials, and that the Pe would be larger for bilinguals

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[6] It should be noted that inspection of the left panel of Figure 12 appears to show a Trial Type difference for the monolinguals, particularly at site Cz. For this reason a supplemental within-subjects ANOVA was conducted including site Cz and time intervals from 20-80 ms for the monolinguals only. The effect of Trial Type was not significant (p=.21).

relative to monolinguals (i.e., if bilinguals are better conflict monitors they should be more aware of errors). We found no significant difference in Pe amplitude between congruent and incongruent trials, or between language groups for any of the tasks.

3.5.2.5 Neutral trials. To our knowledge no studies have investigated the neural responses to neutral trials in the tasks used here, thus this is the first and our hypotheses were speculative. Recall that we expected reduced N2 and ERN amplitude, and larger P3 and Pe amplitude with no delay in peak P3 amplitude. These predictions were based on the absence of conflict in neutral trials.

In terms of the N2 we found that, for the Simon task, N2 amplitude was largest for neutral trials relative to both congruent and incongruent trials, suggesting greater conflict monitoring on these trials. For the Eriksen task, the N2 was delayed relative to congruent trials in bilinguals but not in monolinguals, suggesting that conflict monitoring took longer for these trials in bilinguals. Neither of these findings support our predictions, but can be reconciled with the hypothesis that the N2 reflects conflict monitoring. That is, neutral trials did not comprise any conflict, whereas both congruent and incongruent trials either did comprise conflict or had the potential to do so. Each trial type represented one third of the total trials, thus on two thirds of the trials conflict could be present, whereas on the relatively infrequent neutral trials, which for the Simon task comprised a stimulus at the center of the monitor and for the Eriksen task was a single arrowhead, there was no potential for conflict. This may have caused the brain to monitor for another source of conflict on neutral trials, resulting in a larger amplitude N2 for the Simon task and a delayed N2 for the Eriksen task, relative to trials where the source of conflict (or potential for conflict) was apparent.

For the P3, we found a delay in peak amplitude for the Stroop task in both monolinguals and bilinguals, suggesting that stimulus categorization took longer for neutral trials. As was discussed with respect to the N2, this may be due to the relative infrequency of neutral trials, which resulted in these trials being relatively more effortful to process. For the Eriksen task, we found larger P3 amplitude for the neutral trials relative to congruent trials in both monolinguals and bilinguals, suggesting that fewer resources were allocated for these trials, as expected.

With respect to error trials, the bilinguals demonstrated larger ERN and Pe amplitudes for neutral trials relative to both congruent and incongruent trials on the Stroop task, whereas there were no effects in the monolinguals. For the Eriksen task, the bilinguals demonstrated smaller ERN amplitude and larger Pe amplitude for neutral relative to incongruent trials and there were no effects in the monolinguals. These findings do not support our hypotheses; however, it is interesting to note that the observed differences between neutral trials and the other two trial types emerged in the bilingual group only. Thus, although our hypotheses were speculative and were not supported, these findings demonstrate a difference between monolinguals and bilinguals in the processing of errors on trials that do not comprise any conflict.

3.5.3 General Discussion

In sum, the behavioural results reported here do not provide evidence for a bilingual advantage for the Stroop, Simon, or Eriksen flanker tasks used in this investigation. However, the electrophysiological results do reveal differences in processing between monolinguals and bilinguals that do not translate into behavioural differences.

For the Stroop task we found smaller N2 amplitudes in the bilinguals than the monolinguals, which we interpreted as resulting from more efficient conflict monitoring in the bilinguals. With respect to errors, we found larger ERN amplitudes in monolinguals relative to bilinguals, which we suggested is due to the need for greater conflict monitoring in this group.

For the Simon task, we found a language group difference in P3 amplitude. Specifically, P3 amplitude was larger for monolinguals than bilinguals and there was no differentiation in P3 amplitude between trial types in the monolinguals, whereas bilinguals demonstrated smaller P3 amplitude for incongruent trials as expected. We interpreted this finding as an indication that in the monolinguals resources were being used maximally for all three trial types, whereas the bilinguals showed increased resource allocation for incongruent relative to congruent trials.

In the Eriksen task, we found that the monolinguals showed a delay in P3 latency for incongruent trials that exceeded that in bilinguals, indicating a larger delay in the categorization of incongruent stimuli in the monolinguals than in the bilinguals. Although we observed a delay in the N2 for incongruent trials in the monolinguals we interpreted this as reflecting the delay in stimulus categorization.

It is also relevant that the different tasks used here yielded different results. Previous investigations using fMRI have found that similar brain regions are activated during the performance of the tasks included in the present investigation (Fan et al., 2003; see also Peterson et al., 2002), although it has been suggested that there is little relation between the nature of the conflict in each of the tasks (Fan et al.). In the Stroop task a dominant word reading response is the cause of conflict, in the Simon task conflict is caused by irrelevant spatial information, and in the Eriksen flanker task flanking distractors induces conflict. Fan et al. found that the conflict effect produced by a Stroop task, a flanker task, and a spatial conflict task did not correlate[7]. They further investigated this using a dual task interference paradigm. Fan et al. reasoned that if two tasks involve the same process, then performing them simultaneously would result in a greater increase in RT relative to when either was performed alone. Using a hybrid Stroop/flanker task (e.g., an incongruent Stroop stimulus could be flanked by a string of "x"s that were incompatible with the correct response creating a double incongruent condition) it was found that there was not an additive increase in RT when both types of conflict were present. A similar finding resulted when participants performed a hybrid flanker/spatial conflict task. These findings suggest that despite overlapping regions of activation during task performance, the cognitive processes involved in Stroop, flanker and spatial conflict differ.

Based on Fan et al.'s (2003) findings, it is not surprising that our three tasks yielded different results, and that differences between monolinguals and bilinguals manifest themselves differently in each task. Specifically, we found differences between the two language groups for conflict monitoring and error-related processing in the Stroop task, for resource allocation in the Simon task, and for stimulus categorization and error-related processing in the Eriksen flanker task.

This was only the second study to examine language group differences in cognitive control using an imaging technique. The first used MEG and also found differences in the neural correlates of performance of the Simon task between

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[7] Similar to Fan et al. (2003), our behavioural data showed no correlation between the interference effects produced by the Stroop, Simon, and Eriksen flanker tasks in either of the language groups, nor in the entire sample irrespective of language group.

monolinguals and bilinguals in the absence of behavioural differences (Bialystok et al., 2005). Bialystok et al. found that faster responses were correlated with greater activity in the ACC for bilinguals. This is interesting given that the N2 and ERN have both been correlated with ACC activity (Mathalon et al., 2003). Bialystok et al.'s findings suggest that in our investigation bilinguals should show larger N2 and ERN amplitudes relative to monolinguals, reflecting greater activity in the ACC. However, we found no difference between monolinguals and bilinguals in the N2 or the ERN for the Simon task. A possible reason for this is that Bialystok et al. did not examine overall ACC activity; they correlated ACC activity with behavioural measures. Thus, although greater ACC activity was associated with faster responding in the bilinguals, overall differences in ACC activity between monolinguals and bilinguals are unclear. It is possible that there was similar activity in both language groups in Bialystok et al.'s sample, but that in monolinguals it was not correlated with behaviour to the same extent as in bilinguals.

It should be noted that there were differences between our version of the Simon task and those most often used in previous investigations. In our version of the task we included neutral trials in which the stimulus was presented at the center of the computer monitor intermixed with congruent and incongruent trials. Previous investigations have either not included a neutral condition for the Simon task (e.g., Bialystok et al., 2004; Melara et al., 2008; Peterson et al., 2002) or included a neutral/control condition in a separate block rather than intermixed with congruent and incongruent stimuli (e.g., Bialystok, 2006; Bialystok et al., 2005; 2008). We chose to intermix the three types of trials in order to look at RTs in terms of facilitation and interference relative to the neutral condition from within the same block. This type of design is also preferable as it controls for any differences between the trial types that may be a product of block differences (e.g., fatigue, arousal). However, it is possible that this leads to differences in processing for the neutral condition, as discussed with respect to the electrophysiological results.

Similarly, neutral trials comprised of a single arrowhead presented at the center of the monitor were intermixed with congruent and incongruent trials in the Eriksen flanker task. This condition is often omitted in investigations using the flanker task (e.g., Danielmeier et al., 2009; Gehring et al., 1993), which may help to explain differences in the processing of neutral trials, as in the Simon task.

In conclusion, the electrophysiological results revealed differences between monolinguals and bilinguals in the processing of conflict that were not evident from the behavioural data alone. Behaviourally there were no differences between the monolingual and bilingual groups; however, electrophysiologically there were differences between the groups in terms of conflict monitoring, resource allocation and stimulus categorization, and error-related processing. The observed differences were not universal across the three tasks included here suggesting that there are task-related differences in the way conflict is processed. Furthermore, these results highlight the utility of electrophysiological methods in investigations of cognitive control. Given that the electrophysiological differences between monolinguals and bilinguals did not translate into behavioural differences it is perhaps misleading to refer to these differences as a bilingual advantage. It is possible that in a population where cognitive functioning is compromised the observed differences in brain responses may confer an advantage behaviourally, but in the present investigation this was not the case. Additional research is required to fully characterize the differences in cognitive control between monolinguals and bilinguals and the suggested bilingual advantage, both behaviourally and electrophysiologically. Given findings suggesting that bilingualism has a positive impact on cognitive aging (e.g., Bialystok et al., 2004; Zied et al., 2004), electrophysiological measures may be a powerful tool for elucidating the potential mechanism(s) underlying this positive effect.

Chapter 4: General Discussion

The manuscripts included in this thesis described studies designed to investigate several questions with respect to the cognitive benefits of being bilingual. In the first manuscript, I present a study which used a Stroop task to examine whether there was an advantage for bilingual relative to monolingual younger and older adults in a homogeneous sample. We found that, in the young adults bilinguals demonstrated a general speed advantage relative to monolinguals, but there were no differences in Stroop interference. With respect to aging, we found that older adults demonstrated greater Stroop interference relative to young adults, but there was no effect of bilingualism in the older adults. Thus, in manuscript 1 we do not replicate previous findings of a bilingual advantage.

In the second manuscript, I present a study that further investigated differences in the processing and resolution of conflict between monolingual and bilingual young adults using both behavioural and electrophysiological methods. The investigation used a Stroop, a Simon, and an Eriksen flanker task in order to fully examine the possible bilingual advantage. Behaviourally, we found no evidence of an advantage for bilinguals relative to monolinguals in any of the three tasks. However, the electrophysiological results revealed differences between monolinguals and bilinguals in terms of conflict monitoring, stimulus categorization and resource allocation, and error-processing, although the differences were not consistent across tasks. Furthermore, given that the electrophysiological differences did not translate into behavioural differences it cannot be concluded that the observed differences correspond to an advantage in the bilinguals.

Taken together, the results of the studies included in this thesis have practical and theoretical implications for research investigating the cognitive consequences of bilingualism, as well as cognitive research in general. In the following sections I will discuss the manuscripts included in this thesis with respect to the literature, as well as the implications, limitations and directions for future research.

4.1 Bilingual Advantage in Conflict Monitoring

As reviewed, the literature points to an advantage for bilinguals relative to monolinguals in terms of attentional control. Furthermore, it has been suggested that being bilingual may provide a buffer against some age-related declines in cognition (e.g., inhibitory processing). However, these conclusions may be questioned in light of some methodological issues. First, the greatest amount of evidence for a bilingual advantage comes from studies using a Simon task (e.g., Bialystok, 2006; Bialystok et al., 2004; Bialystok et al., 2005; Bialystok, Martin, et al., 2005; Martin-Rhee & Bialystok, 2008) despite the assertion by the same author that the Stroop task is “the most important task demonstrating executive control and conflict resolution” (Bialystok, 2009, p. 6). Second, the few studies that have investigated the bilingual advantage using a Stroop task have not used a monolingual control group (Zied et al., 2004), or have not controlled for immigrant status and native/second language (Bialystok et al., 2008). Thus, the first manuscript included in my thesis investigated the bilingual advantage in a Stroop task using a more homogeneous sample of bilinguals. The results from this study provided no evidence of an advantage for bilinguals relative to monolinguals in terms of Stroop interference. I conducted analyses with multiple dependent variables in order to fully scrutinize the data thus I am confident that there were no differences between the two language groups.

The young bilinguals did show a general speed advantage relative to their monolingual peers; that is, the young bilinguals were faster for all three Stroop conditions. This replicated previous findings from a Simon task (e.g., Bialystok, Martin, et al., 2005) and a flanker task (Costa et al., 2009). It has been argued that a speed advantage in bilinguals for both congruent and incongruent trials does in fact represent an advantage in terms of conflict monitoring and switching between the two trial types (Bialystok, Martin, et al.; Costa et al.). However, arguments for this come from studies in which congruent and incongruent stimuli were intermixed within a single block, thus requiring conflict monitoring and switching; given that in the investigation presented in manuscript 1congruent and incongruent items were presented in separate blocks the results cannot be taken as evidence for superior conflict monitoring or switching in bilinguals relative to monolinguals. Instead these results show that bilinguals were faster than monolinguals, but this was not related to Stroop interference.

The findings from the first study in my thesis showed no advantage for bilinguals over monolinguals in terms of RT; however, it did not rule out the possibility that there was an effect too subtle to be detected behaviourally. In the second manuscript a study is described that was designed to more thoroughly assess the presence of a bilingual advantage in young adults. Given that the bilingual advantage has also been demonstrated in a version of the Eriksen flanker task and most strongly (although not consistently) in the Simon task, these two tasks were included in addition to the Stroop task. Furthermore, the dependent measures were both behavioural and electrophysiological. Bialystok et al.

(2005) found that the neural underpinnings of performance of a Simon task differed between monolingual and bilingual young adults in the absence of behavioural differences. Thus, it was reasoned that ERPs would be a more sensitive measure of language group differences, even in the absence of behavioural differences. Behaviourally, the results provided no evidence for a bilingual advantage on the Stroop task, like in the first study, or on either of the other two tasks used. Furthermore, the general speed advantage observed in manuscript 1 was absent in all three tasks included in manuscript 2. The inconsistency of the results obtained across the two studies may be related to differences in stimulus presentation (i.e., blocked by trial type vs. intermixed). In spite of this, the electrophysiological results did point to processing differences between the two language groups. Specifically, the ERP data showed differences between the monolinguals and bilinguals in terms of conflict monitoring, stimulus categorization and resource allocation, and error-related processing; although these findings were not consistent across the three tasks. Furthermore, given that no behavioural differences between the two groups were observed it is not clear whether the observed electrophysiological differences represent an advantage for the bilinguals.

4.2 Theoretical and Practical Implications

There is a growing interest in the observed advantage for bilinguals relative to monolinguals given that studies supporting such an advantage have suggested that being bilingual may buffer against age-related declines in executive/cognitive control, and more importantly may delay the onset of Alzheimer's disease symptoms (e.g., Bialystok & Craik, 2010; Bialystok et al., 2007; Chertkow et al., 2010). Although this advantage has been reported it has not been fully characterized; the studies included here add to the growing literature in this area and raise questions with respect to the robustness and generalizability of the suggested advantage. Specifically, the research presented in my thesis demonstrates that there is a difference between monolingual and bilingual individuals in the processing of conflict. However, this difference is not as robust as previously suggested and in some cases only emerges when electrophysiological measures are used. That is, I have reported differences between monolinguals and bilinguals in the neural correlates associated with performance, but these differences do not translate into behavioural differences in the sample included in the investigation.

The findings presented in manuscript 2 demonstrated differences in the results for the Stroop, Simon and Eriksen flanker tasks suggesting that these three tasks are not entirely equivalent. It is important to note that this was the first investigation to directly compare performance between monolinguals and bilinguals on all three of these in tasks within the same sample. Few studies have compared these three tasks, and those that have concluded that there are differences between them (Fan et al., 2003); however, the three tasks have each been used to investigate the bilingual advantage (mostly in independent investigations; e.g., Bialystok et al., 2004; Costa et al., 2008; Zied et al., 2004). The results from manuscript 2 further demonstrate that there are differences between the tasks. Thus, although there have been reports of a bilingual advantage using each task, there may be differences in the cognitive process(es) that the advantage represents. It is possible that the different results for the three tasks observed in manuscript 2 reflect different effects of bilingualism on cognitive control. Furthermore, it is unclear whether these differences are indicative of an advantage for bilinguals given that there were no differences between the groups behaviourally.

The findings from this thesis demonstrating differences between monolinguals and bilinguals for the tasks included here have implications for cognitive research in general. That is, in cases where bilingualism is not a focus of the research, bilingualism is usually not considered as a potential mitigating factor; however, the present research suggests that even in cases where there are no obvious behavioural differences between monolinguals and bilinguals, there may be more subtle processing differences. Furthermore, although in manuscript 1 previous findings of an advantage for older bilinguals was not replicated, manuscript 2 demonstrated that this does not eliminate the possibility that there are differences too subtle to be detected behaviourally. Thus, it is recommended that future research investigating cognitive functioning consider bilingualism, or control for bilingualism, particularly when examining an older population. Specifically, these results taken together with the previous research demonstrating an advantage for bilinguals relative to monolinguals, both young and older, raises the possibility of bilingualism and/or multilingualism as a confounding factor in cognitive research.

The research presented in this thesis also has methodological implications given that differences between monolinguals and bilinguals were apparent in the ERP data but not in the behavioural data. Previous research investigating the bilingual advantage has demonstrated mixed results, with some finding an advantage and others not (see Appendix A in Costa et al., 2010). To our knowledge only one other study has used brain imaging techniques to investigate the effects of bilingualism on a cognitive control task (i.e., a Simon task; Bialystok et al., 2005). As was found in manuscript 2, Bialystok et al. found differences between monolinguals and bilinguals in the neural underpinnings of task performance in the absence of behavioural differences. Thus, manuscript 2 is the second investigation to demonstrate differences between monolinguals and bilinguals in the neural correlates of task performance despite similar behavioural performance, but using a comprehensive array of tasks. This suggests that although behavioural differences may not be universal in the literature, more sensitive measures (e.g., MEG and ERPs) may be more suitable for detecting such differences.

It is also important to note that in manuscript 2 the participants were highly educated young adults, a population that is at the height of cognitive functioning and therefore may not demonstrate a further advantage of bilingualism on cognition. Despite this I did find differences between monolinguals and bilinguals in the electrophysiological data. It is possible that in a population that is not at the height of cognitive functioning, the differences in brain processing observed in young adults would translate into behavioural differences. That is, older adults, who experience age-related declines in executive control, may benefit from being bilingual to a greater extent than young bilinguals, which would be apparent in both behavioural and electrophysiological measures. In fact, some studies that have found an advantage for bilinguals have reported that this advantage is larger in older adults (e.g., Bialystok et al., 2004). It remains to be seen whether electrophysiological methods will provide further insight into the interaction between age and bilingualism.

These results also have implications for research with patient populations. For example, patients with Alzheimer's disease have demonstrated impaired performance on the Stroop task (e.g., Bélanger et al., 2010), as well as other tasks requiring inhibition (e.g., Belleville et al., 2006). However, bilingual status has not been considered in these investigations. Given that it has been suggested that there is a delay in the onset of Alzheimer's symptoms in bilinguals there may be an interaction between bilingualism and performance on tasks requiring inhibition in Alzheimer's disease patients. Furthermore, given that inhibition may be important for language comprehension (e.g., lexical ambiguity resolution) this could have implications for the language impairments observed in Alzheimer's disease patients (Taler & Phillips, 2008).

In terms of practical implications, the present findings may promote bilingual education and the early attainment of fluency in a second language if they do correspond to an advantage for bilinguals, although this remains to be established. Early studies of bilingualism and second language learning suggested negative effects on intellectual development (e.g., Saer, 1923; Smith, 1923), and thus argued against bilingual language education. Although this has long been recognized as false and bilingual education in Canada is available in all provinces and territories, it is not mandatory across Canada, and the attainment of fluency in a second language is not necessary to function successfully in society throughout Canada. The findings presented here suggest that bilingualism has an effect on cognitive function, although whether this effect is an advantage remains unclear. Furthermore, recent findings suggest that the experience of lifelong bilingualism may provide a form of "cognitive reserve" that mediates against age-related cognitive decline (Bialystok et al., 2007; Chertkow et al., 2010; Kavé et al., 2008). Given the increasing number of older adults in our society, i.e., according to the 2006 Census there was an 11.5% increase in the number of Canadians 65 years and older from 2001 (Statistics Canada, 2007), and increased incidence of dementia (Alzheimer's Society of Canada, 2010), promoting bilingual education and the attainment of fluency in a second language may provide some form of preventative measure, or increase the quality of life of adults as they age.

4.3 Limitations

The research included in this thesis is not without its limitations. Limitations common to both of the studies include difficulties with participant recruitment. That is, our goal was to include a homogeneous group of native English monolinguals and bilinguals whose L2 was French, with stringent criteria for the age of acquisition and use of L2 in bilinguals. As can be inferred by the sample sizes in each study, it was difficult to obtain a large number of individuals who met these criteria, particularly in the older adult population. The stringent inclusion criteria are an advantage in the investigations included here, although this resulted in a smaller sample size.

There were also methodological issues that were specific to each manuscript, and that make direct comparisons between the results of the two investigations complex. For example, in manuscript 1 the conditions of the Stroop task were presented in blocks, whereas in manuscript 2 the trial types were intermixed for all three tasks. Previous studies have demonstrated that the size of the Stroop effect can be modulated by the proportion of incongruent and congruent trials within a block (e.g., Engle, 2002; Kane & Engle, 2003; Tzelgov, Henick, & Berger, 1992), and it has been suggested that in blocks comprised purely of one trial type there can be reliance on alternative strategies that do not require inhibition (e.g., Kane & Engle; Spieler, Balota, & Faust, 1996). Thus, although the results presented here demonstrate the absence of a bilingual advantage in manuscript 1 and evidence for differences between monolinguals and bilinguals on electrophysiological measures that were not observed in the behavioural measures manuscript 2, it is not known whether differences would have been observed in the older adults had the stimulus presentation been intermixed. That is, the older adults in manuscript 1 may have been relying on a strategy that was effective given our presentation method; however, in intermixed blocks such a strategy may have been rendered ineffective and differences between the two language groups may have emerged.

Similarly, it is not known if differences in the neural correlates of performance between the monolinguals and bilinguals would have been observed if the stimuli were presented in a blocked fashion. This can be considered a limitation given the findings of Costa et al. (2009) that demonstrate a bilingual speed advantage for both congruent and incongruent trials only when there was a high proportion of each trial type intermixed in a single block. Costa et al.'s findings were taken as evidence for a bilingual advantage in conflict monitoring; however, in manuscript 1 a general speed advantage for bilinguals was found when the stimuli were blocked by trial type, whereas manuscript 2 does not find a speed advantage when the stimuli were intermixed, which does not support Costa et al.'s findings.

4.4 Future Directions

In manuscript 1 no bilingual advantage was found for either age group included in the investigation; however, the results from manuscript 2 suggest that electrophysiological measures are more sensitive and capable of detecting subtle language group differences. Future research is required to determine whether these observed electrophysiological differences represent an advantage and the methods of manuscript 2 should be extended to include older monolingual and bilingual participants.

Given that bilingualism has been associated with a delay in the symptoms of Alzheimer's disease (Bialystok et al., 2007; but see Chertkow et al., 2010) it would be interesting to determine whether the processing differences between monolingual and bilingual young adults does in fact extend into older adulthood, and whether the differences are present in patient populations. Some have suggested that the bilingual advantage is even larger in older adults relative to young adults (Bialystok et al., 2004); ERP methodology would permit an examination of this in terms of electrical brain activity. Furthermore, the studies reporting a delay in the onset of Alzheimer's symptoms have examined the medical records of patients, but have not conducted any experimental investigations. Thus, although there is some support for an association between bilingualism (or multilingualism) and protection against the symptoms of Alzheimer's disease, the mechanism of this potentially protective influence is unclear. Examining cognitive control in monolingual and bilingual healthy older adults, individuals with mild cognitive impairment and Alzheimer's disease may provide insight with respect to the mechanism(s) of protection.

Other avenues for future research include an examination of other benefits associated with being bilingual. That is, past and present research has focused on an advantage for bilinguals on tasks measuring executive/cognitive control, and demonstrated generalization of the function of language control processes from the specific language domain to the more general cognitive domain. However, it is possible that other processes requiring implementation of the general processes of executive/cognitive control could be influenced by bilingualism. For example, lexical ambiguity resolution; when individuals encounter lexically ambiguous words (e.g., words with the same orthography but with different semantic features; *bank* meaning "a financial institution" or "the edge of a river") executive control processes are important for selecting the contextually appropriate meaning and suppressing the contextually inappropriate meaning. Thus, it is possible that bilinguals would show superior lexical ambiguity resolution relative to monolinguals. This is a particularly interesting question given that bilinguals have also been found to demonstrate a disadvantage relative to their monolingual counterparts in the verbal domain (see Bialystok, 2009; Michael & Gollan, 2005).

I have begun to investigate language based differences in lexical ambiguity resolution in young and older monolingual and bilingual adults (Kousaie & Phillips, in preparation). Using sentence terminal homographs (e.g., He made a large deposit at the <u>bank</u>.), and varying the relationship between the homograph and a target word (e.g., *money* – related, contextually appropriate; *edge* – related, contextually inappropriate; *game* – unrelated) in a naming paradigm I have found different effects of bilingualism in young and older adults. Specifically, in young adults, monolinguals appear to demonstrate superior lexical ambiguity resolution relative to bilinguals, whereas, under certain conditions bilingual older adults show an advantage relative to their monolingual peers. This suggests that in terms of lexical ambiguity resolution there are differences between monolinguals and bilinguals that may be advantageous in individuals with many years of experience manipulating two languages. Despite these findings, additional research is required to fully characterize the observed interaction between aging and bilingualism; electrophysiological methods may be a practical tool in such investigations.

Changes in language comprehension have also been associated with healthy aging (e.g., Kemper, 2006) and Alzheimer's disease (see Taler & Phillips, 2008 for review). These changes are particularly important given that communication difficulties in aging can lead to social isolation which has consequences for the physical and mental health of the individual (Cacioppo & Hawkley, 2003; Hall & Havens, 2001). It is possible that the effects of bilingualism on cognitive control may positively affect communication in ambiguous situations. If this is the case it may have implications for communication in healthy aging, as well as in mild cognitively impaired and Alzheimer's disease patients.

Finally, there are different types of bilinguals and it is possible that a bilingual advantage may not be present in all bilinguals. That is, bilinguals learn their second language at different ages, in different environments (e.g., school vs. home), achieve different levels of proficiency, and use their second language in different situations (e.g., only at school, on a regular basis with friends and family, only when travelling). These factors may influence the effects of bilingualism on cognitive control processes. The bilingual participants included in my thesis were all highly proficient second language French speakers who had learned French at a relatively young age, were living in Montreal and using their second language on a regular basis. It is not known how proficient a bilingual need be, if there is a critical age before which the second language needs to be learned, or if there is a minimum L2 usage criterion necessary in order for differences between monolinguals and bilinguals to emerge. Furthermore, immigrant status and the specific languages that a bilingual speaks may have an effect on the bilingual advantage (e.g., Chertkow et al., 2010). These are interesting research questions that should be investigated in order to further characterize the bilingual advantage.

4.5 Conclusions

In conclusion, the goal of the studies included here was to further investigate the bilingual advantage using important methodological innovations. That is, a highly controlled sample, multiple experimental paradigms, and electrophysiological measures to elucidate brain mechanisms. Manuscript 1 demonstrated that there was no bilingual advantage for younger or older bilinguals relative to their respective peers using a behavioural Stroop task. However, manuscript 2 showed that there were differences between monolingual and bilingual young adults when electrophysiological data were considered. Based on the findings of these investigations it appears as though the differences between monolinguals and bilinguals may be more subtle than some have suggested, and that more sensitive measures (e.g., ERP) may be more suited for measuring such differences. The results reported here have implications for cognitive research in general, as well as for future research examining healthy older adults and patients.

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Appendix A

Sample Stimuli

Simon task: “Please respond with a left button press if the stimulus is blue, and a right button pres if the stimulus is red”

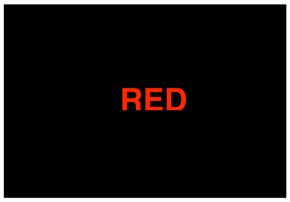
Neutral

Congruent

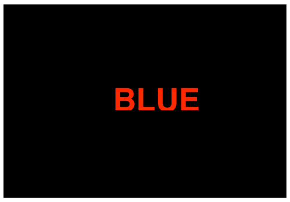
Incongruent

Stroop task: “Please name the colour of the print, do not read the word” or “please indicate the colour of the print using the corresponding button”

Neutral

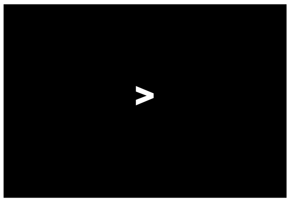


Congruent

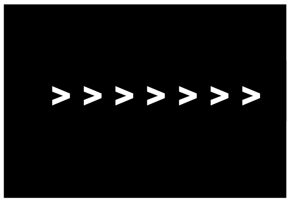


Incongruent

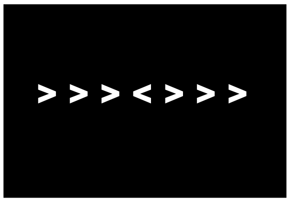
Eriksen flanker task: “Please indicate the direction of the central arrowhead. Use the left button if the arrowhead is pointing to the left and the right button if the arrow is pointing to the right”



Neutral



Congruent



Incongruent

Appendix B

Consent Form
Aging, bilingualism and lexical ambiguity

Purpose of the Study:

I have been informed that the purpose of this research is to examine the effects of age on a naming task in order to increase our present understanding of age-related changes in processing lexical ambiguity and how these changes may differ in monolingual and bilingual individuals.

Details of the Study:

The study will take place in the Cognitive Psychophysiology laboratory of the Department of Psychology at Concordia University. The study will be conducted in a small testing room. I will be seated in a comfortable chair and will be presented with sentences, one word at a time, on a computer monitor. I will be asked to read each sentences and then name a word that follows the sentence as quickly and accurately as possible. I understand that I may make errors but the most important thing is that I will try to do my best. I will also be asked to complete a colour naming task, in which I will be asked to name colours and read colour words, and a living/nonliving judgement task in which I will be asked to judge whether words refer to living or nonliving objects, in French and English. Two other paper and pencil tasks will be used to assess my cognitive performance, these include the Montreal cognitive assessment and the digit-symbol coding subtest of the Wechsler Adult Intelligence Scale, 3rd edition. Finally, I will be asked to read sentences that will be presented on a computer monitor and decide whether the sentences make sense. Following each set of sentences I will be asked to repeat the final word of each sentence in the set.

I will be asked to visit the Laboratory at Concordia University on one occasions and the testing session will last approximately 2 ½ hours. I understand that I will not be required to complete any tasks other than the ones mentioned above and I have been informed that certain demographic information (age, sex, education, language, and health status) will be recorded. I understand that this test is for research purposes only and that it is not diagnostic, meaning that it will not yield any results about my health. I understand that my individual results will not be provided to me; however, I will be informed of the general findings of the study.

Disadvantages and Risks of Participating in the Study:

It is possible that this task will lead to fatigue and frustration because I may not be able to accurately read or judge all the information with which I will be presented. However, I am asked to do the best that I can and I will be given frequent breaks whenever required to avoid this.

Advantages to Participating in the Study:

The researchers hope to learn more about how monolingual and bilingual individuals process ambiguity in language and any age-related differences in the processing of such words. Although this will not benefit me directly, this research could add to our scientific understanding of age related differences in language comprehension, communication and cognitive functioning. In addition, I will gain knowledge about how psychological research is conducted.

Confidentiality:

I understand that my participation in this study is *confidential*, that is, the researcher will know but will not disclose my identity in any published report or scientific communication. My records will not be identified by name; instead a subject code will be used. If the present study is published, only group results will be mentioned, ensuring my confidentiality as a participant in this experiment.

Withdrawal from the Study:

I understand that my participation in this study is voluntary and, if I agree to participate, I may withdraw my consent and discontinue participation *at any time* without negative consequences.

Participant's Rights:

I have fully discussed and understood the purpose and procedure of this study and have had the opportunity to ask any questions.

The following is the name, address, and telephone number of the researcher whom I may contact for answers to questions about the research or any injuries or adverse reactions which might occur:

Dr. Natalie Phillips, Department of Psychology, Concordia University, 7141 Sherbrooke Street West, Montreal, Quebec, H4B 1R6; tel: 848-2424 ext. 2218

Signature:

I have understood the contents of this consent form and have had the opportunity to ask questions. I agree to participate in this study.

____

Date

________________________________ ________________________________

Signature of Subject Print Name

Signature of Investigator 	Print Name

Signature of Person explaining Informed Consent 	Print Name

Appendix C

Consent Form
Electrophysiological Investigation of Conflict Processing and Bilingualism

Purpose of the Study:

I have been informed that the purpose of this research is to examine the effects of bilingualism on the processing of conflict in order to increase our understanding of the effects of bilingualism on attention control.

Details of the Study:

The study will take place in the Cognitive Psychophysiology laboratory of the Department of Psychology at Concordia University. The electroencephalogram (EEG) is a recording of electrical brain activity measured at the scalp (similar to an EKG recording of heart activity). To record the EEG, a nylon cap will be placed on my head, and an electrolytic gel will be applied to each of the small plastic electrode holders to obtain proper recordings. Sensors (electrodes) will be placed in each of these holders in order to record the EEG. Sensors will also be applied to the area around my eyes (to record eye movements) and my earlobes (to record a non-active reference). The gel resembles a hair gel and is used to make contact between the scalp and the recording sensor.

The study will be conducted in a small testing room. I will be seated in a comfortable chair and will perform three tasks presented on a computer monitor. For each of these tasks I will be asked to respond using the keyboard. For one of the tasks I will be asked to identify the colour of a word presented on the monitor. For a second task I will be asked to identify the direction in which an arrow is pointing. For the third task I will be asked to identify the colour of a square presented on the monitor. I understand that I may make errors but the most important thing is that I will try to do my best. I will also be asked to complete a living/nonliving judgement task in which I will be asked to judge whether words refer to living or nonliving objects, in French and English. Two other paper and pencil tasks will be used to assess my cognitive and working memory performance; these include the Montreal Cognitive Assessment and Letter-Number Sequencing subtest of the Wechsler Adult Intelligence Scale, 3rd edition.

I will be asked to visit the laboratory at Concordia University on one occasion and the testing session will last approximately 2.5 hours. I understand that I will not be required to complete any tasks other than the ones mentioned above and I have been informed that certain demographic information (age, gender, education, language, and health status) will be recorded. I understand that this test is for research purposes only and that it is not diagnostic, meaning that it will not yield any results about my health. I understand that my individual results will not be provided to me, however, I will be informed of the general findings of the study. In the unlikely event that any potentially significant abnormality in my EEG is observed, this information will be forwarded to my family physician with my permission.

Disadvantages and Risks of Participating in the Study:

EEG testing is a painless and non-invasive procedure (using no foreign substances like medications, tubes, or needle injections). Nevertheless, sometimes the nylon cap may feel tight and may cause some discomfort. It is also possible that the tasks will lead to fatigue and frustration. However, I am asked to do the best that I can and I will be given frequent breaks to avoid/minimize this. I understand that, in the *unlikely* event that any finding of possible clinical significance is made and communicated to my physician, it may be recommended that I have additional testing which would not have taken place if I had not participated in this study.

Advantages to Participating in the Study:

The researchers hope to learn more about the brain processes that are involved in conflict monitoring, detection and resolution, and how these may be affected by bilingualism. Although this will not benefit me directly, this research will add to our scientific understanding of potential advantages or disadvantages of language abilities on other, non-linguistic cognitive processes. In addition, I will gain knowledge about how psychological research is conducted.

Confidentiality:

I understand that my participation in this study is *confidential*, that is, the researcher will know but will not disclose my identity in any published report or scientific communication. My records will not be identified by name; instead a subject code will be used. If the present study is published, only group results will be mentioned, ensuring my confidentiality as a participant in this experiment.

Withdrawal from the Study:

I understand that my participation in this study is voluntary and, if I agree to participate, I may withdraw my consent and discontinue participation *at any time* without negative consequences.

Participant's Rights:

I have fully discussed and understood the purpose and procedure of this study and have had the opportunity to ask any questions. The following is the name, address, and telephone number of the researcher whom I may contact for answers to questions about the research or any injuries or adverse reactions which might occur:

Dr. Natalie Phillips, Department of Psychology, Concordia University, 7141 Sherbrooke Street West, Montreal, Quebec, H4B 1R6; tel: 848-2424 ext. 2218

Signature:
I have understood the contents of this consent form and have had the opportunity to ask questions. I agree to participate in this study.

Date

Signature of Subject	Print Name
Signature of Investigator	Print Name
Signature of Person explaining Informed Consent	Print Name