Testing Effects of Bilingualism on Inhibition, Shifting and Working Memory Ability in Adults

by

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Abstract

Bilingualism is a prevalent experience and the notion of bilingual advantage in cognitive abilities has been debated hotly over the past decades. Researchers have sought to investigate the long-term impacts of knowing a second language on executive function (EF) enrichment. Some studies have found a bilingual advantage in executive functioning skills, including inhibition, attention, working memory, mental flexibility, creativity, and problem-solving. Other studies have failed to replicate these findings. Yet other studies found a bilingual disadvantage in some EF tasks. The first aim of this study was to test for a bilingual advantage in EF among a large number of young adults. One possible reason for the varied results in previous studies is that some variables might moderate the relationship between bilingualism and EFs. Another aim of this study is to investigate whether this bilingual advantage is moderated by age of acquisition (AoA), socioeconomic status (SES), and immigration status. The findings showed no difference between monolinguals and bilinguals on EF tasks and the abovementioned variables did not show a moderating effect. These results do not support the argument that there is a bilingual advantage in EF. I discuss other possible variables that might contribute to the mixed results across studies.

Preface

This thesis is an original work by Farzaneh Anjomshoae. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name "How does bilingualism affect executive function components?", No. 00102974, October, 29, 2020.

To my husband Shervin

For all the love, support and companionship.

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Introduction

The number of individuals who speak more than one language has been increasing in the world (Ansaldo et al., 2008). In many countries like Canada, an official bilingual country, students who enroll in second language programs such as French immersion have increased from 10.6% in 2015 to 12.0% in 2019. According to Statistics Canada (2016) approximately seven million people, 21.1% of the Canadian population, speak another language than English at home. There are many privileges of being bilingual. For example, being bilingual allows communication with different peoples from different cultures. Moreover, bilinguals have advantages in the job market, including more employment opportunities and higher salary over monolinguals (Grin et al., 2010).

Beyond cultural and material advantages, some studies have shown bilingualism is related to differences in cognitive abilities in positive ways. This effect has been known as a bilingual advantage in the literature (Bialystok et al., 2004). This advantage is thought to stem from the competition between two languages. In other words, bilinguals have two activated languages simultaneously and they have access to lexical representations in both languages (Costa et al., 2006; Van Hell & Dijkstra, 2002). Consequently, they have to practice managing attention through inhibiting the non-target language to communicate in the target language effectively, cross-culturally, and across the lifespan (Bialystok et al., 2004; Namazi & Thordardottir, 2010; Starreveld et al., 2014; Yang, 2017). This process involves greater cognitive demands to solve this conflict (Ursino, Cuppini, & Magosso, 2014). That is, the repeated practice in cognitive control skills among bilinguals might generalize to other situations, including experimental tasks.

One of the ongoing and hotly debated questions is whether bilingualism boosts executive functioning (Bialystok, 2011; Bialystok et al., 2005; Poulin-Dubois et al., 2011; Pelham and Abrams, 2014; Antón et al., 2016), creative thinking (Lee & Kim 2011), dual-tasking (Sörman et al., 2017) and delay in the onset of dementia (Bialystok et al. 2008). Many studies have found a bilingual advantage on tasks tapping executive function (Bialystok et al., 2008; Brito et al., 2016; Grundy & Timmer, 2017; Hernández et al., 2010; Morales et al., 2013). However, other studies have not found this advantage (Anderson et al., 2017; Antón et al., 2016; Blumenfeld & Marian, 2013; Desjardins et al., 2020; Filippi et al., 2020; Kousaie et al., 2014; Massa et al., 2020; Mor et al., 2014; Morrison & Taler, 2020; Nichols et al., 2020; Papageorgiou et al., 2019; Salvatierra & Rosselli, 2010; Weyman et al., 2020). Moreover, a few studies have shown a bilingual disadvantage (e.g., Folke et al, 2016; Gonzalez, 2017; Kousaie & Phillips (2012), Samuel et al., 2018). The bilingual advantage hypothesis has been the subject of many individual studies and meta-analyses. In the following session, I will discuss some of the evidence for and against a bilingual advantage.

Bilingual Advantage Hypothesis

A great body of studies (more than 100 studies) have examined this hypothesis and shown inconsistent results (Adesope et al., 2010; Donnelly et al., 2019; Lehtonen et al., 2018; Paap, 2019). Many individual studies found supporting evidence for the bilingual advantage hypothesis, across the lifespan. These studies have proposed this advantage might be evident among bilingual infants (Kovàcs & Mehler, 2009), toddlers (Poulin-Dubois et al., 2011) preschool children (Bialystok & Martin, 2004, Carlson & Meltzoff, 2008), young adults (Costa et al., 2009, Costa et al., 2008, Prior & MacWhinney, 2010) and older adults (Bialystok et al., 2007, Bialystok et al., 2004). In spite of some support, the results of many reviews, interestingly, were mixed.

Paap (2018), for instance, did a meta- analysis study of 99 studies reporting RT for 177 language-group comparisons. The results showed that out of 174 comparisons, reporting a statistical test to compare the interference effects between monolinguals and bilinguals, only 26 (14.7%) comparisons supported the bilingual advantage, interestingly, all of those comparisons were from the studies with small sample sizes. 144 (81.4%) of the comparisons yielded null results and 4 (2.3%) showed a bilingual disadvantage. Additionally, van den Noort et al. (2019) reviewed the results of 46 studies comparing bilingual and monolingual children and adults, on tasks tapping executive functioning. They found that 54.3% of the selected studies supported a bilingual advantage, 28.3%, showed mixed results, and only 17.4% showed a bilingual disadvantage. They reported that the bilingual advantage was more evident in the earlier studies in the period between 2004 and 2012, while studies showing null results and bilingual disadvantage were conducted more recently from 2013 until October 2018. One key explanation is the improved methodology including the use of larger samples and different experimental tasks, which has been used more in recent studies than earlier ones.

Some of the inconsistency of results could be due to differences in operationalizations of executive functioning. I next turn to how executive functioning has been conceptualized and operationalized in light of the bilingual advantage hypothesis.

Executive Functions

Executive functions (EFs), also known as executive control or cognitive control, refer to a set of top-down cognitive abilities that are required to control individuals' thoughts, actions and underlie goal-directed behavior (Diamond, 2013; Miyake et al., 2000). EFs play an important role in mental and physical health, social and psychological development (Diamond, 2013). EFs have been found to play a fundamental role in different aspects of an individual's development such as planning, decision making, and problem-solving (Friedman et al., 2006; Miyake et al., 2000), academic achievement (Blair & Razza, 2007; Schmitt et al., 2015), classroom learning (Blair & Razza, 2007), social-emotional development (Broidy et al., 2003; Ferrier et al., 2014), physical health (Moffitt et al., 2011, Riggs et al., 2010), career success (Bailey, 2007), making and keeping friends (Hughes & Dunn, 1998), and marital harmony (Eakin et al., 2004). Various models of EFs have been proposed, which are either conceptualized as a unitary system (e.g., Fuhs & Day, 2011; Wiebe et al., 2008) or multicomponent (Miyake et al., 2000).

One of the most prominent models of EF has been suggested by Miyake and his colleagues in 2000. According to this model EFs consist of different interconnected yet separate components: inhibition (the process of managing attention purposely), switching (switching between different concepts concurrently), and working memory (keeping and processing information in mind for a short time). They administered nine EF tasks, three for each component, and conducted confirmatory and exploratory factor analysis to test the individual components and to assess how those components are connected and loaded onto a common factor. They used a Stroop task, an Antisaccade task, and a Stop-signal task to measure inhibition, a Keep-track task, a Letter memory task, and a Tone-monitoring task to assess working memory and a Plus–minus task, the Number–letter task, and the Local–global task to measure shifting ability. The results confirmed the three-factor model. For this study I focused on this model as those three factors of EFs have been mainly discussed in the literature and it has been well documented that EF has a multicomponent nature among adults (e.g., Karr et al., 2018; Vaughan & Giovanello, 2010). Furthermore, this model allows an understanding of EFs at a behavioral level (rather than a neural level). All the factors in the three-factor model of EF have been extensively studied in the literature on bilingualism; however, a bilingual advantage in inhibition has received the most attention (De Cat et al., 2018; Hilchey &Klein, 2011). I will discuss in detail the three components, how these components have been measured and the related bilingual studies results in the following sections.

Inhibition. Inhibition or inhibitory control (IC), also known as response inhibition, is a key component in cognitive control that refers to managing attention purposely and inhibiting prepotent responses which can be caused by internal or external (environmental) factors and distractors (Diamond, 2013). Diamond (2013) suggested inhibition allows individuals to ignore the irrelevant information. One example of inhibition would be ignoring the conversation and background noises while studying. Green (1986, 1993, 1998) provided a strong theoretical model of the impact of bilingualism on IC. He suggested that there is a distinction between active and reactive inhibition. Active inhibition uses a central inhibitory system relative to local inhibitory connections to solve the two competing languages. According to this model, with experience active inhibition may extend from language stimuli to non-language stimuli, explaining a possible bilingual advantage on non-verbal executive tasks. Reactive inhibition refers to the repression of an already initiated response when triggered by a cue (Aron, 2011). Reactive inhibition (Desimone & Duncan, 1995), the target language could be reinforced by supporting a link between the hypothetical goal system and the target language. In other words, by supporting the target language, the activation of the target language might not only be enhanced, but it also refers to the inhibition of non-target language through the inhibitory link. Based on this model, for bilinguals there is always competition when selecting lexical information for one of the two languages and the domain-general inhibition system suppresses the non-target lexical items. Bialystok et al. (2004) argued bilinguals exercise this process regularly which would lead to an advantage and show a small interference effect as compared to monolinguals. It has been well documented in many behavioral studies and some neuroscience research that bilinguals' two languages are simultaneously active to some degree and compete for selection (Bialystok et al., 2005; Colomé, 2001; Green & Abutalebi, 2013; Kroll et al., 2015; Kroll, Bobb, & Wodniekca, 2006). Therefore, bilinguals need to control and inhibit the non-target language constantly, which can, in turn, increase their ability to inhibit irrelevant information (Costa, 2005; Kroll et al., 2012, Prior & Mac Whinney, 2010). For example, if a French-English bilingual thinks of the concept of cat, the lexical representations for both languages ("cat" and "chat") will be active. In this situation, the bilingual individual needs to manage the conflict and choose the target word according to the context. Different studies investigated the association between inhibition and other EFs. Inhibition in young adults can be measured with several tasks including the Antisaccade task (Hallett, 1978), the Stroop task (Golden, 1976), the Stop-signal task (Colzato et al., 2008; Li et al., 2006;), the Eriksen Flanker task (Eriksen & Eriksen, 1974), the Shape-matching task (DeSchepper & Treisman, 1996), the Word-naming task (Kane et al., 1994), the Simon task (Białystok et al. 2004), the Go/No-Go task (Godefroy & Rousseaux, 1996), and the Competing Motor Program (CMP) test (McKay et al., 1994). Although there are some differences in these tasks, all of them involve inhibiting an irrelevant stimulus to produce a relevant response.

Many previous studies have shown that both children and adult bilinguals outperform monolinguals when the task involves inhibition (Bialystok et al., 2004; Bialystok, Craik, & Ryan, 2006; Bialystok, Craik, & Luk, 2008; Blumenfeld & Marian, 2011; Carlson & Meltzoff, 2008, 2013; Emmorey et al., 2008; Kapa & Colombo, 2013; Martin-Rhee & Bialystok, 2008; Poarch & van Hell, 2012; Tao et al., 2011; Yang, Yang & Lust, 2011). Bialystok, Craik and Luk (2008), for instance, used Stroop and Simon tasks, and the results indicated that bilinguals showed lower inhibitory cost over monolinguals. Similarly, Blumenfeld and Marian (2014) used Stroop and Simon tasks to test if a bilingual advantage is apparent among bilingual and monolingual adults. The results showed bilinguals were significantly better than monolinguals in both tasks.. Likewise, the results of a study by Xie (2018) showed a bilingual advantage and that high-proficient bilingual adults outperformed those with low levels of proficiency on the Flanker and Wisconsin Card tasks. Moreover, Weissberger et al. (2015) found a bilingual advantage and that the Flanker task as a non-linguistic task is more related to bilingual advantage than other tasks.

However, some studies have not found evidence for the bilingual advantage in inhibition (Arizmendi et al., 2018; Costa et al., 2009; Colzato et al., 2008; Hilchey & Klein, 2011; Kroll & Bialystok, 2013; Lehtonen et al., 2018; Morton & Harper, 2007). Paap and Greenberg (2013) found equivalent performance on the Flanker and Simon tasks among bilingual and monolingual adults. Another study used two tasks (Dichotic listening task, Simon task) tapping visual and auditory inhibition and the results showed no significant difference between their monolingual and bilingual adults (Desjardins & Fernandez, 2018).

There are some debates in the literature regarding the nature of IC that bilinguals use to inhibit the non-target language and how bilingualism affects tasks tapping other forms of inhibition (e.g., Bialystok, 2011; Carlson & Meltzoff, 2008; Paap & Greenberg, 2013). Some researchers suggested a distinction between types of IC including response inhibition and attentional inhibition (interference control). For example, Bunge et al. (2002) proposed bilinguals have an advantage over monolinguals in an interference effect, namely, inhibiting task-irrelevant information rather than response inhibition, whereby the prepotent motor response is inhibited. In summary, a bilingual advantage may emerge in some aspects of IC, as bilinguals have to inhibit the non-target language while producing speech. However, research results have not always supported a bilingual advantage in IC.

Working Memory. Inhibition is highly related to working memory (WM) (Klauer, Schmitz, Teige-Mocigemba, & Voss, 2010; Unsworth & Spillers, 2010). WM refers to the limited capacity to store and process information for a short time (Baddeley & Hitch, 1994; Just & Carpenter, 1992; Miyake et al., 2000). WM requires keeping and processing information simultaneously without depending on environmental cues (Alloway, Gathercole, & Pickering, 2006; Baddeley & Hitch, 1994; Best & Miller, 2010; Huizinga et al., 2006). For example, using instructions to perform a task, doing any math in our heads, or holding a new number in mind while looking for a pen to write it down would constitute examples of WM. Various experiences can affect the capacity and structure of WM in adults. For instance, musical training can affect WM ability (Gagnon & Nicoladis, 2020) and IC (Travis, Harung, & Lagrosen, 2011).

Another possible experience that might impact WM is bilingualism (Bialystok, 2017; Bialystok, Craik, & Luk, 2012). Learning and using more than one language can affect WM capacity because WM underlies the inhibition of attention shifting required to reduce the interference of two languages (Costa et al., 2006; Namazi & Thordardottir, 2010). Inhibiting one language while using another one can enhance WM capacity and efficiency. That is, inhibition and WM capacity are highly correlated and the efficiency of WM is mediated by IC processes (Bialystok et al., 2004; Bialystok, Craik, & Luk, 2008; Fernandes, Craik, Bialystok & Kreuger, 2007; Just & Carpenter, 1992; Michael & Gollan, 2005). Moreover, it has been suggested that WM abilities could be increased among bilingual speakers, as they have to process and pay attention to information regarding the context and the discourse to choose the appropriate language. Furthermore, monitoring and updating WM constantly during discourse can increase WM abilities (Delcenserie & Genesee, 2016).

One of the well-known models of WM has been proposed by Baddeley and Hitch (1974). According to this multi-component model, the central executive component is responsible for processing attention and transferring information to the two slave systems, known as the phonological loop and visuospatial sketchpad that are specified for storing and rehearsing verbal and visuospatial stimulus, respectively. Some of the well-known WM tasks in young adults are the n-back task (Kirchner, 1958), Digit Span tasks forward and backwards (Wechsler, 2008), Corsi blocks task (Lezak, 1983), the Word Span Test (Gathercole, 1999), the Listening Span Task (Pickering & Gathercole, 2001), Operation Span (Turner & Engle, 1989), Counting Span (Case, Kurland, & Goldberg, 1982), Reading Span (Daneman & Carpenter, 1980), and the Symmetry Span task (Unsworth, Redick, Heitz, Broadway, & Engle, 2009). All of these tasks require keeping some information in mind then recalling them as accurately as possible a short time later.

As for WM structure, based on the dual coding theory, bilinguals often encode verbal information in both verbal and visuospatial formats (Clark & Paivio, 1991). The key point of this theory is that two separate but interconnected systems constitute the WM system, one is responsible for dealing with nonverbal stimuli and the other for dealing with verbal information. The bilingual dual coding theory suggested bilinguals develop separate but interconnected "logogen systems" for two languages (to process verbal information) and that both of them are also associated with a nonverbal "imagen system". According to this theory, bilinguals can have greater cross-modal integration in WM than monolinguals. This theory has been supported by many studies (e.g., Clark & Paivio,1991; Paivio & Lambert, 1981).

However, studies have found mixed results about the hypothesis that bilinguals have greater WM capacity and cross-modal integration than monolinguals. With regard to WM capacity, some studies suggested that bilinguals have enhanced ability in one WM store or both verbal and visuospatial WM (Bialystok et al., 2005; Bialystok et al., 2008; Blom et al., 2014; Hernandez et al., 2012; Kudo & Lee Swanson, 2014; Luo et al., 2013; Morales et al., 2013; Mota & Kramer, 2015). Grundy and Timmer (2017) conducted a meta-analysis on the impact of bilingualism on WM capacity. They considered 88 effect sizes, 27 independent studies, and 2,901 participants. Their results indicated greater WM capacity for bilinguals than monolinguals, with a significant small to medium effect size (.20).

Other studies found that bilinguals performed on par with monolinguals in WM tasks (Anjomshoae et al., 2021; Namazi & Thordardottir, 2010; Ratiu & Azuma, 2015). For instance, the results of a recent meta-analysis study by Lehtonen et al. (2018) demonstrated a very small bilingual advantage for WM, which disappeared after correcting for publication bias (.07). They synthesised the results of 152 studies using 891 effect sizes, comparing the performance of monolinguals and bilinguals on six different tasks.

In conclusion, as with inhibition, previous studies have not yielded consistent results regarding whether knowing another language can lead to an advantage in WM performance among bilinguals.

Switching. The third component of Miayke and colleagues' EF model is switching which is also known as shifting or cognitive flexibility. Switching refers to switching between different tasks, concepts and mental sets concurrently (Monsell, 1996) such as returning one's attention to studying after speaking with a friend. Switching ability plays a critical role in performing complex tasks in day-to-day life, adapting to changes in the environment, and it is also related to creativity, problem-solving, multi-tasking, and decision-making (Diamond, 2013; Rolls, 2000; Ionescu, 2012; Dajani & Uddin, 2015).

From a behavioral point of view, bilinguals have the ability to switch mental sets as they shift between languages easily and quickly without making major mistakes (Muysken, 2000; Myers-Scotton, 2002). Bilinguals use switching to manage which language to use and to code-switch (Hernandez et al., 2001; Rodriguez-Fornells et al., 2005). Abutalebi and Green (2008) provided evidence about an overlap between some areas of the brain that are responsible for cognitive control and switching between languages. They suggested some parts of the brain including the left dorsolateral prefrontal cortex (DLPFC) and the anterior cingulate cortex (ACC) were active in the bilingual brain while they switched between languages. With experience and switching between two languages on a daily basis, bilinguals may show an advantage in the switching component of EFs (Bialystok, Craik, Klein, & Viswanathan, 2004). In daily life there are many situations where everyone, regardless of language ability, needs to inhibit non-relevant responses and monitor the environment constantly. For instance, monolinguals also need to switch between comprehension and production during conversations, or inhibit salient responses and adjust their speech and manner according to the social situation (i.e., casual vs. formal). That being said, it remains unclear whether switching between languages leads to a switching-task advantage among bilinguals (Antón & Carreiras, 2019).

Some of the well-known switching tasks are the Wisconsin Card Sorting task (Kongs, Thompson, Iverson, & Heaton, 2000), Number-Letter task (Rogers & Monsell, 1995), Hierarchical Figures task (Navon, 1977), Creature Count task (Manly et al., 1999; Milte et al., 2012) and Color-Shape task (Prior & MacWhinney, 2010; Prior & Gollan, 2011).

Many studies have found a bilingual advantage in switching (Bialystok & Martin, 2004; Garbin et al., 2010; Prior & MacWhinney, 2010; Prior & Gollan, 2011; Wiseheart, Viswanathan, & Bialystok, 2016). Bialystok and Martin (2004) provided evidence for switching advantages among bilingual preschoolers. They used a Dimensional Change Card Sort task (Zelazo, Resnick & Pinon, 1995) and the results showed bilinguals successfully performed this task at an earlier age than their monolingual counterparts. Prior & MacWhinney (2010) argued that switching practice leads to an advantage on non-linguistic switching tasks. They compared the performance of three groups: Spanish–English and Mandarin–English bilinguals who used different rates of switching between their languages and English speaking-young adults. The results of their study revealed that bilinguals outperformed monolinguals and those who switched between languages more frequently performed better than those who switched less often between their first and second languages. Additionally, in a recent study, Woumans et al. (2019) found a bilingual advantage for shifting in the Color-Shape task among monolingual and bilingual young adults.

However, some studies have failed to support the bilingual advantage in switching (Kroll & Bialystok, 2013; Bialystok et al., 2012; Shokrkon & Nicoladis, 2021). For example, Paap and Greenberg (2013) found equivalent performance of monolinguals and bilinguals on a switching task. Similarly, Greene (2015) found no bilingual advantage in switching-costs, RT and accuracy rate among monolingual and bilingual adults. Given that fewer studies of task switching are conducted as compared to inhibition and WM, it has been suggested that more studies should be conducted to demonstrate the bilingual advantage in switching.

Why are the results so mixed?

Taken together, the results are mixed with respect to the existence of bilingual advantage in all subdomains of EF. Researchers have proposed a number of explanations for this discrepancy. One possible contributor to varied results is small sample sizes. Paap et al. (2015) argue that most of the studies showing a bilingual advantage used small sample sizes (n<50) which could lead to type 1 error. Other researchers suggested that larger sample sizes (n>138) are needed to demonstrate a bilingual advantage with sufficient levels of statistical power (Bakker, 2015; Paap et al., 2016), however a number of studies with relatively large sample sizes have been carried out and have also failed to find a bilingual advantage in cognitive control (Paap et al. 2013, Duñabeitia et al., 2014). Therefore, more studies with large sample sizes are needed to test the bilingual advantage hypothesis. In sum, given these mixed results some recent studies have argued that researchers should go beyond the yes/no debate on the existence of bilingual advantage (Bak, 2015; Baum & Titone, 2014). Instead, it has been argued that the focus should be on the moderating factors (Woumans et al., 2015). Thus, one purpose of this thesis is to test three possible moderating variables on the so-called bilingual advantage: socioeconomic status (SES), immigration status, and age of acquisition/language proficiency. I consider each of these in turn.

Socioeconomic Status and Bilingual Advantage. As noted earlier, bilinguals vary considerably amongst themselves on multiple variables. For example, in Canada, many bilinguals are immigrants and Canadian immigration policy favors immigrants with high socioeconomic status (SES; Morton & Harper, 2007). SES has been found to be an important factor that plays a crucial role in cognitive skills including EFs across the lifespan (Morton & Harper, 2007). People with higher SES often have higher EF abilities and perform better on EF tasks than people with lower SES (Dilworth-Bart, 2012; Hackman & Farah, 2009; Rosen, Sheridan, Sambrook, Meltzoff, & McLaughlin, 2018). Some studies have shown that children from low SES families underperformed as compared to children from higher SES on tasks measuring IC, working memory, executive attention, flexibility, and planning (Engel, Santos & Gathercole, 2008; Lipina, Martelli, Vuelta & Colombo, 2005; Lipina, Martelli, Vuelta, Injoque-Ricle & Colombo, 2004; Mezzacappa, 2004; Noble, McCandliss & Farah, 2007). Studies have found that bilingualism and SES have a significant, yet, distinct impact on bilinguals' EF performance (e.g., Calvo & Bialystok, 2014). SES includes not only economic factors such as a person's income and material wealth, but also the non-economics such as social prestige, education, and years of parental education (Adler & Rehkopf, 2008; Bradley & Corwyn, 2002). SES can affect development of EF through learning resources, parenting style and warmth, toxin exposure, and nutrition (Conger & Donnellan, 2007; Hoff, 2003). The results of a recent study by Last et al. (2018) have shown that the association between childhood SES and EF persists into adulthood. It is unclear whether higher educational levels among participants enhance the bilingual advantage in cognitive control (Ansaldo et al., 2015). While SES impacts the development of EF, perhaps more than bilingualism (Mezzacappa, 2004), this factor has not been measured in many studies with bilinguals. SES has been found to be an important factor which could better explain group difference in EF tasks than acquiring another language (Morton & Harper, 2007; Paap & Greenberg, 2013; Antón et al., 2014; Duñabeitia et al., 2014; Paap et al., 2015; Von Bastian et al., 2016; Goldsmith & Morton, 2018). Morton and Harper (2007) have found that children from families with higher levels of SES outperformed their peers from lower levels of SES in tasks tapping EF. However, they found equivalent performance among monolingual and bilingual children from the same levels of SES.

Not all previous studies on a bilingual advantage have measured or controlled for possible SES differences between bilinguals and monolinguals. In Canada, it is possible that an apparent bilingual advantage could actually be related to SES. Many bilinguals in Canada are immigrants. Canada is one of top ten counties with largest number of immigrants (about 8 million; Statistics Canada, 2016) and an officially bilingual country, Canada's immigration policy prioritizes people with high academic achievement and SES for immigration (Morton & Harper, 2007). As will be discussed next, immigration status itself might be related to EF. It is important to disentangle the effects of SES and immigration on a possible bilingual advantage.

Immigration Status and Bilingual Advantage. As noted earlier, many bilinguals, at least in Canada, are immigrants (e.g., Bialystok et al., 2007; Paap & Greenberg, 2013). Above and beyond the association between SES and immigration status, immigration itself may impact EF (Fuller-Thomson, 2015). Immigration can lead to changes in the culture, ethics, education, and lifestyle of individuals which can in turn lead to an advantage in EFs. For example, in a study by Carlson and Choi (2009), a bilingual advantage existed when they compared a group of Korean-English bilinguals with their American monolingual counterparts living in the United States using six measures including Attention Network Task (ANT). However, this advantage disappeared when they compared the bilingual group with Korean monolinguals. This pattern of results suggests that an apparent difference between bilinguals and monolinguals might be the result of culture rather than bilingualism per se, and, further, that cultural differences could play a crucial role in EF development. Additionally, immigrants have to adjust to new circumstances, and consequently, their shifting ability may be increased. Indeed, some studies have found that immigrants relative to non-immigrants have greater cognitive control (Hill et al., 2012). Furthermore, immigration status may be related to EF through the "healthy immigrant effect" (Fuller-Thomson, 2015). In other words, healthy individuals are more likely to immigrate to other countries and learn new languages than those who are unhealthy. White Hispanic immigrants in the USA, for example, have EF impairments that are 26% lower than white non-immigrant people in the USA (Thomson et al., 2013).

Many studies with monolingual and bilingual adults have poorly controlled for immigration status (e.g., Bialystok et al., 2008; Fernandez et al., 2013; Fernandez et al., 2014; Garbin et al., 2010; Kousaie & Phillips, 2012; Luk, Green, Abutalebi, & Grady, 2011; Mor, Yitzhaki-Amsalem, & Prior, 2014; Tao et al., 2011). Therefore, immigration status is an important but neglected factor in the case of the bilingual advantage debate.

Language Proficiency and Bilingual Advantage. Some researchers have suggested that longer experience of managing two languages could lead to an EF advantage in bilinguals (Yang et al., 2016). In other words, an earlier age of acquisition (AoA) and/or greater language proficiency would lead to greater EF among bilinguals. Luk et al. (2011) found some results in favour of this explanation. They found a smaller Flanker effect among bilinguals who had acquired both languages early in life compared to both late bilinguals and monolinguals who had equivalent performance. Similarly, another study, conducted by Tao and colleagues (2011), used the lateralized attention network test (LANT) to compare EFs among early (who immigrated to another country at or before the age of six) and late (who immigrated to another country at or after the age of 12) bilinguals. The results indicated both early and late bilinguals showed an advantage in conflict resolution relative to monolinguals and the greatest advantage including smallest RT cost was found for the early bilinguals. However, some other studies have failed to replicate these findings (Linck et al., 2008; Paap et al., 2015; Pelham & Abrams, 2014).

AoA is closely intertwined with proficiency in a language (Birdsong, 2014; Mishara, 2014). The results of a study by Yow and Li (2015) showed that younger AoA is related to more balanced bilingualism, which may, in turn, be a predictor for the performance in some EF tasks, particularly the Stroop test. In addition, AoA can impact the structure of the bilinguals' brain and language lateralization (Hull & Vaid, 2007). Perani et al. (2003), for instance, proposed there is an association between AoA and cortical activation compared to lexical access. Above and beyond the effects of AoA on language learning and proficiency, some studies found AoA can lead to superior domain-general cognitive control and therefore is related to bilingual advantage hypothesis (Luk, De Sa, & Bialystok, 2011; Tao et al., 2011). Abutalebi and Green (2007) argued that brain activation in bilinguals might be different based on participant L2 proficiency. That is, speech production in the second language is more controlled than automatic when the L2 proficiency is low, requiring more inhibitory skill (especially prefrontal cortex). They also argued high proficiency in both L1 and L2 is an important factor in controlling the cross-language interference (Green & Abutalebi, 2013). Similarly, Branzi et al. (2014) found that highly proficient bilinguals may control languages differently from less proficient bilinguals and thus switching between languages would not be dependent on inhibitory mechanisms. Likewise, another study consisting of Hindi-English bilingual adults with different levels of L2 (English) language showed bilinguals with superior L2 proficiency demonstrated a faster overall speed in completing the target detection task (Mishra et al., 2012). Similarly, Iluz-Cohen and Armon-Lotem (2013) demonstrated using a Stroop task there was a correlation between RT in incongruent trials and both proficiency in L1 and L2, showing that language proficiency modulates performance in this task. Additionally, the results of a recent study by Xei (2018) supported the argument that language proficiency seems also to be associated with performance on the Flanker task. Xei (2018) investigated the performance of three groups of Chinese-English bilingual adults with different levels of L2 proficiency on the Flanker task. The results showed that bilinguals with highest levels of L2 proficiency were faster in all conditions of this task rather than the bilingual group with lowest L2 proficiency. However, unlike Iluz-Cohen and Armon-Lotem (2013), the results of their study failed to support the association between language proficiency and shifting ability. Similarly, Gathercole et al. (2010) provided evidence that children who were exposed to both English and Welsh at home outperformed another group of bilingual children from Welsh-only homes, and English monolinguals on a Stroop task in English. Their results were in support of bilingual advantage but they discussed other factors at play beyond bilingualism, including frequent or balanced use of both languages on a daily basis and linguistic knowledge. In a similar vein, studies with bilingual adults have shown that a higher frequency of switching between languages is associated with better performance on EF tasks (Soveri, Rodriguez-Fornells, & Laine, 2011; Woumans, Ceuleers, & Duyck, 2013).

Likewise, some studies argued that balance of language usage impacts inhibitory control and shifting ability (Woumans et al., 2015; Yow & Li, 2015; Verreyt et al., 2016). Unlike the above-mentioned studies, Paap et al. (2014) found no evidence that L2 proficiency predicts young adults' performance on EF tasks (see also Kousaie & Phillips, 2012; Paap et al., 2015).

In summary, bilinguals' language proficiency and AoA are factors that might impact the association between bilingualism and EF advantages.

Bilingual advantage and EF measurements. Another explanation for varying results across studies is that the bilingual advantage is significantly dependent on the specific task tapping executive function. Ware et al. (2020) synthesised the results of 170 studies to examine the hypothesis that the bilingual advantage depends on task. The results were in favour of a significant relationship between task and bilingual advantage. They found an advantage in all studied variables of interest such as congruent trials, incongruent trials and interference effect for ANT. However, no advantage was found for other tasks like the Flanker task, in spite of the fact that these two tasks are similar and were assumed to measure the same EF components. The authors suggested some explanations for these results (Ware et al., 2020). First, bilingualism can impact a specific neural network that is not necessarily activated in all EF tasks. In addition, task complexity and the initial processing effort required for some EF tasks impacts on the association between bilingualism and superior EF advantage. Bialystok et al. (2004, 2006) posited the advantage is present only if bilinguals use controlled, but not automatic, effort to complete the tasks, such as in the incongruent conditions of the Stroop task (Bialystok, Craik & Luk, 2008) and the Simon task (Bialystok, Craik, Klein & Viswanathan, 2004). Task difficulty is another factor playing a role in the bilingual advantage line of research. Teubner-Rhodes (2020) proposed that bilinguals present an advantage only in challenging tasks. Ware et al. (2020) also suggested different studies used different versions of a task with different reliability and validity, which in turn can affect the results of their meta-analysis study. That is, as the reliability of a test decreases, the effect size decreases.

In the present study, we include both linguistic and non-linguistic tasks tapping EF. A linguistic task needs judgments of phonetics and semantics for performing the task such as the Digit Span task, with language proficiency believed to be an important factor affecting the bilingual advantage. Some studies reported that insufficient language proficiency is the reason for the absence of a bilingual advantage in linguistic relative to non-linguistic tasks (Bialystok, 2009; Bialystok & Feng, 2009; Namazi & Thordardottir, 2010). In other words, lower language proficiency among bilinguals relative to monolinguals might lead to null results or even bilingual disadvantage on linguistic tasks but an advantage on non-linguistic tasks. It has been suggested that bilinguals with lower proficiency in a second language may underperform on tasks that require language knowledge (Bialystok, 2009; Masoura & Gathercole, 1999; Thorn & Gathercole, 1999). Many bilinguals might have lower L2 proficiency relative to their monolingual peers explaining the bilingual disadvantage in linguistic tasks which are related to the language ability. Moreover, according to some evidence indicating that the bilingualism effects depend on linguistic domain (Costa et al., 2004; 2006), there may be a bilingual advantage on RTs and processing costs on non-linguistic tasks only. Hernández et al (2010) proposed that verbal stimuli require language control processes rather than executive control processes.

The Present Study

The primary purpose of the present study is to test if there is bilingual advantage in EF tasks, while taking into account some important potential modulating factors. Given that I have a large sample size**,** I hypothesize that there should be a difference between groups on measures of all three EF components: inhibition, WM, and shifting. Some previous studies have reported a bilingual advantage on non-linguistic tasks tapping EF, relative to linguistic tasks. In this study, the bilingual advantage may therefore emerge on non-linguistic EF tasks.

The secondary purpose of this study is to test for three possible moderators of a bilingual advantage: immigration status, SES, and AoA/proficiency in the participants' L2 English. In the case of immigration status and SES, I predicted that both of these factors moderate the association between bilingualism and EFs in a positive way. That is, high SES level and being an immigrant to Canada may strengthen the bilingual advantage. I hypothesized, in line with previous studies (DeLuca et al., 2019; Donnelly et al., 2019; Grundy & Timmer, 2017; Pelham & Abrams, 2014) AoA and L2 (English) proficiency will moderate the bilingual advantage indicating high level of L2 proficiency and learning second language at earlier age can strengthen the effect of bilingualism on EF.

Methods

Analyses in G-Power revealed that the total sample size of 308 participants gave us power (1– = .80) enough to find at least a medium effect size (d = .40).

Participants

Participants of this study were 308 students at the University of Alberta. All participants (214 females, 99 males, M_{age}= 19.52, SD= 2.57) were recruited from the Psychology Research

Participation Pool. They were all undergraduate students and received one course credit for their participation and completion of this study. This study was conducted in the English majority language part of Canada. The participants were required to be either English-speaking monolinguals or bilinguals who speak various native languages and English as their second language in order to participate in this study and they classified themselves into monolingual or bilingual groups. The monolingual group consisted of 160 participants (105 females and 55 males, M_{age}= 19.62, SD= 2.79) and 148 (105 females and 43 males, M_{age}= 19.79, SD= 2.31) participants were included in the bilingual group. For this study, we defined immigrants as those who were born outside of Canada and left the country of their birth by the age of six. They also started to acquire English after 6 years of age. Non-immigrants are those who were born or immigrated to Canada before the age of six. The demographic information is summarized in Table 1.

Table 1

Sample demographic characteristics

Demographics	options	%	
		M	B
Immigration status	born	87.0	21.1
	Child	8.6	30.6
	Adolescence	1.8	16.3
	Student	2.5	32.0

EN proficiency	Beginner	0	0
	Advance Beginner	0	0
	Intermediate	.6	9.3
	Advance intermediate	1.2	14.2
	Near Fluency	1.2	16.0
	Fluent	53.4	38.3
	typical native speaker	43.6	22.2
SES(mother)			
	Primary Education	1.8	4.9
	Secondary Education	16.6	9.9
	Prior to university education	12.3	24.7
	Undergraduate education	41.7	38.9
	Post-graduate education	27.6	21.6
SES (father)	primary Education	4.3	6.8
	Secondary Education	14.7	6.8
	Prior to university education	11.7	21.6
	Undergraduate education	33.7	37.7
	Post-graduate education	35.6	27.2

Procedure

Apparatus and device setup. Six computerized tasks were chosen for the present study.

All of the tasks have good validity, reliability and it has been well documented, using these tasks showed a bilingual advantage. In the consent form, participants were asked for doing the experiment through Google Chrome browser and make sure their computer speakers work well. They also were informed; they will be needing the keyboard. Task's instructions were printed in white and Arial 18 on a black screen. For each task the stimuli were presented on the center of the screen in 36-point. More detail about the stimuli is provided in each task description. Psytoolkit and Qualtrics websites were used to manage experiments. Both Psytoolkit and Qualtrics websites are freely online programs in which researchers can build surveys and create modified versions of cognitive tests. There are some studies about Psytoolkit's timing reliability. A recent study showed that PsyToolkit is valid and reliable for administering both general and psycholinguistic experiments using response choice and response time (Kim et al., 2019). They found Psytoolkit's timing is on par with one of the most lab-based software packages E-Prime. Psytoolkit uses standard JavaScript technology; which is the same in all browser-based RT measurements. Qualtrics' website was used to conduct digit span tasks to measure verbal working memory. That being said, all steps of the data gathering were done remotely. All of the participants used their own computers to perform the tasks. They completed all tasks in a single experimental session taking approximately 45 minutes. Participants completed a demographic questionnaire and then they performed Flanker, Color-Shape, Stroop, Letter-Number, forward and backward Corsi-block, and forward and backward Digit Span tasks, respectively. The tasks were all presented in the same order to equate it across participants. After the completion of all tasks, participants received one course credit as compensation.

Measures

We measured SES by the highest level of parent education, a measure adopted from a study by Gathercole et al. (2016). Following this study, parents' highest educational levels were classified into 5 categories: 1 = Primary Education, 2 = Secondary Education, 3 = prior to university education, 4 = undergraduate education, and 5 = post-graduate education.

Bilinguals rated their second language (English) proficiency on a Likert scale from 0 (beginner) to 7 (typical native speaker), a measure adopted from Paap and Greenberg (2013). Self-ratings of language proficiency have been used widely in bilingualism studies and different studies have shown that self-reported studies are highly associated with standardized measures of language proficiency (e.g., Marian et al., 2007; Sörman et al., 2019).

Tasks that have been used in this study are presented in the table below. There is some evidence that language ability is related to the linguistic tasks including Stroop (Hilchey & Klein, 2011), Letter-Number (Yow & Li, 2015) and Digit Span (Service et al., 2002).

Table 2

Cognitive tasks tapping Inhibition and Shifting

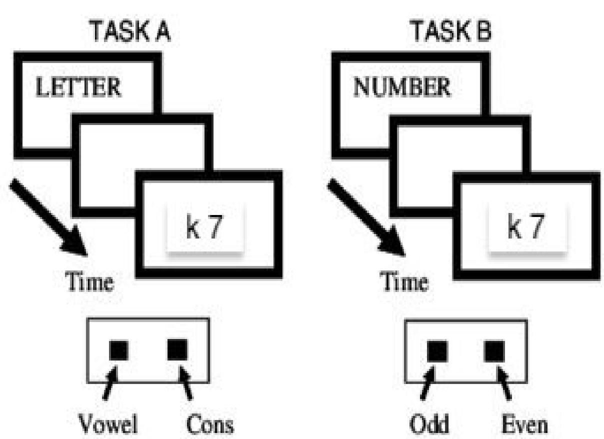
EF construct	Linguistic tasks	Non-linguistic tasks
Inhibition	Stroop colour-naming task	Flanker task
Shifting	Letter-Number switching task	Colour-shape switching
Working Memory	Digit Span task	Corsi Block task

For the linguistic inhibition task, we used a modified version of the classic Stroop color-naming task (1935) to measure inhibition components. This computerized task has two levels of trials, congruent and incongruent, with four colors red, yellow, green, and blue. In the congruent trials, a color word is written in the same color, e.g., the word “RED” printed in red but in the incongruent condition, a color word is written in another color, e.g., the word “RED” printed in yellow. The words were presented in a 36-point Chicago font and the letters were lower case. There were 8 practice trials and the participants received feedback on their performance. Following that there were 48 trials (with no feedback) that starts with a centered white cross symbol on a black background. Four keys on the keyboard were labeled and assigned for each color and participants were asked to perform the task based on the font’s color (e.g., r for “RED”, y for “YELLOW”, g for “GREEN” and b for “BLUE”). Each trial started with a centered white fixation cross displayed on a black background for 1000 ms, and the stimulus stayed on the screen until they responded or for 5000 ms. We consider global RT (mean RT for both congruent and incongruent trials) as global RT is a very common variable when bilingual advantages are examined (Paap et al., 2014). Another dependent variable is the difference between the RTs in congruent and incongruent trials is the interference (Stroop) effect which shows the cost of inhibiting reading the word. That is, greater Stroop effect indicates weaker interference suppression and inhibition ability.

The linguistic task for measuring shifting ability was the Letter-Number task (Rogers and Monsell, 1995). In this task participants saw a mixture of one digit (even or odd) and one letter (vowel vs. consonant). The targets of this task included five consonants (f, k, s, n, p), five vowels (a, e, i, o, u), five odd (1, 3, 5, 7, 9) and five even digits (2, 4, 6, 8, 0), which were printed in 36-point Chicago font. Each letter was randomly combined by a digit. Trials started first by a centered fixation cross shown on screen for 1000 ms, then the task cue (the word LETTER or NUMBER) was shown for 200 ms. After that a combination of letter-number was shown on the screen for a maximum of 5000 ms. The test started with two single blocks consisting of 80 trials. The word NUMBER or LETTER displayed on the screen as a task cue. In the number task, participants were asked to respond by pressing O on the keyboard when the digit is odd and P is for the even digits. As for the letter task, O was for consonant and P was for vowel letter. In the mixed block of 40 trials that half of them were switch trials, where the current trial was different from the previous one (e.g., NUMBER-LETTER) and half of them were no switching trials, in that the current trial was the same as the previous trial (e.g., NUMBER-NUMBER). There were 4 practice trials before each single block and 8 practice trials before the mixed block. The variables of interest in this task were global RT and switching cost which was the difference in RT between switch and non-switch trials in the mixed-task block.

Figure 1

The Letter-Number Task



The Digit Span task was used to measure verbal memory (i.e., linguistic working memory). We used the Qualtrics website and a native speaker researcher read a list of digits and then participants needed to recall the digits and type the sequence out. One practice trial was included in the test to make sure that participants were ready to start the test and the sound and their speaker worked well. The first phase started with two digits and the list of digits increased in length with each phase and reached nine digits by the end of the test. For the backward version the first phase included two digits and reached six digits. The same sequence of digits was represented to all participants. There was no feedback for this task and they had to complete both forward and backward versions of the test from two digits to nine or six digits. Participants gained one point for each trial if they recalled the sequence of digits completely correctly, they scored 0 if they recalled at least one digit of the list incorrectly. The highest possible score for forward digit span was 8 and for backward version was 5. The variable of interest was accuracy in this task.

To measure non-linguistic inhibition ability, the computerized version of the Flanker task (Eriksen and Eriksen, 1974) has been used. In the Flanker test a row of five horizontally arranged stimuli (in Chicago form) displayed on the center of the screen. The test used in the present study has only two conditions: congruent and incongruent. This task involves 32 trials of each condition and the number of correct responses and reaction time were recorded. Participants were asked to press the assigned key on the left (A) or right (L) of the keyboard based on the target stimuli which is flanked by other stimuli. Each trial was displayed by a fixation cross of 300 ms in the middle of the screen. The Flanker effect which refers to the processing cost to inhibit the non-target response was measured by the difference between the RT on the congruent and incongruent condition. A lower Flanker effect score indicates a lower cost in responding to the incongruent trials as opposed to congruent trials, showing better inhibition ability. Trial types are presented in the Figure 2, below.

Figure 2

Flanker task

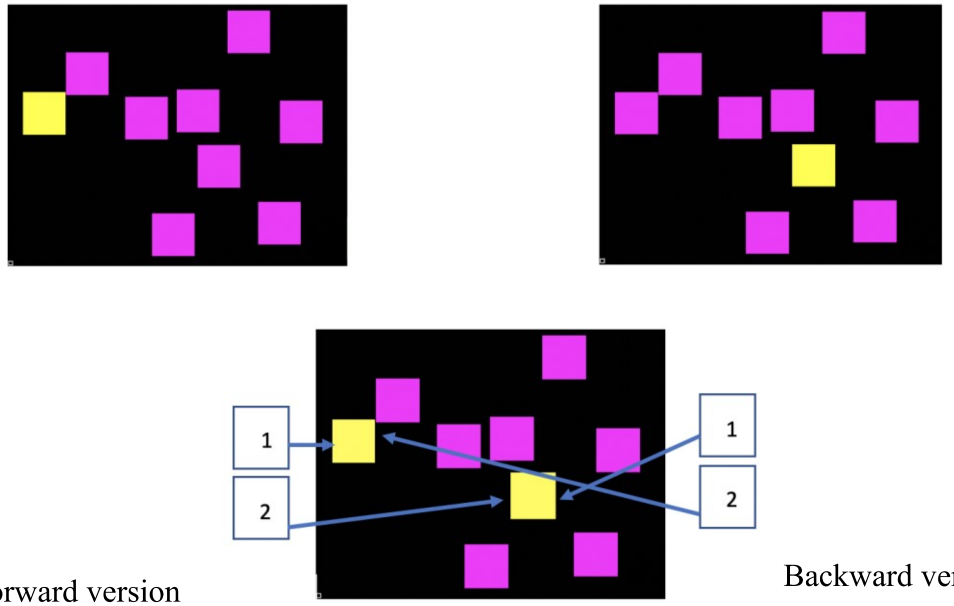
Congruent trials	Incongruent trials
XXXXX	XXBXX

To assess non-linguistic shifting ability, the modified version of the Color-Shape Switching task was used to measure switching cost (Prior & MacWhinney, 2010). This task consists of three dimensions: pure blocks of color and shape, as well as mixed blocks. In each trial a target appeared on the screen that was either circles or triangles, or blue or yellow. For the color trials, participants were asked to respond with two fingers (index and middle) of one hand by pressing the assigned bottoms on the keyboard. They were asked to press N if the target was blue and B if the target was yellow. Likewise, in the shape blocks, they were asked to press the designed keys with the index and middle finger of the other hand and decide if the target was triangle or circle. For the single blocks, all trials presented either shape or color but for the mixed block, trials could change and presented both types of the color or shape. Each trial began with a fixation cross for 350 ms. Following that, the screen turned blank for 150 ms and then the block cue showed on the screen for 250 ms next the target appeared and remained on the screen until the participants responded or for the maximum time of 5000 ms. Participants started with a single block of 8 practice and 16 experimental trials followed by 38 trials in the mixed block. The screen turned blank between each block of the test for 250 ms. Each trial in a mixed block was either a repeat (same dimension as the previous trial) or a switch (different from the previous trial). That is 50% of trials were switch (shape-color or color-shape trials) and 50% non-switch trials (shape-shape or color-color). The variables of interest for this task were global RT and switching cost which is the difference between mean RT on switch trials and mean RT on repeat trials.

The Corsi block task was used to assess visual working memory (i.e., non-linguistic working memory). A string of the blocks was highlighted on the screen and participants were asked to recall the sequence of the blocks and press the sequence in the same or reverse order. Each phase consisted of 2 different trials for the same sequence length. In order to move onto the next phase participants needed to do both trials totally correct. The highest possible score was 12. For the backward Corsi block task in which participants needed to recall the sequence in the reverse order, the highest possible score was 9. A sample of forward and backward version can be found in Figure 3.

Figure 3

Corsi block task



Forward version

Backward version

Analytic Strategy

Univariate distributions for all variables were examined for outliers. Outliers were removed to 2 standard deviations from the mean. Moreover, the RTs below 200 ms were excluded because within this time it is not possible to respond to the tests (Gärtner & Strobel, 2021; Lamm et al., 2006; Yang et al., 2018). In all tasks there was a little missing item in which participants did not complete the task which was under 8%. For the Flanker task it was 6.8%, Stroop task 3.6%, Color-shape and Letter-Number tasks 4.3%, forward and backward DS 1.8% and for forward and backward CBT 2.1%.-A multivariate analysis of variance (MANOVA) was used to compare between-group performance. The MANOVA controls for inflating the Type I error rate due to multiple comparisons. Multiple t-tests were used as a follow-up test to compare between-group performance. Multiple regression analyses were used to test any possible impact of the sociodemographic factors in the indices obtained in each of the tasks separately. Lastly, moderation analyses were employed to test possible moderators on the relationship between bilingualism and performance on EF tasks.

Results

Background Tasks Analysis

A two-way ANOVA for task condition (congruent vs. incongruent) as a within-participant factor and language group as a between-participant factor (monolingual vs. bilingual) was performed on the RTs in tasks tapping into inhibition and shifting. The main effect of trial type was significant for RTs in Flanker $F\ (1, 313) = 45.01$, $p <.001$, partial $\eta^2 = .12$ and Stroop task $F\ (1, 302) = 794.50$, $p<.001$, partial $\eta^2 = .72$. The main effect of language group was not significant in both analysis ($F(1,313) = 3.14$, $p = .07$; $F(1,302) = .68$, $p = .41$; for Flanker and Stroop tasks, respectively). In addition, the interaction between trial type and language group was not significant (all *p*s>.05). Regarding the shifting ability, the main effect of trial type was significant for Letter-Number $F\ (1, 314) = 816.68$, $p <.001$, partial $\eta^2 = .72$ and Color-Shape task $F\ (1, 305) = 630.57$, $p <.001$, partial $\eta^2 = .67$, showing trials in the single-task blocks were performed faster than nonswitch trials. However, the main effect of language group and interactions between trial type and language group were non-significant (all *ps*>.05).

Descriptive Statistics

Descriptive statistics for the measures of EFs in both groups are summarized in Table 3. The bar chart representing mean RTs in different groups is in the Appendix 1. Participants' demographic information are presented in Table 3. Correlations among EF measures are presented in Table 4 (see the scatterplots in Appendix 2). Among both monolingual and bilingual groups, RTs in Flanker and Stroop tasks were significantly and highly correlated. Likewise, for Color-shape and Letter-Number tasks, RTs were highly correlated. For the WM tasks, the accuracy for both forward and backward DS were significantly correlated but surprisingly there was a correlation between forward and backward versions of the CBT task among bilinguals, but not monolinguals. Previous studies have often shown that both versions of this task are correlated (Higo et al., 2014; Siquara et al., 2018; Vandierendonck et al., 2004).

Table 3

Descriptive statistics for the measures of EFs for Monolinguals and Bilinguals

Construct	*M*		*SD*		*Range*		*N*	
	M	*B*	*M*	*B*	*M*	*B*	*M*	*B*
F. RT	*735.72*	*774.17*	*133.55*	*140.47*	*458.73-1195.22*	*535.50-1192.74*	*157*	*137*
F. Effect	*29.08*	*21.64*	*58.66*	*65.51*	*-112.95-220.58*	*-169.60-234.75*	*151*	*143*
F.Accuracy	*.87*	*.87*	*.103*	*.103*		*.47- .53*	*152*	*147*
S. RT	*896.55*	*967.89*	*160.33*	*159.58*	*448.39-1455.02*	*566.85-1436.20*	*160*	*146*
S. Effect	*156.86*	*184.95*	*95.96*	*101.83*	*-142.16-405.62*	*-49.79-525.88*	*160*	*160*
S.accuracy	*.95*	*.94*	*.06*	*.07*	*.58-1.0*	*.36- 1.0*	*162*	*162*

FDS	*5.05*	*5.28*	*1.37*	*1.49*	*1- 8*	*2- 8*	*158*	*145*
BDS	*3.86*	*3.95*	*1.10*	*1.13*	*1- 5*	*1- 5*	*158*	*145*
FCB	*4.61*	*4.47*	*1.63*	*1.99*	*1- 7*	*1-8*	*158*	*158*
BCB	*4.35*	*4.18*	*1.32*	*1.46*	*1-7*	*1-8*	*158*	*158*
C-S. RT	*638.42*	*679.49*	*1141.18*	*135.89*	*385.26-1160.36*	*435.40-1054.24*	*158*	*157*
C-S. effect	*183.08*	*183.57*	*118.03*	*122.67*	*-147.33-621.20*	*-113.56-606.12*	*153*	*158*
C-S. accuracy	*.67*	*.68*	*.03*	*.04*	*.57- .78*	*.57- .78*	*160*	*155*
L-N RT	*862.51*	*913.78*	*144.14*	*126.61*	*645.34-1770.46*	*626.07-1211.54*	*158*	*152*
L-N effect	*360.02*	*364.07*	*252.82*	*206.47*	*-288.77-1255.00*	*-136.90-888.55*	*158*	*149*
L-N accuracy	*.93*	*.93*	*.03*	*.04*	*.80- 1*	*.78- .99*	*157*	*157*

Note: M= Monolinguals, B= Bilinguals. F.RT= Global Flanker reaction time, F.Effect= Flanker effect, F.accuracy= Flanker accuracy rate, S.RT= Global Stroop reaction time, S.Effect= Stroop effect, S.accuracy= Stroop accuracy rate, FDS= Forward Digit Span, BDS= Backward Digit Span, FCB= Forward Corsi Block, BCB= Backward Corsi Block, C-S. RT= Color-Shape global reaction time, C-S effect= Color-Shape switching cost, C-S accuracy= Color-Shape accuracy rate, L-N RT= Letter-Number Global reaction time, L-N effect= Letter-Number switching cost, L-N accuracy= Letter-Number accuracy rate.

Is there a bilingual advantage?

The MANOVA revealed a statistically significant *F* value for RTs, Wilk's Lambda = .911, $F (12, 258) = 2.09$, $p < .05$, partial $\eta^2 = .08$, showing that there was a significant difference between group. Regarding the processing effects, MANOVA analysis showed non-significant difference between groups, $F (4, 260) = 1.67$, $p > .05$, Wilk's Lambda = .97, partial $\eta^2 = .02$. In order to test where the language group difference is, multiple t-tests were conducted as a follow-up procedure.

Inhibition. For each task, total RT, processing effect and accuracy rate were the variables of the interest. To investigate the difference between-groups t-test analyses were conducted on RTs and processing effects, respectively. The results indicated a significant effect of language group $t(304)= -3.89$, $p=.000$, $d= .42$-indicating that monolinguals were faster than bilinguals in the Stroop task. Similarly, the results for the Flanker task showed a significant difference between groups $t(292)= 2.40$, $p=.00$, $d= .23$ for RTs showing that monolinguals were faster than bilinguals. There was a significant difference between groups in terms of Stroop effect $t(304)=2.11$, $p=.03$, $d= .23$. That is monolinguals showed smaller Stroop effect (difference between incongruent and congruent RT) indicating better inhibition ability. The results of the t-test, however, showed no significant difference between monolinguals and bilinguals regarding the Flanker effect $t(304)= -.93$, $p=.35$, $d= -.10$ -I conducted the t-test for accuracy rate. The results showed no difference between groups for Flanker and Stroop task's accuracy $t(298)= -.40$, $p= .68$, $d= -.04$; $t(300)= 1.86$, $p= .06$, $d= -.26$. However, there was a difference regarding accuracy rate in Stroop task *t(300)= -2.28, p= .02, d= -.26.* In sum, no bilingual advantage was found in inhibitory control (see Table 2). In fact, there was a no difference between groups regarding accuracy, although, bilinguals performed the tasks slower than monolinguals. There was a bilingual disadvantage on the Stroop effect.

Working Memory Capacity. There was no significant difference between groups regarding the Verbal Working Memory measuring with FDS (*t (*304*)* = 1.17*, p*= .24*, d*= .13) and BDS *(t* (304)= .79*, p*= .42*, d*= .08*)*. Likewise, monolinguals and bilinguals performed forward Corsi Block task equivalently (*t* (304)= .03*, p*= .97*, d*= .00). In contrast, there was a significant difference between groups regarding backward Corsi Block *(t (*304*)*= -1.79, *p*= .02*, d*= .20*)*. Together, bilinguals did not outperform monolinguals on verbal working memory and forward Corsi Block task. However, a bilingual advantage was found in the backward Corsi Block task (i.e., a non-linguistic WM task).

Shifting ability. The results of the independent t-test indicated a significant difference between groups in both tasks tapping into shifting, t (300)= 2.86, p=.004, d= .32 *and* t(300)= 3.71, p=.000, d=.42 for the Color-Shape and Letter-Number tasks, respectively. Surprisingly, the monolinguals performed both tasks faster than bilinguals. With respect to the switching costs, the results showed no significant difference between groups, t(307)= .73, p=.46, d = .08 and t(299)= .91, p=.35, d=.10 for the Color-Shape and Letter-Number switching costs, respectively. The between group differences for Color-Shape and Letter-Number tasks tapping on shifting was nonsignificant, t(300)= .84, p=.40, d = .09, t(304)= -.98, p=.32, d = -.11, sequentially. That is bilinguals and monolinguals performed similarly on tasks tapping shifting.

Regression analysis

To examine the possible predictors for the performance on EF tests, multiple regression was employed on global RTs and processing costs for each task separately among bilinguals. Two models of predictors were used. The first model included bilingualism-related background factors (age, AoA, English proficiency) and the second model included SES and immigration status. Neither model explained enough of the variability for global RT in the Flanker, Stroop tasks (R2<.2, adjusted R2< .05) and reached significance level (ps> .05). Moreover, none of the models explained enough variance of the data for Flanker effect (R2<.2, adjusted R2< .06) and reached significance level (ps> .05). The beta- values are presented in Table 5. Likewise, for the Color-Shape and Letter-Number measuring shifting ability (both switching cost and global RTs), the results of multiple regression indicated none of the models explained significant enough variance in the data. The results of multiple regression are summarized in Table 6. For the WM tasks, the same regression approach was used. The results showed multiple regression with age, AOA, L2 proficiency, language exposure, SES and immigration status was significant for the forward CBT, $F(10,117) = 2.45$, $p = 0.011$, and the model explained 7% (Adjusted $R2 = 0.07$) of the variance. Similarly, for the backward CBT, the first model with age, AOA, L2 proficiency and language exposure was significant $F(10,128) = 2.04$, $p = 0.03$ and explained 7% (Adjusted $R2 = 0.07$) of the variance. For the DS task both forward and backward versions none of the models explained enough of the variability in the data. These results are presented in Table 7. In sum, none of the variables (namely, age, AoA, L2 proficiency, immigration status and SES) significantly predicted the performance of participants on EF tasks among bilinguals.

Moderation analysis

I tested the moderation effect separately for RTs and processing costs in each task. Because the moderators were categorical variables with multiple levels (Language proficiency, Immigration and SES) I changed them to continuous variables by centering the mean (e.g., Francoeur, 2013; Yaremych et al., 2021). The results showed none of the interactions between bilingualism, EN proficiency, SES and immigration status were significant for the Flanker, Stroop, Color-Shape, Letter-Number tasks and WM tasks (all *p*s >.05).

Table 4

Correlations between EF tasks

	1	2	3	4	5	6	7	8	9	10	11	12

1.FRT	-	-.07	**.42****	.02	**.38****	**.16***	**.36****	.03	-.02	-.01	-.06	-.14
2.Feffect	.03	-	**-.19***	.05	-.07	-.13	-.03	-.02	.08	.01	-.14	-.11
3.SRT	**.48****	.06	-	**.23***	**.50****	**.17***	**.47****	.04	-.12	-.12	-.02	**-.18***
4. Seffect	**.21****	.06	**.40****	-	.09	**.16***	.06	.00	-.06	-.08	**-.20***	.03
5.CS RT	**.38****	.13	**.42****	.13	-	**.43****	**.44****	.11	-.02	-.07	-.08	-.10
6.CS effect	.14	.05	**.25***	.01	**.33****	-	.10	.06	-.11	-.07	-.04	.01
7.L-N RT	**.40****	-.04	**.46****	**.18***	**.37****	**.18***	-	**.30****	-.04	.00	-.14	**-.25***
8.L-Neffect	**.22***	-.03	.13	-.01	.11	-.05	**.27****	-	.04	.08	.06	.00
9.FDS	-.09	-.01	-.21	.01	**-.18***	-.22	-10	.07	-	**.37****	-.03	.13
10.BDS	-.08	-.09	-.09	.01	**-.15***	-.14	-.03	.08	**.44****	-	.05	.08
11.FCB	-.17	.06	.03	.00	.07	-.11	-.03	-.01	. 08	.07	-	-.10
12.BCB	-.14	.02	-.18	-.14	**-.16***	**-.15***	**-28****	-.04	**.15***	**.28****	.06	

Note. FRT:Flanker total RT,F.effect:Flanker effect; SRT: Stroop total RT, Effect, Stroop effect; CS RT: Color-Shape total RT, CS effect: Color-Shape switching cost; Top of the matrix above diagonal indicates correlations for monolinguals, bottom of matrix below diagonal indicates correlations for bilinguals.
** $p < .01$
* $p < .05$

Table 5

Beta- values of the multiple regressions for the Flanker and Stroop tasks performance.

	Flanker global RT	Flanker effect	Stroop global RT	Stroop effect
Age	-.11	.05	.19	.04
AOA	.15	.07	.06	-.11
English proficiency				
Beginner	NA	NA	NA	NA
Advanced beginner	NA	NA	NA	NA
Intermediate	.21	.10	.18	.11
Advanced intermediate	NA	NA	NA	NA
Near fluency	.03	.14	.04	.14
Fluent	.05	.04	-.07	-.18
Super fluent	REF	REF	REF	REF
SES				
Mother				
primary Education	REF	REF	REF	REF
Secondary Education	.12	-.07	.02	-.00
prior to university education	.05	-.06	-.05	.13

Undergraduate education	.08	-.36	-.02	.09
Post-graduate education	NA	NA	NA	NA
Father				
primary Education	REF	REF	REF	REF
Secondary Education	.08	-.00	-.17	.00
prior to university education	NA	NA	NA	NA
Undergraduate education	-.20	-.14	-.11	.12
Post-graduate education	-.22	-.09	-.12	.09
Immigration Status				
Born	REF	REF	REF	REF
Child	.13	-.04	-.05	-.10
Adolescence	.14	.57	.07	-.06
University	.28	-.47	.20	-.35

Note. Flanker RT: for block 1 ($F(8, 121) = 1.73$; $p > .05$); for Block 2 ($Fchange(10, 111) = .55$; $p > .05$). Flanker effect: for block 1 ($F(8, 126) = .88$; $p > .05$; for Block 2 ($Fchange(10, 116) = .46$; $p > .05$). Stroop RT: for block 1 ($F(8, 128) = 1.44$; $p > .05$); for Block 2 ($Fchange(10, 118) = .45$; $p > .05$). Stroop effect: for block 1 ($F(8, 128) = 1.43$; $p > .05$); for Block 2 ($Fchange(10, 118) = .40$; $p > .05$).

Table 6

Beta- values of the multiple regressions for the Color-Shape and Letter-Number tasks performance.

	CS global RT	CS cost	L-N global RT	L-N cost
Age	.15	.02	.15	.00
AOA	-.05	-.14	-.09	.07
English proficiency				
Beginner	NA	NA	NA	NA
Advanced beginner	NA	NA	NA	NA
Intermediate	.20*	-.04	.23*	.06
Advanced intermediate	NA	NA	NA	NA
Near fluency	.20	-.09	.10	.09
Fluent	.06	-.16	.29	.20
Super fluent	REF	REF	REF	REF
SES				
Mother				
primary Education	REF	REF	REF	REF
Secondary Education	.00	.03	.17	-.23*
prior to university education	.07	-.16	-.12	-.08
Undergraduate education	.04	-.05	.03	.06
Post-graduate education	NA	NA	NA	NA
Father				
primary Education	REF	REF	REF	REF
Secondary Education	.01	.01	.13	.05

prior to university education	NA	NA	NA	NA
Undergraduate education	-.03	-.04	.11	.10
Post-graduate education	.07	-.09	.08	-.01
Immigration Status				
Born	REF	REF	REF	REF
Child	-.11	-.09	-.08	.05
Adolescence	-.03	-.01	.06	-.18
University	.09	.21	.17	-.03

Note. *Color-Shape (CS) RT: for block 1 ($F(9, 126) = .96$; $p > .05$); for Block 2 (Fchange$(9, 115) = .46$; $p > .05$). CS switching cost: for block 1 ($F(8, 121) = 1.73$; $p > .05$); for Block 2 (Fchange$(9, 117) = .80$; $p > .05$). Letter-Number (L-N) RT: for block 1 ($F(9, 121) = 1.25$; $p > .05$); for Block 2 (Fchange$(9, 112) = 1.49$; $p > .05$). L-N switching cost: for block 1 ($F(9, 119) = .45$; $p > .05$); for Block 2 (Fchange$(9, 119) = 1.04$; $p > .05$).*

Table 7

B-values of the multiple regressions for the Digit Span and Corsi Block Tapping tasks performance.

	FCBT	BCBT	FDS	BDS
Age	.15	.02	.13	.00
AOA	-.02	-.14	-.09	.07
English proficiency				
Beginner	NA	NA	NA	NA

Advanced beginner	NA	NA	NA	NA
Intermediate	.20*	-.04	.23*	.06
Advanced intermediate	NA	NA	NA	NA
Near fluency	.20	-.09	.10	.09
Fluent	.06	-.16	.29	.22
Super fluent	REF	REF	REF	REF
SES				
Mother				
primary Education	REF	REF	REF	REF
Secondary Education	.00	.03	.17	-.23*
prior to university education	.06	-.16	-.15	-.08
Undergraduate education	.07	-.05	.08	.06
Post-graduate education	NA	NA	NA	NA
Father				
primary Education	REF	REF	REF	REF
Secondary Education	.01	.01	.10	.03
prior to university education	NA	NA	NA	NA
Undergraduate education	-.03	-.04	.17	.10
Post-graduate education	.07	-.09	.08	-.01
Immigration Status				
Born	REF	REF	REF	REF
Child	-.11	-.11	-.08	.05

Adolescence	-.03	-.02	.06	-.16
University	.06	.17	.19	-.01

Discussion

Some previous studies have shown a bilinguals outperform monolinguals on EF tasks measuring inhibition and interference control (Bialystok, 2001; Bialystok, Craik, Klein, & Viswanathan, 2004), shifting (Garbin et al., 2010; Prior & MacWhinney, 2010) and WM (Bialystok, Craik, & Luk, 2008a; Luo et al., 2013). This bilingual advantage has been reported in many studies with participants of different age-ranges including children and adults. The notion of bilingual advantage has been criticized recently and some studies and meta-analyses have suggested that there is no difference between bilinguals and monolinguals (Duñabeitia et al., 2014; Donnelly, 2016; Paap et al., 2015; Paap et al., 2014; Shokrkon & Nicoladis, 2021). While rare, a handful of studies have also reported a bilingual disadvantage in EF tasks (Barac, Blaye, & Poulin-Dubois, 2010; Folke et al, 2016; Lowe et al., 2021), as I will discuss more fully below.

The first purpose of this study was to test for the bilingual advantage using a large sample size and tasks tapping all three EF components (both linguistic and non-linguistic). I hypothesized that bilinguals would perform better than monolinguals, particularly on the non-linguistic tasks. In contradiction to my hypothesis, the present study found a bilingual disadvantage with respect to Global RTs (although the effect sizes were considerably small) on linguistic tasks namely, Stroop and Letter-Number tasks and the Stroop effect as well. These results are in line with the previous studies reporting a bilingual disadvantage in linguistic tasks such as picture naming (Gollan, Montoya, Fennema-Notestine & Morris, 2005; Kaushanskaya &

Marian, 2007), lexical decision (Ransdell & Fischler, 1987) and verbal fluency task (Bialystok et al., 2008), where monolinguals, compared to bilinguals perform linguistic tasks better, even when bilinguals are tested in their dominant or native language. For instance, Bialystok and Feng (2009) reported a bilingual advantage in proactive interference task only when they controlled for vocabulary knowledge, indicating that both EF and vocabulary knowledge affect how bilinguals perform the linguistic tasks. Some studies have reported that Stroop task is closely related to language abilities (e.g., Hilchey & Klein, 2011). Thus, the results of this study showing a bilingual disadvantage on linguistic tasks do not necessarily challenge the claim of a bilingual advantage.

However, the results of the present study also showed a bilingual disadvantage on some non-linguistic tasks, namely the Flanker and Color-Shape tasks, again with very small effect sizes. It is interesting to note that the bilingual advantage is mostly reported for non-linguistic tasks, therefore finding a slower RT for non-linguistic tasks among bilinguals than monolinguals could conflict with the claim that bilingualism leads to enhanced executive functions (e.g., Goldsmith & Morton, 2018; Paap & Greenberg, 2013; Segal et al., 2019).

The second purpose of this study was to test the possible moderating effect of SES, immigration status, and AoA/language proficiency. Given the inconsistent results across the previous studies, I hypothesized these variables would moderate the relationship between bilingualism and executive functions. The results of this study, however, showed that none of the above-mentioned variables modulated the relationship between bilingualism and executive functions. The possible explanations are discussed in more detail below.

Our results are in contrast with the previous studies showing that SES (Mezzacappa, 2004; Farah & Noble, 2005; Noble et al., 2005) can lead to the bilingual advantage on EF tasks.

While it has been well documented that SES and EF are highly correlated among children, it remains unclear if SES effects on EF hold consistent into adulthood when individuals are at the peak of EF development. One reason that could explain the absence of a relationship between SES and EF tasks in this study might be that all of the participants were university students. University education could diminish some of the effects of childhood SES on cognitive development. Other studies found that adult SES (e.g., greater social mobility, higher education) is positively related to EF and can reduce the negative effects of childhood SES on EF (Alley et al., 2007; Liu & Lachman, 2019; Lenehan et al., 2015; Stern, 2012).

Also inconsistent with my hypothesis, the results did not show the possible moderating effect of immigration status on any EF domains. This result is congruent with the results of a systematic review by Lehtonen et al. (2018) in which they found that immigration status did not moderate EF performance. Most of our bilinguals immigrated to Canada to pursue higher education (more than 36%) which can be interpreted that participant of this study have high SES levels as people with higher SES have a greater chance to enter Canada to study (see Table 3). That is, one possible interpretation of not finding a moderating effect of immigration status might be the large effect of SES, and future studies with a wider range of SES, such as including refugees.

Finally, AoA did not moderate the effect sizes on all EF domains among bilingual adults (see similar results in Lehtonen et al., 2018). One explanation for the discrepancy of the results regarding the effect of AoA on executive functioning across various studies is the cut-off age used by researchers in different studies. For instance, Kapa and Colombo (2013) considered early bilinguals who learned L2 before age 3 years and late bilinguals who learned L2 later. Similar to the present study, a study by Paap et al. (2014) early bilinguals were those who learned L2 before age 6 and late bilinguals learned L2 after that. The results of this study indicated no difference between monolinguals, early bilinguals, and late bilinguals.

Different factors can potentially explain the results of this study. One possible explanation for the results comes from the fact that bilingual advantage is dependent on the specific tasks measuring EFs. This explanation was supported in a recent meta-analysis, consisting of 170 studies determining if the bilingual advantage is dependent on the EF tasks (Ware et al., 2020). They found a bilingual advantage for the Attentional Network Task but not the Flanker task. There are at least two possible reasons that bilingual advantage depends on tasks: 1) different tasks measuring executive functioning might activate different regions of the brain, that is bilingualism can impact a certain set of cognitive operation which is not required for all EF tasks, showing a bilingual advantage emerges only in those tasks that activate the cognitive operation that are impacted by bilingualism. 2) the psychometric properties of executive functioning tasks used in different studies might explain the inconsistency of the bilingual advantage hypothesis results. For the first reason, Peterson et al. (2002) suggested that the Stroop and Simon tasks, for instance, target similar regions of the brain but different levels of activations are involved during these tasks. They argued that Simon Task needs greater levels of activation in the superior and inferior regions of the parietal lobe than Stroop task. These regions of the brain are responsible mostly for the allocation of attention (Behrmann et al., 2004). Therefore, the bilingualism effect might be region specific. While I cannot completely rule out an effect of the task for the results of this study, I think this is an unlikely explanation. For this study, the tasks used in this study were ones included in previous studies that had found a bilingual advantage. Moreover, the reliability of these tasks was good (Ware et al., 2020).

Moreover, it might be possible that the bilingual language control process recruits different brain regions than EF components. In other words, the brain activation overlaps between bilingual language control including inhibition, switching, WM and EFs component could be partial for frontal and posterior parietal areas. Some studies found supporting evidence for this explanation. For instance, Weissberger et al. (2015) studied brain activation for language switching and domain-general task switching among bilinguals. They conducted conjunctional analysis and results indicated that different parts of the brain were involved in language switching such as bilateral thalamus, posterior cingulate while in the task switching other parts of the brain like frontal, parietal, temporal were more involved. They concluded, despite some similarities between brain regions for language conflict resolution and EF, there are some unique mechanisms for task and language switching. Similarly, using the Flanker task, Abutalebi et al. (2012) found activation for some regions of the brain which were not activated for language tasks. In addition, researchers studied people with brain injuries and found supporting results that they perform differently on verbal and non-verbal task. Green et al. (2010), for example, found that a patient with a lesion in frontal cortex showed no impairment in a linguistic task (Stroop) but impairment in a non-linguistic task (Flanker). Further studies are needed to examine bilingual speakers with brain damage to test whether a common neural network is required to inhibit a language during conversation and general inhibition processing.

Another possible reason for reporting results inconsistent with some previous studies is age. Bilingual advantage was found mostly among children and older adults who are not at the peak of their cognitive functioning (Bak, Nissan, Allerhand, & Deary, 2014; Bialystok et al., 2008; Luo, Luk, & Bialystok, 2010). Bunge et al. (2002) proposed that the brain, especially the prefrontal regions of the brain which support executive functioning, is still developing among children and it will be fully developed until early adulthood. In line with this study, one comprehensive meta-analysis on bilingual advantage showed that this advantage is dependent on age (Ware et al., 2020). They found bilingual advantage is mostly existence among individuals at 30 to 49 age range. Additionally, they found a bilingual advantage RT for incongruent trials was larger in older adults (50-years and above) than young adults (18 to 29 years old). A plausible explanation for these results is that young adults are at their peak of their EF abilities and in consequence ceiling effect might occur. The ceiling effect could lead to non-significant differences between monolingual and bilingual young adults especially on more simple EF tasks (Białystok et al., 2014). This, too, seems to be an unlikely explanation for the results of the present study, since I often found bilingual disadvantages on EF tasks.

The Hawthorne effect has been reported as yet another possible reason for discrepant findings across studies. This effect suggests that if the participants have some knowledge about the experiments and the studies of the particular labs investigating the bilingual advantage they might likely perform in line with the researchers' expectations (Donnelly et al., 2015). In the present study, participants filled out the consent form which provided the title of the study, some information about the study, and that we were looking for both bilingual and monolingual participants. After that they could choose either agree or disagree to participate in this study. The bilinguals may therefore have spent more time on the tasks, leading to longer reaction times. Most of the results showing a bilingual disadvantage were related to reaction times, with the exception of the Stroop effect. Future studies could ensure that participants are unaware of the importance of bilingualism before they do the tasks.

Another potential factor for the discrepant results of this study is that our bilingual group consisted of people with different first languages. The similarity between first and second language play a role in whether bilinguals show an advantage in EFs. In support of this explanation some studies suggested the more two languages are similar the greater EF demand is needed to use each language effectively leading to superior performance in EF tasks. That is, similar L1 and L2 could lead to stronger cross-language interference. Consequently, selecting the target language and inhibiting the non-target language is more challenging and more executive control is needed to inhibit the interfering language, to reduce the costs of switching between languages, and to monitor the contents that gain access to WM (Linck et al., 2008; Barac and Bialystok, 2012; Coderre and van Heuven, 2014). This provides an interesting venue for future studies to check this explanation among young adults with a large sample size.

Still another possible explanation of inconsistency between the results of this study and previous studies showing a bilingual advantage is the publication bias (most of the journals are in favor of confirmatory results of bilingual advantage) which can lead researchers to not publish their studies with null or negative effect sizes on the relationship between bilingualism and EFs. Moreover, researchers' confirmation bias may explain the results supporting bilingual advantage. Paap et al. (2020) argued that small but significant effect sizes showing bilingual advantage in the recent meta-analysis, might vanish by controlling for the researcher confirmation bias. Consistent with this explanation, De Bruin et al. (2015) claimed that publication bias is a possible factor supporting the bilingual advantage in EFs. In their study, de Bruin and her colleagues investigated the conference abstracts from 1999 to 2012 on bilingualism and EF and found that studies finding a significant bilingual advantage were more likely to be published. The studies with mixed results, null results and those that showed a bilingual disadvantage had lower chances of getting published. Some recent meta-analysis studies posited that the bilingual advantage hypothesis might be the result of publication bias. For instance, Donnelly et al. (2019)

and Paap (2019) found a small bilingual advantage in their studies which disappeared after correcting for publication bias using the PET-PEESE method. There is a link between researcher confirmation and publication bias. First, most of the editors and authors are bilingual themselves and that might affect the way they design the studies and present their findings in favor of bilingual advantage. Second, the publication bias will motivate the authors to report the finding showing a bilingual advantage with a higher chance of getting acceptance by journals. In a similar vein, Lehtonen et al. (2018) reported the publication bias by analyzing both published and unpublished studies. They found a bias in the distribution of the reported results according to the funnel plot and the PET-PEESE analysis. They argued that those studies with smaller sample sizes and low precision showing positive effect sizes are more likely to be published in the peer-reviewed literature rather than those showing large negative effect sizes.

One recent meta-analysis corrected for publication bias. Including 1,194 effect sizes from 10,937 bilingual and 12,477 monolingual participants, researchers found the bilingual advantage is small (if there is any) and inconsistent (Lowe et al., 2021). They found asymmetries in the funnel plots which was caused by a growing number of large positive effects among studies with low precision. After correcting for publication bias, they found the effect sizes were statistically indistinguishable from zero ($g = -.04$, 95% CI = [−.13, .05], $p = .414$). Among all EF domains, bias-corrected effect size estimates indicated a bilingual disadvantage in nonverbal WM ($g = -.19$) and for the other EF domains the language status effects were indistinguishable from zero. In other words, there may be no bilingual advantage in EF.

Findings of this study should be interpreted with caution because of the study's limitations. First, all of the tasks in this study were computer versions and all participants used their own computers to perform the tasks online. Their RTs while performing the tasks could have been variable, because possibly some of them had access to high-speed computers and internet and others did not. Second, this study did not control for all of the variables that could lead to a group difference on the EF among individuals such as IQ and neurodevelopmental disorders like ADHD. Third, more studies with strong psychometric properties that also include more than one task tapping each component of EF are needed. The measures of EFs in this study were modified versions with fewer trials for each condition which can affect the RT, complexity and processing demand of these tasks relative to tasks used in the previous studies. Another potential limitation of this study is the use of a self-rating scale for second language proficiency, because it may be affected by individual bias. However, this method of assessing language proficiency is common and is used widely in studies testing for bilingual advantage (e.g., Bialystok & Depape, 2009; Bialystok, 2006; Blumenfeld & Marian, 2013; Colzato et al., 2008; Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Kousaie & Phillips, 2012; Kousaie et al., 2014; Salvatierra & Rosselli, 2010; Linck et al., 2008; Luk et al., 2011).

In conclusion, in this study, I tested for differences between monolinguals and bilinguals on EF components including inhibition, WM capacity, and shifting. I found no differences between groups in both processing costs and WM capacity (except for backward CBT). There were, however, differences between groups on the Global RTs. Monolinguals performed the tasks faster than bilinguals in inhibition and shifting ability. I tested for the moderation effect of SES, immigration status and second language proficiency (English), and found these variables were not moderators on the relationship between bilingualism and EF. While there may be a number of factors contributing to these results, behavioral studies alone might not be able to reveal the bilingual advantage. More longitudinal and neuroscience studies are needed to test if the bilingual advantage is real within this age range. If there is a bilingual advantage, future studies are needed to test the generalizability of these findings, as well as including measures of possible mitigating variables.

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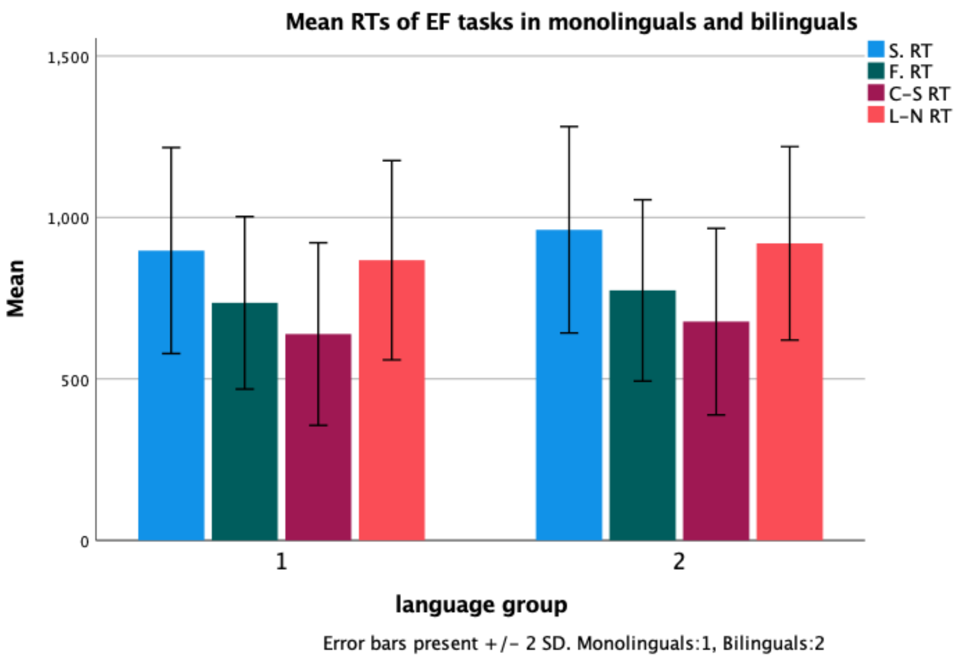
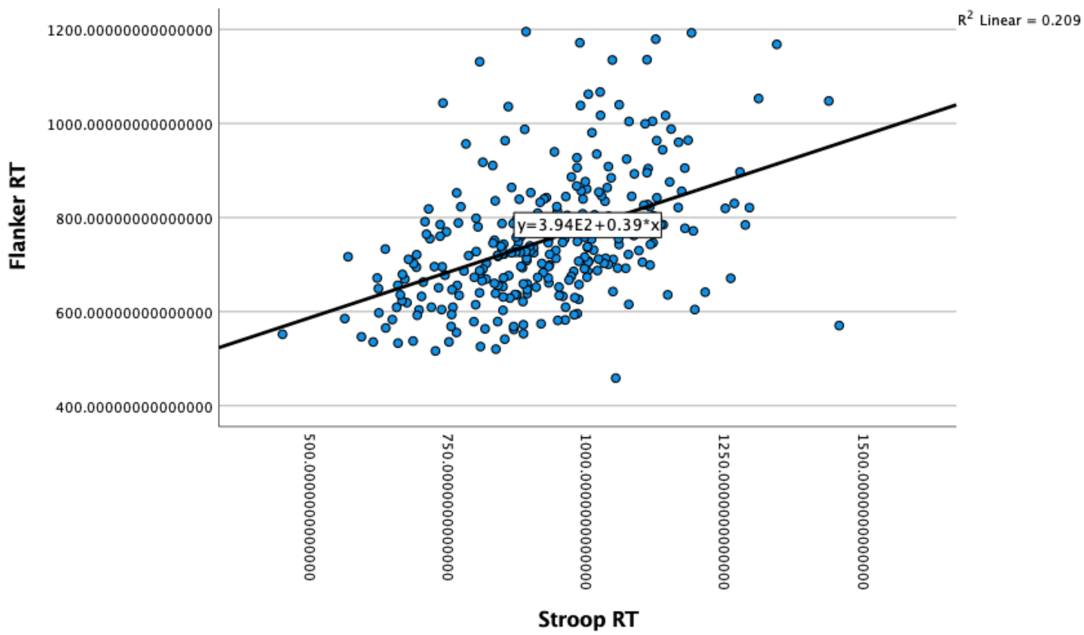
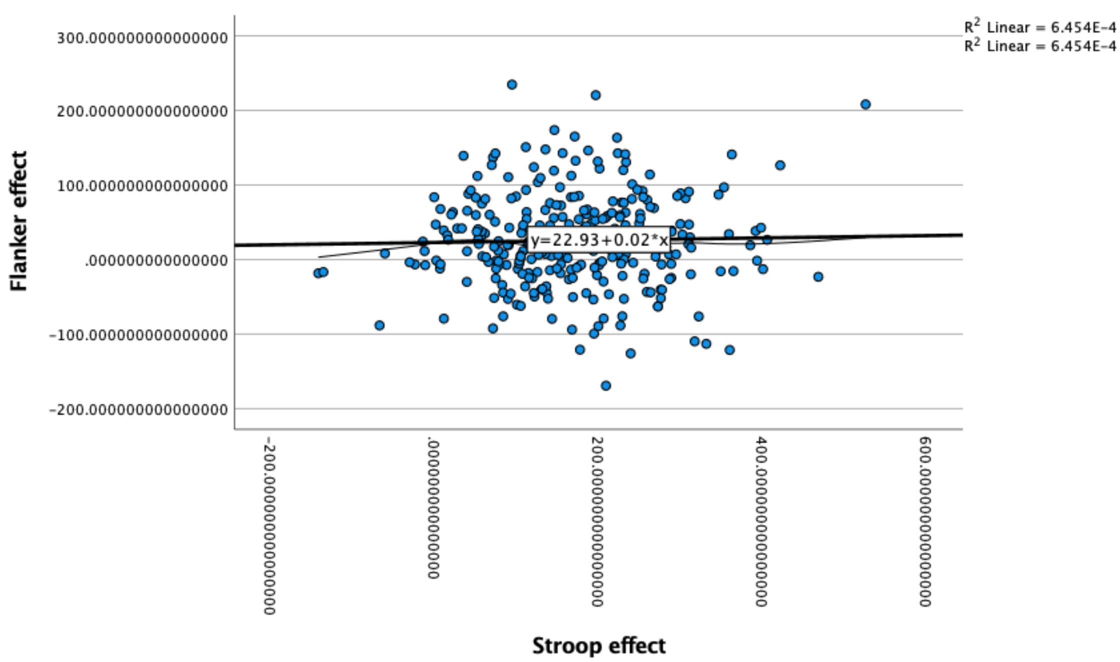
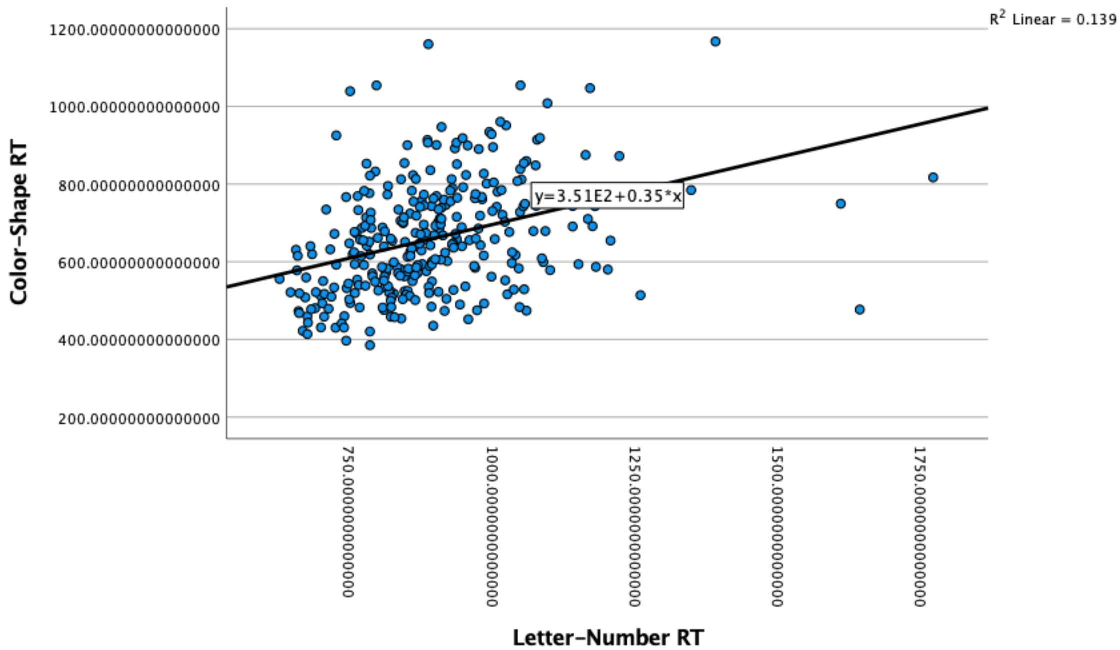
Appendix 1: Bar chart on the RTs of EF tasks

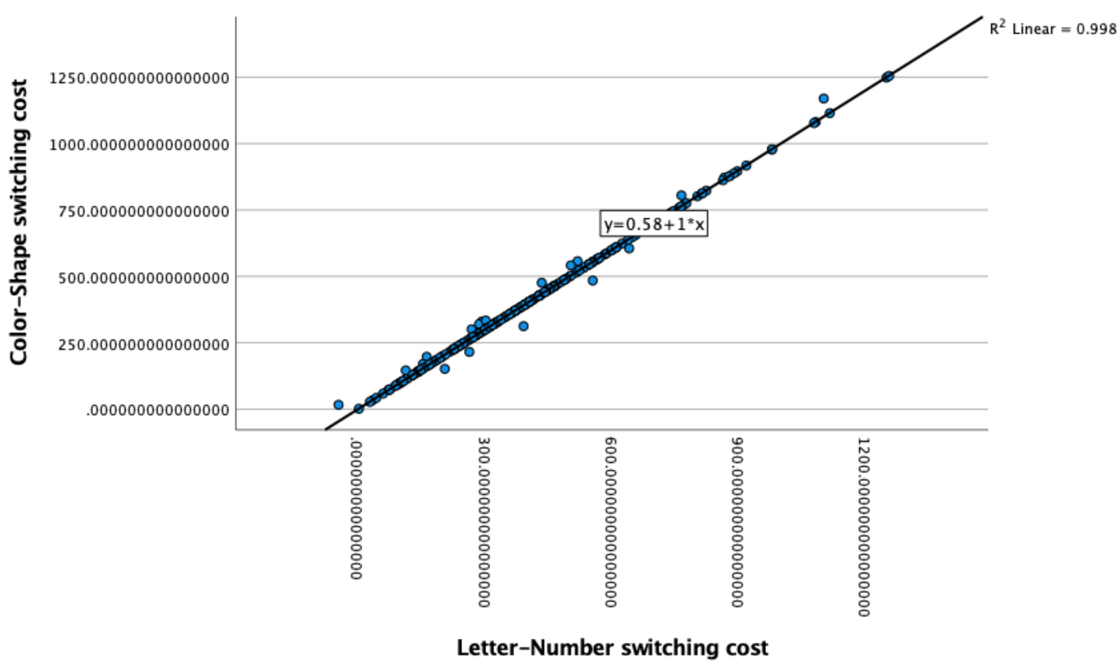


Appendix 2: Correlation between EF tasks






R^2 Linear = 0.139
y=3.51E2+0.35*x
Color-Shape RT
Letter-Number RT
1200.000000000000000
1000.000000000000000
800.000000000000000
600.000000000000000
400.000000000000000
200.000000000000000
750.0000000000000
1000.0000000000000
1250.0000000000000
1500.0000000000000
1750.0000000000000


R^2 Linear = 0.998
y=0.58+1*x
Color-Shape switching cost
Letter-Number switching cost
1250.000000000000000
1000.000000000000000
750.000000000000000
500.000000000000000
250.000000000000000
.000000000000000
.0000000000000
300.0000000000000
600.0000000000000
900.0000000000000
1200.0000000000000