

Executive Function Skills in English Monolinguals and Mandarin-English Bilinguals

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Abstract

Executive Function Skills in English Monolinguals and Mandarin-English Bilinguals

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Previous studies have shown a relationship between one's language background and executive function skills. Thus far, evidence has suggested that bilinguals may have a cognitive advantage compared to monolinguals in inhibition and shifting abilities. Some studies have shown that bilingualism has a positive correlation with inhibition and shifting abilities while other studies have shown mixed or no differences between monolinguals and bilinguals. For this study, our aim is to further delve into this controversial topic and replicate previous studies to examine the effects of bilingualism on executive function skills. We recruited a group of adult English monolingual (N=22) and Mandarin-English bilinguals (N=22), and compared their executive function skills measured by four tasks: Simon, Stroop, Letter-Number Switching and Color-Shape Switching (Cued). Two dependent measures were calculated and analyzed from these tasks: reaction time and percentage accuracy. We hypothesized that the bilinguals would outperform monolinguals on all tasks. Two-way mixed ANOVAs revealed mixed results

between monolinguals and bilinguals across trial types. Results from the Simon task revealed that both groups responded significantly faster to compatible trials than incompatible trials, though both groups were similarly accurate in both trial types. Bilinguals also responded significantly slower than monolinguals to both trial types while a significantly larger difference was found between trial types in monolinguals than bilinguals. Results from the Stroop task revealed that both groups responded significantly faster and were more accurate in responding to compatible trials than to incompatible trials. However, no group differences or interaction effect were found. Results from the Letter-Number Switching and Color-Shape Switching (Cued) task revealed that both groups responded significantly faster and were more accurate in responding to repeat than to switch trials. Bilinguals also had a significantly higher accuracy percentage than monolinguals in the Letter-Number Switching task though no significant group differences were found in reaction time. No significant group differences were found in both dependent measures for the Color-Shape Switching (Cued) task. We discussed current results in relation to previous studies in terms of similarities and differences in methodology as well as potential confounding variables. We also discussed the limitations of our current study. In summary, while our results did not replicate previous research, it added to the existing literature on whether bilingualism affects inhibition and shifting skills and future research is warranted to address the methodological differences and potential confounding variables in cognitive tasks.

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Introduction

I. Executive Function

Executive function is central in human cognition and is highly associated with a child's cognitive, linguistic, behavioral and social-emotional development. Past studies have shown that the development of executive function skills predict several areas of development, including: early literacy (Zhang et al., 2017), language (Gooch, 2016), gestures (O'Neill & Miller, 2013), theory of mind (Henning et al., 2011) and early mathematics (Verdine, 2014).

Furthermore, deficits in executive functions skills are likely found in individuals with various disorders including: Attention Deficit Hyperactivity Disorder (ADHD) (Schoemaker, 2012), Autism Spectrum Disorder (ASD) (Kenworthy et al., 2008), traumatic brain injury (TBI) (Tate et al., 2014) and Alzheimer's disease (Stopford et al., 2012). Executive dysfunction can potentially impact these individuals in multiple activities of their daily living, such as the ability to plan a trip to the grocery store or remember the steps for self-dressing or toileting. In the area of speech-language pathology, these disorders are frequently presented in patients seen by a speech-language pathologists. Therefore, it is important to understand the development of executive functions and factors that can affect such development. This will then help clinicians understand how it can impact these individuals with disabilities, which subsequently helps inform future clinical evaluation and treatment decisions.

Given its importance, it is crucial to understand what executive function is composed of. For the past two decades, several descriptions and models have been used to define and examine the components that make up of executive function (Baddeley, 1996; Logan, 1985; Lyon & Krasnegor, 1996; McCloskey et al., 2012; Miyake et al., 2000). While there has yet to be a

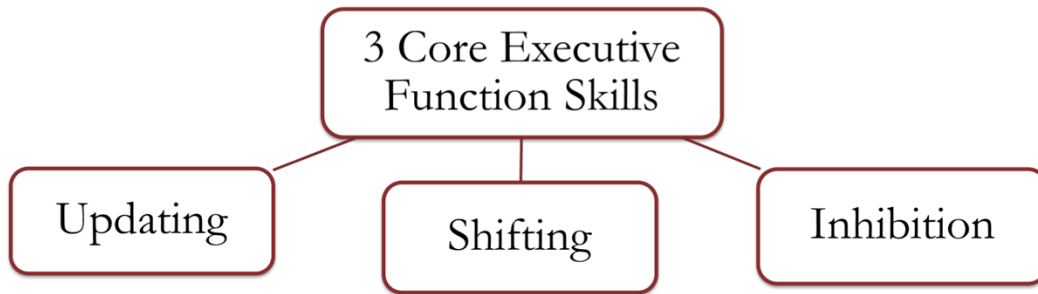


Fig. 1. Three core components of executive function (Miyake & Friedman., 2000)

consensus on an universal definition, most would agree that executive function is an interrelated, multi-dimensional construct that consists of numerous cognitive abilities required for one to perform purposeful, goal-directed behaviors. Specifically, Miyake and colleagues (2000 & 2012) proposed that the various cognitive abilities in executive function are correlated with one another by yet also separable and independent of one another. In addition, they suggested that executive function can be categorized into three core skills: updating, shifting and inhibition (see Figure 1). Their unity and diversity model was commonly used in previous bilingual studies to define executive function given that two out of the three components, shifting and inhibition skills, were often suggested to be enhanced in bilinguals (Bialystok et al., 2004; Bialystok et al., 2008; Bialystok et al., 2009; Bialystok, 2017; Garbin et al., 2010; Marton et al., 2017; Prior & Gollan, 2011; Prior & MacWhinney, 2010; Seçer, 2016; Wiseheart et al., 2016; Woumans et al., 2015). Therefore, in the current study, we will focus on the inhibition and shifting skills.

Inhibition skills, also known as inhibitory or interference control, is defined as the ability to consciously inhibit or suppress “dominant and prepotent” responses when necessary (Miyake et al., 2012). For example, an individual who is intentionally suppressing the music lyrics in the background to focus on the conversation at the dinner table is actively using his or her inhibition skills. On the other hand, shifting skills, also known as task-switching, attentional switch or set-shifting skills, is defined as the ability to switch between tasks or mental sets (Miyake et al.,

2000). For example, an individual who is continuously switching from listening to the music lyrics in the background to the dinner conversation at the table is actively using his or her shifting skills.

Overall, given the importance of executive function in predicting early child development skills and its impact on individuals with disabilities, it is vital to address the definition of executive function and its components to better interpret the results of this study.

II. Bilingualism and Executive Function Skills

What is bilingualism? Who is considered a bilingual? A bilingual is commonly described as an individual who uses two languages in his or her everyday life. At this moment, more than half of the world's population were speculated to be bilinguals (Bialystok, 2017). According to the U.S. Census Bureau (2018), about 35% of the population in the United States speaks another language besides English at home, of which includes at least 350 different languages. Given the immeasurable amount of people who are likely to be bilinguals, it is important to understand the effects of language background on the development of executive function. Many researchers such as Ellen Bialystok and Anat Prior concur on the lack of understanding on the effects of bilingualism with regards to cognitive skills. This subsequently initiated the era of bilingual research.

Thus far, research has suggested that bilingualism may have a positive effect on one's cognitive abilities in various age groups including children as young as at the age of four (Barac & Bialystok, 2012; Yang et al., 2011) to young adults (Prior & Gollan, 2011; Woumans et al., 2015) and older adults as old as 70 years old (Bialystok et al., 2014; Goral et al., 2015). Specifically, studies have proposed that there could be a cognitive advantage for bilinguals compared to monolinguals in inhibition (Bialystok et al., 2004; Bialystok et al., 2009; Marton et

al., 2017; Woumans et al., 2015) and shifting (Garbin et al., 2010; Prior & Gollan., 2011; Prior & MacWhinney, 2010; Seçer, 2016; Wiseheart et al., 2016) skills.

Past researchers such as Bialystok and colleagues (2009) proposed that while bilinguals are using one language, the other language is actually still active in the brain. If that is the case, bilinguals will have to constantly make use of their inhibitory control to suppress the unused language while focusing on the language being used. Over time, they suggested that bilinguals' ability to suppress an active language daily could enhance inhibition skills, subsequently generalizing their inhibition skills in verbal tasks to nonverbal tasks. Therefore, the current study aimed to further examine the cognitive advantage bilinguals may have in inhibition skills.

Researchers such as Garbin and colleagues (2010) also suggested that bilinguals may have enhanced shifting skills. The idea behind this hypothesis is that bilinguals are presumed to often switch between languages or at the very least, are able to switch from one language to another efficiently. Given that monolinguals do not have to frequently switch between languages, it is not a surprise that bilinguals were suggested to have relatively stronger shifting skills. Specifically, Garbin and colleagues' (2010) study revealed that while bilinguals activated their left inferior frontal gyrus in the prefrontal cortex, which is an important area for bilingual language control, during non-linguistic switching tasks, monolinguals activated their right inferior frontal gyrus. Not only did their results indicated that the cortical network in monolinguals and bilinguals were distinctly different, but there could also be some overlap occurring between the network responsible for performing linguistic and non-linguistic switching tasks in bilinguals. If that is the case, improved shifting skills in linguistic task (switching between languages) may potentially also improve shifting skills in non-linguistic tasks.

Therefore, the current study also aimed to further examine the cognitive advantage bilinguals may have in shifting skills using linguistic and non-linguistic tasks.

Since these theories of bilingual advantage on cognitive skills were proposed, numerous studies attempted to determine the effects of bilingualism on inhibition and shifting skills. However, this area of topic continued to be a controversy in the field of bilingual research.

Inhibition Skills

Bialystok and colleagues (2004) were one of the first researchers to conduct studies examining the bilingual cognitive advantage in inhibition skills in adults. Specifically, in their first study, they examined the possible effects of bilingualism between younger and older monolinguals and bilinguals on inhibitory skills using the Simon task. They recruited 40 adults, of which half were younger adults between the age of 30 and 54 years old and the other half were older adults between the age of 60 to 88 years old. The adults in each age group were divided evenly into two groups: English monolinguals and Tamil-English bilinguals. Besides the Simon task, a language background questionnaire, Peabody Picture Vocabulary Test and Raven's Standard Progressive Matrices were administered to examine each participant's language background, receptive vocabulary skills and abstract nonverbal reasoning abilities respectively. The results of the study showed that bilinguals outperformed monolinguals in the Simon task, indicating that bilinguals may be better at inhibiting information than monolinguals. This suggests a possible cognitive advantage that bilinguals have over monolinguals in inhibition skills.

Although additional studies were conducted following Bialystok et al's (2004) findings on the adult population, the subsequent studies recruited adults that were of a younger age than their study. For example, Bialystok and colleagues (2008) recruited 96 participants that were

divided evenly into three groups: young monolinguals, young bilinguals and older bilinguals. The average age of the young monolinguals, young bilinguals and older bilinguals were 20.7, 19.7 and 67.2 respectively. Bilinguals in this study were of a general bilingual population¹. With these three groups of participants, they conducted a study to investigate the effects of bilingualism on working memory, lexical fluency and executive control. They administered the forward and backward Corsi blocks, and self-ordered pointing to assess working memory, the Peabody Picture Vocabulary Test (PPVT) and Boston naming task to assess lexical fluency as well as the Simon arrows task, Stroop color-naming task and Sustained Attention to Response Task (SART) to assess cognitive control skills (e.g., inhibition skills). Evidence shown in the results indicated that while the groups' performances did not differ in the working memory tasks, monolinguals outperformed bilinguals on lexical retrieval tasks and bilinguals outperformed monolinguals in the executive control tasks. This suggests that while bilinguals may be weaker in lexical retrieval, they may have a cognitive advantage in executive control tasks measuring inhibition skills compared to monolinguals.

Besides that, Marton and colleagues (2017) conducted a study to examine the effects of bilingualism on executive control. They recruited 77 participants between the ages of 18 and 35, of which 36 were highly proficiency bilinguals from a general bilingual population. The Language Experience and Proficiency Questionnaire (LEAP-Q) was administered to examine each participant's language background. Executive control of each participant was also assessed by administering an information processing battery. Tasks administered from the battery included baseline word categorization, implicit learning condition, resistance to proactive interference condition, performance monitoring condition and switching condition to assess

¹ "General bilingual population" refers to a group of bilinguals whose first and second language were of different languages.

speed of processing, implicit learning skills, interference control, monitoring skills with auditory cueing and switching skills respectively. The results of the study suggested that bilinguals were faster in implicit learning, had better interference control and better switching skills than monolinguals, suggesting the possible effects of bilingualism on both inhibition and shifting skills.

Additionally, Woumans and colleagues (2015) conducted a study to find out the effects of bilingualism on verbal and nonverbal cognitive control. Their study recruited a total of 30 French monolinguals as well as 34 unbalanced, 31 balanced and 28 interpreters who were Dutch-French bilinguals. The participants' average age was about 22 years old. They administered a language background questionnaire to assess language background, Raven's Advanced Progressive Matrices to assess nonverbal intelligence, semantic verbal fluency task to assess verbal language control as well as two cognitive tasks: Simon task and shortened Attention Network Test (ANT) to assess nonverbal executive functions. Both of these cognitive tasks require inhibition skills. Evidence shown in the results indicated that while only the balanced bilinguals showed a significant positive correlation between verbal and nonverbal cognitive control, all bilingual groups outperformed monolinguals in both cognitive tasks. This further suggests the possible cognitive advantage bilinguals have over monolinguals in inhibition skills.

While previous research showed that bilingualism can enhance inhibition skills (Bialystok et al., 2004; Bialystok et al., 2008; Marton et al., 2017; Woumans et al., 2015), similar studies also reported that bilingualism had no beneficial effects on inhibition skills (Desjardins & Fernandez, 2018; Kousaie et al., 2014; Paap & Greenberg, 2013; Scaltritti, 2017). Desjardins & Fernandez (2018) conducted a study to examine the effects of bilingualism on auditory and visual tasks measuring inhibition skills. They recruited a total of 20 English monolinguals and 19

Spanish-English bilinguals who were between the ages of 18 and 30. The Language Exposure and Proficiency Questionnaire (LEAP-Q) was given to each participant to obtain their language background information while the digit span subtest of the Wechsler Adult Intelligence Scale-III was administered to assess cognitive ability. An auditory inhibition and Simon task were also administered to assess inhibition skills. The results of this study revealed no statistical differences between the monolinguals and bilinguals in both inhibitory tasks, suggesting that bilinguals may not have a cognitive advantage in inhibition skills compared to monolinguals.

In addition, Kousaie and colleagues (2014) conducted a study to investigate the effects of bilingualism on executive function and language skills for young and older adults. 121 young adults (51 bilinguals) with an average age of 21 years old and 97 older adults (36 bilinguals) with an average age of 72 years old were recruited. All monolinguals were divided into English-speaking and French-speaking monolinguals while all bilinguals were highly proficient French-English bilinguals. All participants completed an animacy judgment task to assess second language proficiency, cognitive screening to assess general cognitive function, Stroop, Simon and Sustained Attention Response task (SART) to assess inhibition skills, digit span subtests of the Wechsler Adult Intelligence Scale-III to assess working memory, Wisconsin Card Sort test (WCST) to assess shifting skills, Boston naming task to assess language skills as well as a letter and category fluency task to assess verbal fluency. The overall results of this study regarding young adults presented no significant differences between the performance of the monolingual groups and bilingual group in the verbal fluency tasks and in the cognitive tasks measuring inhibition skills, suggesting no relation between bilingualism and inhibition skills. Furthermore, their results suggest a potential bilingual disadvantage in shifting skills given that the French

monolinguals outperformed the English monolinguals and French-English bilinguals on the WCST.

Besides that, Scaltritti (2017) also conducted a study to examine the effects of language-switching in bilinguals in inhibitory tasks. In their study's second experiment, they recruited 97 participants with an average age of 23 years old, of which 41 were Italian monolinguals and 56 were Italian-Venetian dialect bilinguals. The Raven's Progressive Matrices and the flanker task were given to each participant to assess nonverbal intelligence and inhibition skills respectively. Evidence shown in the results indicated that there was no statistical difference between the two participant groups' performance in the flanker task, further suggesting no bilingual advantages in inhibition skills.

Paap & Greenberg (2013) also conducted three studies to investigate if the bilingual cognitive advantage would be consistently found in several tasks measuring executive processing skills. 90, 86 and 110 undergraduate students were recruited in Study 1, 2 and 3 respectively. Bilinguals belonged to the general bilingual population and spoke different languages. For all the studies, a language proficiency questionnaire and Raven's Advanced Matrices test was administered to each participant to assess language background and nonverbal intelligence respectively. The antisaccade (Study 1), Simon (Studies 1-3), flanker (Study 3) and color-shape switching tasks (Studies 1-2) were administered to measure inhibitory control and shifting skills in the three studies. The results of this study showed findings consistent with a bilingual disadvantage in inhibition skills in the Simon and flanker task while no significant evidence of a bilingual advantage was found in the antisaccade and color-shape switching task. Overall, the study suggests that not only could there be no cognitive advantages in bilinguals on inhibition and shifting skills, but it also raised the awareness of convergent validity with regard to the types

of inhibitory tasks used in bilingual research. Specifically, they questioned whether cognitive tests measuring inhibition skills (e.g., Simon, flanker, antisaccade) can be used interchangeably to examine the effects of bilingualism given the inconsistent findings found in their results.

Shifting Skills

Besides the study conducted by Marton & colleagues (2017) which revealed positive results indicating potential cognitive advantages for bilinguals in shifting skills, several other studies also generated similar results. Prior & MacWhinney (2010) conducted a study to investigate the effects of lifelong bilingualism on shifting skills. Their study recruited 92 participants between the ages of 18 to 19.5 years old, of which 47 were general bilinguals. Every participant were assessed on their verbal ability via the verbal scores in the SAT and the Peabody Picture Vocabulary Test (PPVT), as well as their language background via a language history questionnaire. A color-shape switching (cued) task and an operation span task were also used to assess shifting skills and working memory respectively. Evidence shown in this study suggests that bilingualism may be related to enhanced shifting skills, specifically indicating that bilinguals may have a cognitive advantage in shifting skills compared to monolinguals.

Additionally, Seçer (2016) conducted a study to examine the effects of bilingualism on cognitive flexibility (i.e., shifting skills). A total of 162 participants between the ages of 18 to 34 years old, of which 74 were Turkish-English bilinguals, were recruited in this study. They administered a demographic questionnaire to obtain demographic and language background information, tests of verbal fluency to assess verbal abilities and the Trail Making Test (TMT) to assess executive functions. The TMT consisted of two parts: TMT-A assesses attentional control (i.e., sustained attention) while TMT-B assesses cognitive flexibility. The results of this study indicated that while there were no significant differences between the groups' performances in

the TMT-A task, bilinguals responded faster to trials than monolinguals in the TMT-B task. This suggests that bilingualism may have a positive impact on skills of cognitive flexibility, such as shifting skills.

Besides that, Wiseheart and colleagues (2016) conducted a study to find out whether the language-switching skills in bilinguals could be transferred to non-linguistic switching skills. Their study recruited 68 participants with an average age of 19.1 years old, of which 31 were general bilinguals. A language background questionnaire, Kaufman Brief Intelligence Test, Peabody Picture Vocabulary Test, box completion task and task-switching paradigm using a color and animal task were administered to assess language proficiency, nonverbal intelligence, receptive vocabulary, processing speed and shifting skills respectively. Evidence shown in the study reveals that bilinguals may have specific cognitive advantages that may positively impact the development of shifting skills.

However, mixed results were also obtained in a study conducted by Prior & Gollan (2011) investigating the effects of bilingualism on shifting skills in two bilingual populations. In their study, they recruited 47 English monolinguals, 41 Spanish-English bilinguals and 43 Mandarin-English bilinguals of which the average age among the participants was 20 years old. The Shipley Vocabulary Test was administered to assess crystallized knowledge and fluid reasoning while the verbal fluency task was administered to assess lexical retrieval. The Kaufman Brief Intelligence Test was also used to assess non-verbal reasoning. Computer tasks measuring shifting skills included a color-shape switching task and a language-switching task. The results of the study showed that while Spanish-English bilinguals outperformed monolinguals in both switching tasks, Mandarin-English bilinguals did not have a task-switching advantage compared to monolinguals. They also proposed that the frequency of language-switching experience could

be an important factor in the extent of bilingual advantage in shifting skills. This suggests that not only are there limitations in the bilingual advantage in shifting skills, but also that bilingual language experience could be a contributing factor that should be considered and studied in future research.

In addition, Moradzadeh and colleagues (2015) conducted a study to examine the effects of music training and bilingualism on task-switching and dual-task performance. A total of 153 participants between the ages of 18 to 31 were recruited and categorized into four groups: monolingual musicians, monolingual non-musicians, bilingual musicians and bilingual non-musicians. Bilinguals in the study were of the general bilingual population. A language and musical background questionnaire, the Kaufman Brief Intelligence Test 2, a task-switching paradigm and a dual-task paradigm were administered to assess language, music and socio-economic background, vocabulary and nonverbal intelligence as well as shifting and dual-task skills respectively. The results of the study showed that while musicians performed better than non-musicians, bilinguals did not outperform monolinguals in both task-switching and dual-task paradigms. This suggests that bilingualism may not be correlated with benefits in shifting and dual-task skills.

Moreover, similar to the results obtained in Kousaie and colleagues' (2014) study, Paap & Greenberg's (2013) study also revealed findings that is consistent with a bilingual disadvantage further suggesting no correlation between bilingualism and shifting skills.

III. The Present Study

As of now, there are over 1.1 billion of people who speaks Mandarin (*Ethnologue: Languages of the World*, 22nd ed., 2019). Additionally, there is an increasing amount of people from Mandarin-speaking backgrounds who are beginning to learn English as their first or second

language. Therefore, it is crucial to further understand this specific bilingual population and the effects of bilingualism on this population with regards to executive function skills.

In the current literature, studies have either selected specific target populations such as Spanish-English (Desjardins & Fernandez., 2018; Prior & Gollan., 2011), Dutch-French (Woumans et al., 2015) or Tamil-English (Bialystok et al., 2004) while other studies recruited a more general bilingual population (Bialystok et al., 2008; Marton et al., 2017; Moradzadeh et al., 2015; Paap & Greenberg., 2013; Prior & MacWhinney., 2010; Wiseheart et al., 2016). Yet, the Mandarin-English speaking population has not been commonly studied in past research. Given the increasing amount of people who could be Mandarin-English bilinguals and that it has been understudied in previous studies, this specific bilingual population was selected in the current study to add onto the current literature investigating the effects of bilingualism on inhibition and shifting skills.

IV. Research Question

To summarize, there is some conflicting data in the research regarding the effect of bilingualism on executive functioning skills. Therefore, the primary goal of this study is to specifically examine whether Mandarin-English bilinguals perform differently from English monolinguals on inhibition and task-switching skills.

To assess executive function skills, four cognitive tasks were administered using PsyToolkit (Stoet., 2010 & 2017). Specifically, the Simon and Stroop tasks were selected in this study to measure inhibition skills in participants while the Letter-Number Switching and Color-Shape (Cued) Switching data were selected to measure shifting skills. The Simon task, initially designed by Simon & Ruddell (1967), was used to measure interference or inhibitory control, also known as the stimulus-response compatibility effect in auditory verbal tasks. This effect is

described as the extent to which one's interpretation of an information is compatible with the required action. A visual version of the Simon task was administered in this study. Stroop task, initially designed by Stroop (1935), was also used to measure inhibitory control or the Stroop effect. The Stroop effect is described as one's difficulty with naming the ink of colored words due to a mismatch in the stimuli (e.g., ink color vs. written word). On the other hand, the two switching tasks used in this study were based on similar tasks used in previous bilingual studies (Paap & Greenberg., 2013; Prior & Gollan., 2011; Prior & MacWhinney., 2010) to measure shifting skills.

We hypothesized that bilinguals would outperform monolinguals in the cognitive tasks measuring inhibition and shifting skills.

Methods & Materials

I. Participants

Participants were recruited in the city of Seattle via the University of Washington's Psychology Research Subject Pool. These participants were students taking psychology courses at the University of Washington and received course credit for their participation. A total of forty-four participants (11 males and 33 females), ranging from 18 to 27 years of age ($M = 19.23$ yrs, $SD = 1.777$) were recruited. All participants had no history of speech, language or hearing difficulties. The UW Human Subjects Review Committee approved all study procedures and informed consent was obtained from each participant at the beginning of the study. The LEAP-Q questionnaire (Marian et. al., 2007) was given to collect data on each participant's language background. The LEAP-Q measures a number of demographic and linguistic variables related to bilingual individuals such as self-rated proficiency. Given that past studies have indicated that private music training could also enhance executive function skills (DePape, 2007; Bialystok &

Depape, 2009; Moradzedeh et al., 2015), an additional self-generated questionnaire was also given at the beginning of the study to collect data on each participant's music background.

Participants were assigned to the monolingual or the bilingual group based on pre-determined criteria. We recruited 22 participants (Monolingual group: 6 males and 16 females; Bilingual group: 5 males and 17 females) for each group. The monolingual group (age range = 18-27 yrs, $M = 19.27$) met the following criteria: they are monolinguals who are only fluent in English ($M_{AoA} = 0.86$, $SD = 1.13$) and they do not report being fluent in any of their previously learned foreign languages. The bilingual group (age range = 18-24; $M = 19.18$) met the following criteria: they are Mandarin-English speakers who can speak both languages fluently at least at conversational level and have started learning the second language before the age of five (First language: $M_{AoA} = 0.5$, $SD = 0.74$, Second language: $M_{AoA} = 3.45$, $SD = 1.42$). All except three bilinguals had Mandarin as their first language of acquisition. Through processing the participants' questionnaires, three subjects who were listed as a monolingual were found to have a measurable amount of daily usage and exposure to another language (e.g., Japanese, Hindi, Amharic). As this does not fulfill our study's criteria as a monolingual, data from these subjects were discarded. The final sample comprised of 41 participants.

From the LEAP-Q, data on the percentage of daily language exposure and levels of proficiency in three areas of language (i.e., speaking, understanding spoken language, reading) in both participant groups were obtained and analyzed. Participants rated their percentage of daily language exposure on a scale from 0 to 100 percent while they rated their levels of proficiency on a scale from 0 to 10. Figure 2A shows the data comparison computed by using the percentage of language exposure rated by each monolingual participant. On average, monolinguals were exposed to English 98.2% of the time ($SD = 3.7\%$). Figure 2B shows the data comparison

computed by using the percentage of language exposure rated by each bilingual participant and separating the data into two categories: first and second language. On average, bilinguals were exposed to their first language 59.5% (SD = 28.8%) and second language 39.6% (SD = 28.7%) of the time. This indicated that there is a certain degree of variability between the bilinguals' first and second language exposure.

Figure 3-5A shows the data comparison computed by using the self-rated level of proficiency in speaking, understanding spoken language and reading for each monolingual participant. Monolinguals were determined to be highly proficient in English, with average proficiency levels of 9.37 (SD = 0.60) in speaking, 9.34 (SD = 0.67) in understanding spoken language and 9.13 (SD = 0.81) in reading. In contrast, there is some variability between the proficiency levels of these three areas between each bilingual participant's first and second language. Figure 3-5B shows the data comparison computed by using the self-rated level of proficiency in speaking, understanding spoken language and reading for each bilingual participant's first and second language. Three paired sample t-tests were conducted to determine any significant differences in the bilinguals' proficiency levels in speaking, understanding spoken language and reading between their first and second language. While the test revealed a statistical difference, $t(1, 21) = 2.334, p = 0.021$, in the proficiency levels in speaking between the first and second language of the bilingual group, no differences were found in the proficiency levels in understanding spoken language, $t(1, 21) = 1.530, p = 0.141$, and in reading, $t(1, 21) = 1.136, p = 0.269$. In terms of speaking, results showed that bilinguals were more proficient in their first language (M = 9.00, SD = 1.48) than second language (M = 7.73, SD = 1.35). While no statistical differences were found in the proficiency levels of understanding spoken language and reading, results revealed that bilinguals were slightly more proficient in their first language

(Spoken: $M = 9.00$, $SD = 1.51$; Reading: $M = 8.55$, $SD = 2.56$) than second language (Spoken: $M = 8.23$, $SD = 1.07$; Reading: $M = 7.64$, $SD = 1.76$) in these two areas of proficiency. The 95% confidence interval for the difference in first and second language in speaking, understanding spoken language and reading ranged from 0.211 to 2.334, -0.278 to 1.823 and -0.755 to 2.573 respectively.

A common way of determining a musician in research is often by looking at the average years of private music training (Bialystok & Depape, 2009; DePape, 2007; Moradzedeh et al., 2015). Private music training is defined as having private music lessons with a teacher. Thus, the number of years participants who had previously participated in school-based music curriculum activities (e.g., band, orchestra) were thus not included within the analysis of private music training. Figure 6 shows the data obtained from the music background questionnaire and analyzed using the average years of private music training. An independent t-test was conducted to determine any differences in the average years of private music training between the two participant group. While results showed that the monolingual group ($M = 5.58$, $SD = 4.325$) had a slightly higher average years of private music training than the bilingual group ($M = 5.41$, $SD = 4.768$), the t-test revealed no statistical difference, $t(1, 39) = 0.119$, $p = 0.906$ between the two groups. The 95% confidence interval for the difference in group means ranged from -2.724 to 3.064.

Fig. 2. Percentage of daily language exposure in monolinguals and bilinguals

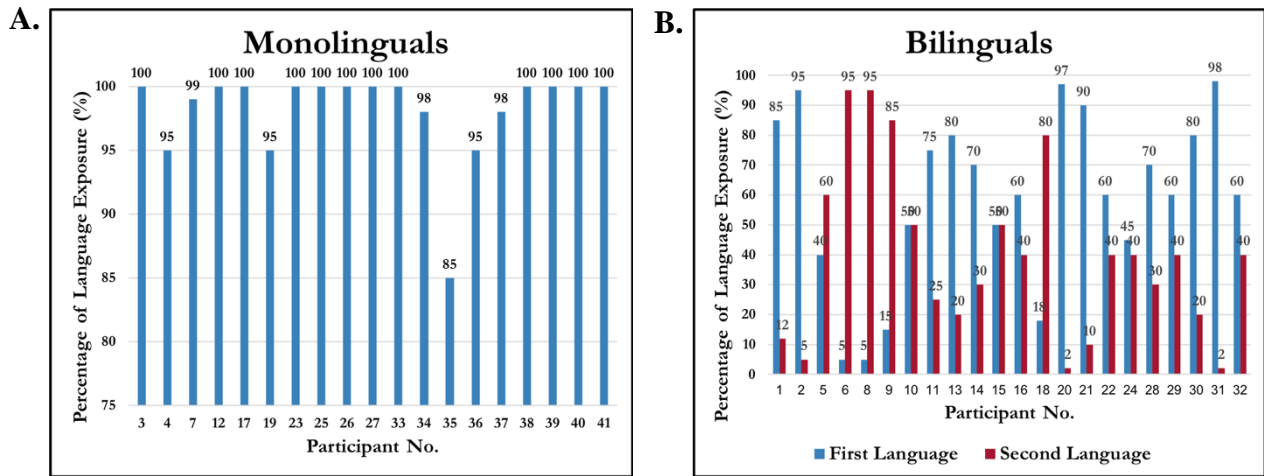


Fig. 3. Self-rated proficiency levels in speaking in monolinguals and bilinguals

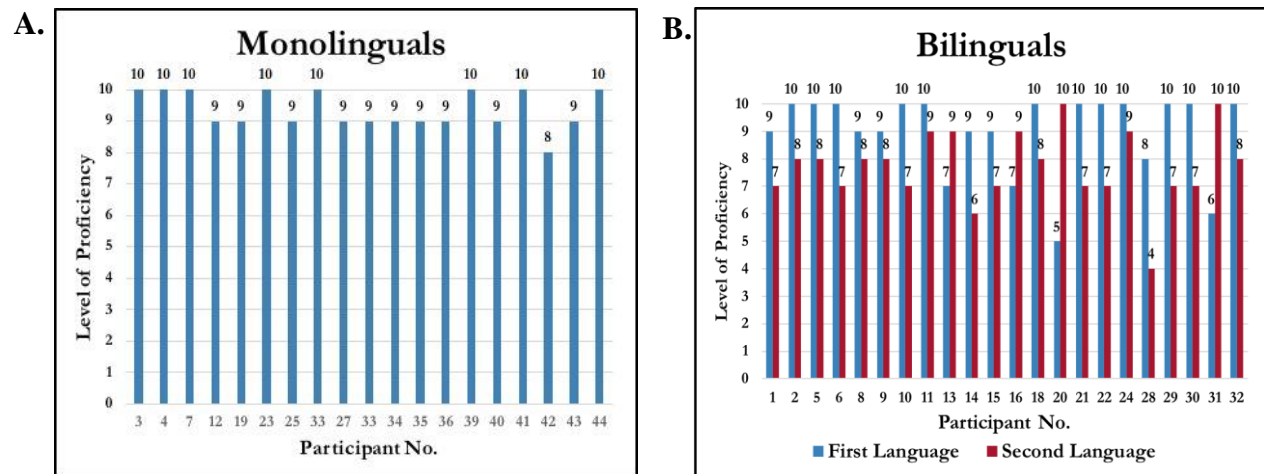


Fig. 4. Self-rated proficiency levels in understanding spoken language in monolinguals and bilingual

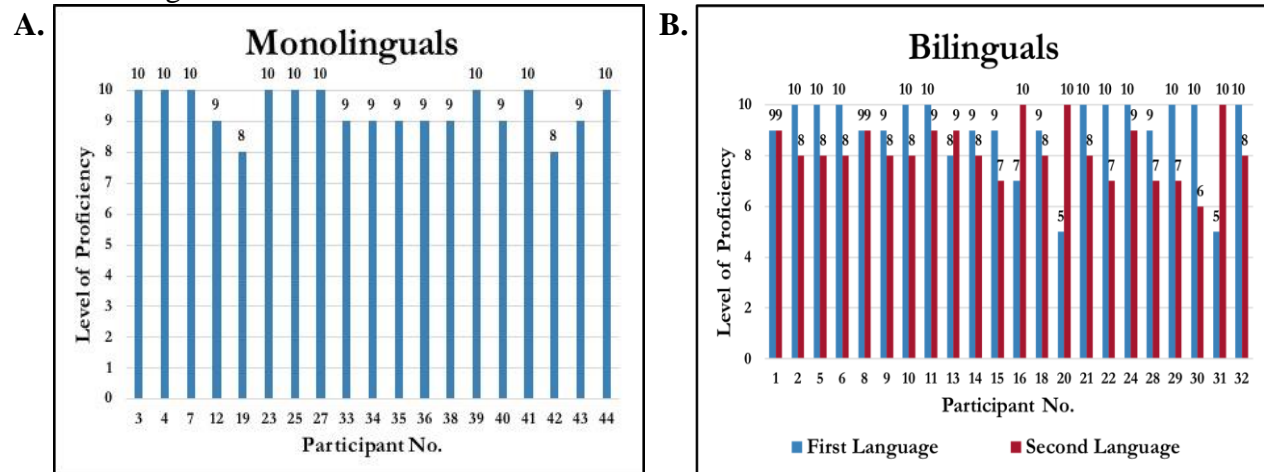


Fig. 5. Self-rated proficiency levels in reading in monolinguals and bilinguals

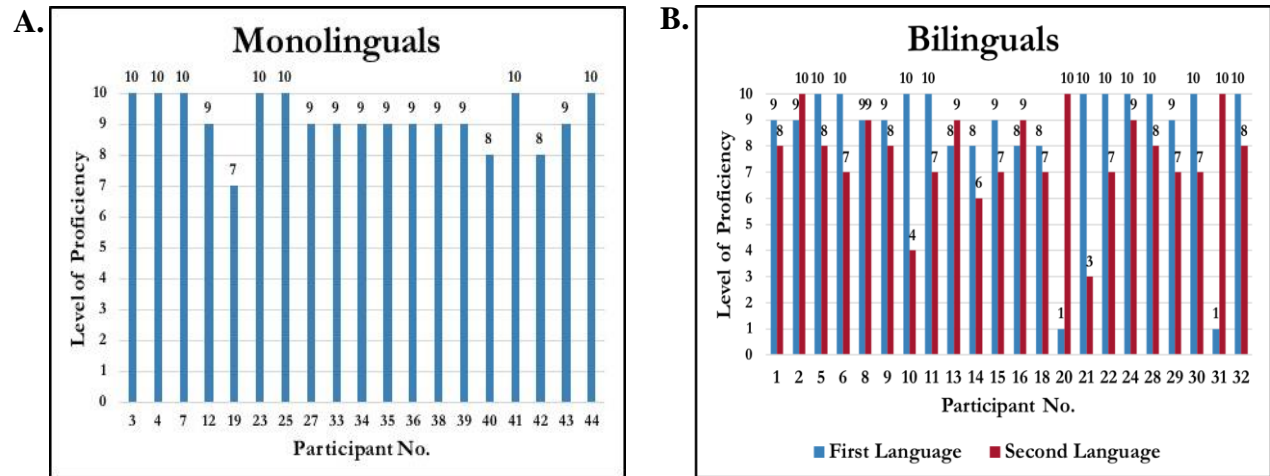
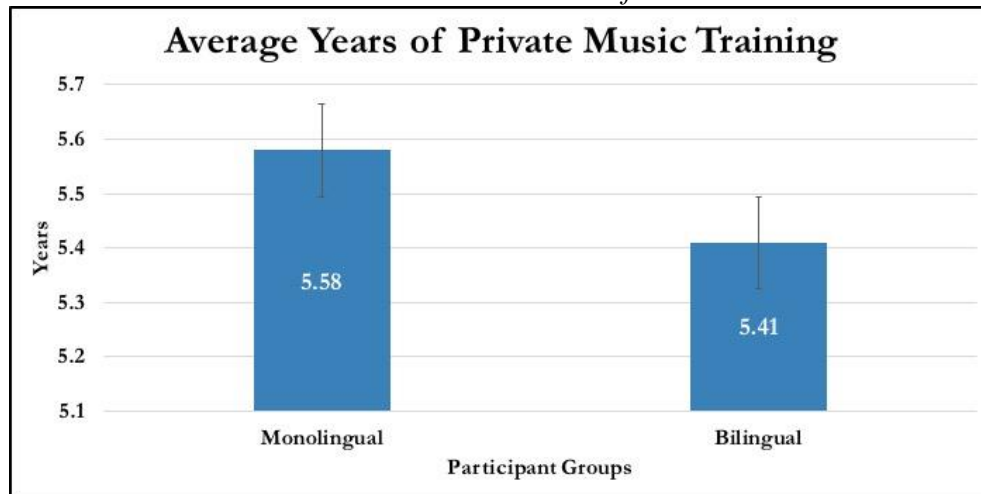


Fig. 6. Mean years of private music training between monolinguals and bilinguals

Note: The error bars at each bar indicate standard errors of means.



II. Experimental Procedures

Participants were tested individually in a quiet room. The entire experiment lasted about an hour. Verbal and written instructions were given in English prior to the questionnaires and each cognitive task. The experiment was given in this order for all participants: 1) LEAP-Q 2) Music Background Questionnaire 3) Cognitive Tasks.

Four cognitive tasks was administered using the PsyToolkit (Stoet, 2010 & 2017) with Google Chrome browser (Version 72.0.3626.109; Official Build; 64-bit) on a Dell (model: XPS13 9333) laptop. The PsyToolkit is a free, online software used for programming

psychology experiments based on Linux operating systems though it can be run on all computers within the browser. It offers multiple pre-programmed cognitive tasks that can be modified according to researchers' needs. Despite only being developed in the past decade, several studies have selected this software for cognitive research (Guo et al., 2019; Li et al., 2019; Pot et al., 2018).

The cognitive tasks were given in this order for all participants: 1) Simon Task 2) Stroop Task 3) Letter-Number (Alternate Runs) Switching Task 4) Color-Shape (Cued) Switching Task. For each cognitive task, participants were instructed to complete a set of up to 20 practice trials. Only those who met the minimum accuracy criteria of 80% were eligible to complete the official trials and immediate feedback on accuracy was only given for the practice trials. Data on the type of trials, reaction time and accuracy for all cognitive tasks were tracked and recorded.

Simon Task

This Simon task, based on the task developed by Simon & Ruddell (1967), was administered as a measure of inhibition skills. It consisted of 20 practice trials and 40 official trials in total. The entire task took approximately 5 minutes to finish. For every trial of the Simon task, participants were presented with a fixation cross presented for 300-ms, followed by an immediate stimulus onset presented for 5 seconds. Participants had to respond to the stimulus within 5 seconds. For each trial, a written word printed in capital letters, "left" or "right", was presented on the right or left side of the fixation cross and of the screen. The participants started each set of practice and official trials by pressing the spacebar on the keyboard. They were instructed to respond to the stimuli word regardless of its position on the right or left side of the screen by pressing the letter "A" for the word "left" and the letter "L" for the word "right" on the keyboard. Trials were classified into two categories: compatible and incompatible trials (Refer to

Figure 7). Compatible trials were defined as when the stimuli word appeared on the corresponding side of the screen (e.g., “left” word on left side of the screen) while incompatible trials were defined as when the stimuli word appeared on the non-corresponding side of the screen (e.g., “left” word on right side of the screen). The order of appearance of the stimuli and the location of the stimuli were randomized in each trial for every participant. Type of trials, accuracy and reaction time data were tracked and recorded.



Fig. 7. Example of a compatible and incompatible trial in the Simon task

Stroop Task

The Stroop task, a version of the standard color-naming paradigm, was administered as a measure of inhibition skills (Stroop, 1935). It consisted of 20 practice trials and 60 official trials in total. The entire task took approximately 10 minutes to finish. For every trial of the Stroop task, participants were first presented with a blank screen for 500-ms and a fixation cross for 200-ms. A blank screen was then presented for 100-ms followed by an immediate stimulus onset presented for 2 seconds. Participants had to then respond to the stimulus within 2 seconds. The stimuli were the colored names *red*, *green*, *blue* and *yellow* printed in capital letters presented in the center of the screen. The printed color name and the color of the word for each trial were randomly alternated with a total of 16 combinations. Participants started each set of practice and official trials by pressing the spacebar on the keyboard. They were instructed to respond to the color of the word regardless of the printed color name by pressing the letter “R” for *red*, “G” for *green*, “B” for *blue* and “Y” for *yellow* on the keyboard. Similar to the Simon task, trials were also classified into two categories: compatible and incompatible trials (Refer to Figure 8).

Compatible trials were defined as when the stimuli color name corresponds to the color of the word (e.g., the word “red” in RED ink) while incompatible trials were defined as when the stimuli color name does not correspond to the color of the word (e.g., the word “red” in BLUE ink). The order of appearance of the stimuli were randomized in each trial for every participant. Type of trials, accuracy and reaction time data were tracked and recorded.



Fig. 8. Example of a compatible and incompatible trial in the Stroop task

Letter-Number Switching Task

The letter-number switching task was administered as a measure of shifting skills. It consisted of 3 blocks of 20 practice trials and 40 official trials in total. The first block of trials contained a pure letter task, the second block of trials contained a pure number task and the last block of trials contained a mixed letter-number switching task. The entire task took approximately 15 minutes to finish. For every trial of this task, participants were first presented a yellow 2-by-2 grid for 150-ms followed by immediate stimulus onset of a letter-number combination presented in one of the grids for 5 seconds. Participants had to then respond to the stimulus within 5 seconds. A letter-number combination would only appear one at a time in one of the grids for each trial. Participants started each set of practice and official trials by pressing the spacebar on the keyboard. They were instructed to respond to each trial by first determining the type of task via the location of the letter-number combinations. If a letter-number combination (e.g., E8) showed up on the top row of the grid, it would be a letter task. If the combination showed up on the bottom row of the grid, it would be a number task. For the letter task, they were instructed to press “B” for consonants (e.g., G, K, M, R) and “N” for vowels

(e.g., A, E, I, U) on the keyboard. For the number task, they were instructed to press “B” for odd numbers (e.g., 3, 5, 7, 9) and “N” for even numbers (E.g., 2, 4, 6, 8) on the keyboard. Trials were classified into two categories: repeat and switch trials. Repeat trials were defined as when the type of task in the previous trial was being repeated in the following trial while switch trials were defined as when the type of task in the previous trial was being switched to the other type of task in the following trial (Refer to Figure 9). The appearance of the letter-number combinations alternated in a fixed sequence in the clockwise direction, beginning from the top-left grid and ending at the bottom-left grid, before the sequence is being repeated again. Participants were not informed of the fixed sequence of this task. Type of trials, accuracy and reaction time data were tracked and recorded.

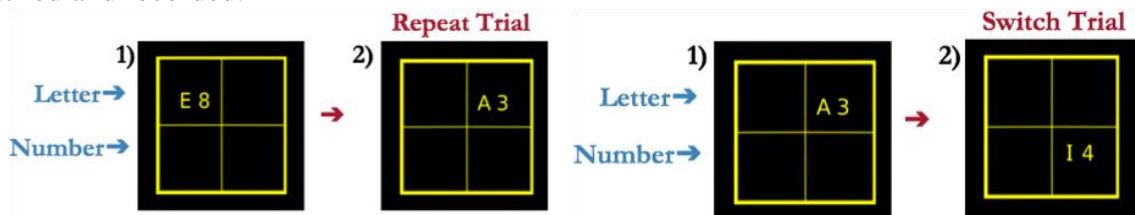


Fig. 9. Example of a repeat and switch trial in the letter-number switching task

Color-Shape Switching (Cued) Task

A color-shape switching (cued) task, a similar version used by previous bilingual studies (Paap & Greenberg, 2013; Prior & Gollan, 2011; Prior & MacWhinney, 2009), was administered as a measure of shifting skills. This task consisted of 20 practice trials and 40 official trials in total. The whole task took approximately 10 minutes to finish. For every trial of this task, participants were first presented with a fixation cross for 150-ms followed by a blank screen for 500-ms. Subsequently, an immediate onset of a cue (e.g., shape, color) was presented followed by a stimulus onset presented for 2 seconds. Participants had to then respond to the stimulus within 2 seconds. Participants started each set of practice and official trials by pressing the spacebar on the keyboard. According to the cue presented in each trial, participants were

informed of the type of task (e.g., color, shape) they should respond to. For the color task, participants were instructed to press “B” for *yellow* and “N” for *blue* on the keyboard. For the shape task, they were instructed to press “B” for *circle* and “N” for *rectangle* on the keyboard. Similar to the letter-number switching task, trials were classified into two categories: repeat and switch trials (Refer to Figure 10). The cue and order of appearance of the stimuli were randomized in each trial for every participant. Type of trials, accuracy and reaction time data were tracked and recorded.

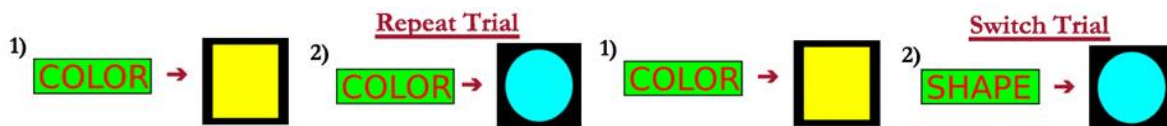


Fig. 10. Example of a repeat and switch trial in the color-shape switching (cued) task

III. Data Analysis

Data from the Simon, Stroop, letter-number switching and color-shape switching (cued) task were collected and analyzed using Python 3.7 for data processing by panda, Excel for data visualization and SPSS Statistics software (Version 19, IBM Corp.) for statistical analysis. From all cognitive tasks, two dependent variables were extracted: reaction time and percentage accuracy. Only correct responses were used in the data analysis.

Simon Task

In the Simon task, the reaction time of the participants' responses in each trial was determined by the amount of time participants took to press the key to respond to each trial. The mean reaction time for each participant was then calculated by looking at the reaction time across all correct official trials. The accuracy of the participants' responses in each trial was determined by whether participants pressed the key for the correct response to each trial. The mean percentage accuracy for each participant was then calculated by looking at the percentage accuracy across all correct official trials. Thereafter, data on reaction time and percentage

accuracy were processed as two separate groups: monolinguals and bilinguals across two trial types: compatible and incompatible trials using Python 3.7. Within these two groups and trial types, the mean, standard deviation and standard error of both reaction time and percentage accuracy were calculated using the SPSS Statistics software. During the data processing, two participants were identified as an outlier. Their data were therefore discarded. Four participants' data were unable to be recorded and saved due to technical difficulties. Data on reaction time and percentage accuracy were recorded and saved individually for each participant. There was 16 monolinguals and 19 bilinguals in the final statistical comparison. A two-way mixed analysis of variance (ANOVA) was used to test our hypothesis that bilinguals would outperform monolinguals in a cognitive task measuring inhibition skills.

Stroop Task

The data processing method used in the Simon task to process and obtain the reaction time and percentage accuracy data was also used as part of the Stroop task's data analysis. Data on reaction time and percentage accuracy were then processed as two separate groups: monolinguals and bilinguals across two trial types: compatible and incompatible trials using Python 3.7. Within these two groups and trial types, the mean, standard deviation and standard error of both reaction time and percentage accuracy were calculated using the SPSS Statistics software. During the data processing, three participants were identified as an outlier and their data were therefore discarded. As previously mentioned, participants who scored a percentage accuracy of lower than 80% in the practice trials were ineligible to complete the official trials and their data would be discarded. Two participants' data were discarded based on this criterion. Data on reaction time and percentage accuracy were recorded and saved individually for each participant. There was 16 monolinguals and 20 bilinguals in the final statistical comparison. A two-way

mixed ANOVA was used to test our hypothesis that bilinguals would have a cognitive advantage in completing a task measuring inhibition skills compared to monolinguals.

Letter-Number Switching Task

In the letter-number switching task, the reaction time of the participant's responses in each trial was determined by the amount of time participants took to press the key to respond to each trial. The mean reaction time for each participant was then calculated by looking at the reaction time across all correct official trials. The accuracy of the participants' responses in each trial was determined by whether participants pressed the key for the correct response to each trial. The mean percentage accuracy for each participant was then calculated by looking at the percentage accuracy across all correct official trials. Thereafter, data on reaction time and percentage accuracy were processed as two separate groups: monolinguals and bilinguals across two trial types: repeat and switch trials using Python 3.7. Within these two groups and trial types, the mean, standard deviation and standard error of both reaction time and percentage accuracy were calculated using the SPSS Statistics software. During the data processing, four participants, one in each of the participant group, were identified as an outlier. Their data were therefore discarded. One participants' data was unable to be recorded and saved due to technical difficulties. Data on reaction time and percentage accuracy were recorded and saved individually for each participant. There was 17 monolinguals and 19 bilinguals in the final statistical comparison. A two-way mixed ANOVA was used to test our hypothesis that bilinguals would perform better than monolinguals in a cognitive task measuring shifting skills.

Color-Shape Switching (Cued) Task

The data processing method used in the letter-number switching task to process and obtain the reaction time and percentage accuracy data was also used as part of the color-shape switching (cued) task's data analysis. Data on reaction time and percentage accuracy were then processed as two separate groups: monolinguals and bilinguals across two trial types: repeat and switch trials using Python 3.7. Within these two groups and trial types, the mean, standard deviation and standard error of both reaction time and percentage accuracy were calculated using the SPSS Statistics software. During the data processing, two participants were identified as an outlier and their data were therefore discarded. As previously mentioned, participants who scored a percentage accuracy of lower than 80% in the practice trials were ineligible to complete the official trials and their data would be discarded. Two participants' data were discarded based on this criterion. One participants' data was unable to be recorded and saved due to technical difficulties. Data on reaction time and percentage accuracy were recorded and saved individually for each participant. There was 15 monolinguals and 21 bilinguals in the final statistical comparison. A two-way mixed ANOVA was used to test our hypothesis that bilinguals would have a cognitive advantage in completing a task measuring shifting skills compared to monolinguals.

Results

Simon Task

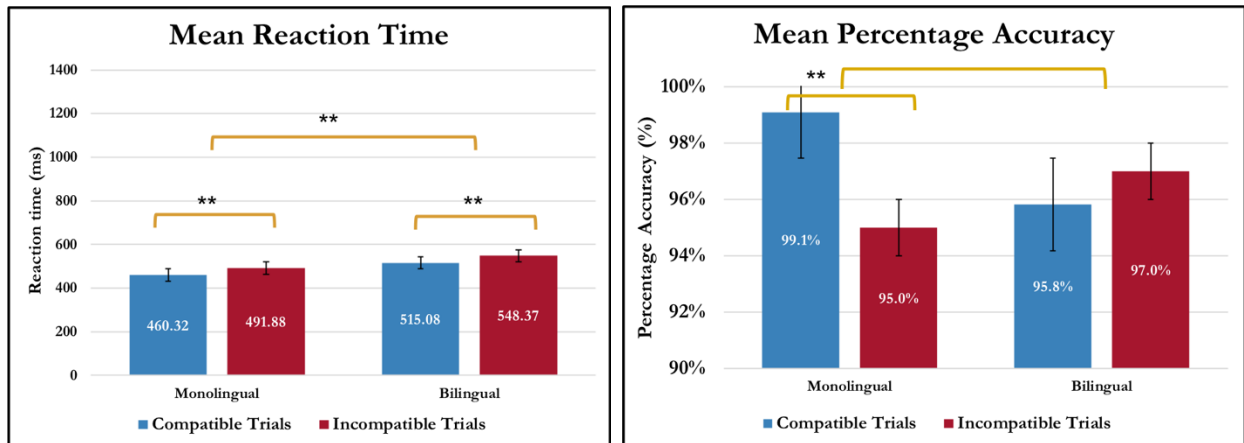


Fig. 11. Mean reaction time and percentage accuracy for Simon task between monolinguals and bilinguals across type of trials (compatible vs. incompatible)

Note: The error bars at each bar indicate standard errors of means

Figure 11 shows the data comparison computed by using the mean reaction time and percentage accuracy of the Simon task and separating the data into two groups: monolinguals and bilinguals across two types of trials: compatible and incompatible. For both tasks, a two-way mixed ANOVA was conducted to evaluate the hypothesis that bilinguals have a cognitive advantage on monolinguals in inhibition skills. The primary dependent variables were the mean reaction time and mean percentage accuracy.

For reaction time, the within-subject factors were type of trials with two levels (compatible and incompatible) and the between-subjects factors were the participant groups with two levels (monolinguals and bilinguals). The Trial Type main effect and Trial Type X Participant Group interaction effect were tested using the multivariate criterion of Wilks's lambda (Λ). The Trial Type main effect was significant, $\Lambda = .65$, $F(1, 33) = 17.86$, $p < .001$, $\eta^2 = .351$. Both groups required more reaction time in responding to incompatible trials (Monolingual: $M = 491.88$, $SD = 36.2$; Bilinguals: $M = 548.37$, $SD = 75.3$) than compatible trials (Monolingual: $M = 460.31$,

SD = 32.4; Bilinguals: M = 515.08, SD = 55.7). The univariate test associated with the Participant Group main effect was also significant, $F(1, 33) = 11.11$, $p = 0.002$, $\eta^2 = .252$. The results showed that on average, bilinguals (compatible: M = 515.08, SD = 55.7; incompatible: M = 548.37, SD = 75.3) required more reaction time than monolinguals (compatible: M = 460.31, SD = 32.4; incompatible: M = 491.88, SD = 36.2) in responding to both type of trials. The Trial Type X Participant Group interaction effect was however insignificant, $\Lambda = 1.0$, $F(1, 33) = 0.01$, $p = 0.912$, $\eta^2 < .001$. This indicated that there were no statistical differences between the two groups across trial types.

For percentage accuracy, the within-subjects factors were type of trials with two levels (compatible and incompatible) and the between-subjects factors were the participant groups with two levels (monolinguals and bilinguals). The Trial Type main effect and Trial Type X Participant Group interaction effect were tested using the multivariate criterion of Wilks's lambda (Λ). The Trial Type main effect was insignificant, $\Lambda = .93$, $F(1, 33) = 2.37$, $p = 0.133$, $\eta^2 = .067$. The Participant Group main effect was also insignificant, $F(1, 33) = 0.384$, $p = 0.540$, $\eta^2 = .012$. However, there was a significant Trial Type X Participant Group interaction effect, $\Lambda = .81$, $F(1, 33) = 7.96$, $p = 0.008$, $\eta^2 = .194$. Bilinguals (M = 97.0%, SD = 3.5%) were more accurate in responding to incompatible trials than monolinguals (M = 95.1%, SD = 5.6%). However, bilinguals (M = 95.8%, SD = 5.1%) were less accurate in responding to compatible trials than monolinguals (M = 99.1%, SD = 2.0%). An independent t-test was therefore conducted for post-hoc analysis to examine any significant percentage accuracy differences between compatible and incompatible trials in each participant group. The test revealed a statistical significance, $t(1, 33) = -2.82$, $p = 0.008$. The results showed that the difference between trial types in monolinguals (M = 4.0%, SD = 5.8%) was greater than in bilinguals (M =

1.2%, SD = 5.0%). The 95% confidence interval for the difference in trial types ranged from -0.089 to -0.014.

Stroop Task

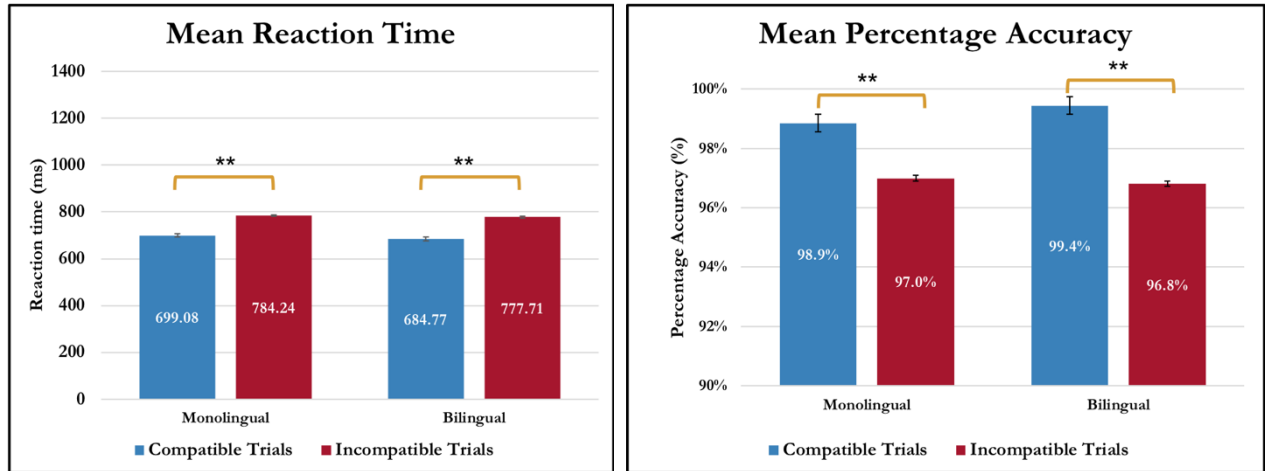


Fig. 12. Mean reaction time and percentage accuracy for Stroop task between monolinguals and bilinguals across type of trials (compatible vs. incompatible)

Note: The error bars at each bar indicate standard errors of means.

Figure 12 shows the data comparison computed by using the mean reaction time and percentage accuracy of the Stroop task and separating the data into two groups: monolinguals and bilinguals across two types of trials: compatible and incompatible. For both tasks, a two-way mixed ANOVA was conducted to evaluate the hypothesis that bilinguals have a cognitive advantage on monolinguals in inhibition skills. The primary dependent variables were the mean reaction time and mean percentage accuracy.

For reaction time, the within-subjects factors were type of trials with two levels (compatible and incompatible) and the between-subjects factors were the participant groups with two levels (monolinguals and bilinguals). The Trial Type main effect and Trial Type X Participant Group interaction effect were tested using the multivariate criterion of Wilks's lambda (Λ). The Trial Type main effect was significant, $\Lambda = .52$, $F(1, 34) = 32.07$, $p < .001$, $\eta^2 = .485$. Both groups required more reaction time in responding to incompatible trials (Monolingual: $M = 784.24$, SD

= 107.1; Bilinguals: $M = 777.71$, $SD = 102.1$) than compatible trials (Monolingual: $M = 699.1$, $SD = 131.2$; Bilinguals: $M = 684.8$, $SD = 100.1$). The Trial Type X Participant Group interaction effect was however insignificant, $\Lambda = 1.0$, $F(1, 34) = 0.06$, $p = 0.806$, $\eta^2 = .002$. The univariate test associated with the Participant Group main effect was also insignificant, $F(1, 34) = 0.098$, $p = 0.756$, $\eta^2 = .012$, indicating no statistical differences between monolinguals and bilinguals in reaction time.

For percentage accuracy, the within-subjects factors were type of trials with two levels (compatible and incompatible) and the between-subjects factors were the participant groups with two levels (monolinguals and bilinguals). The Trial Type main effect and Trial Type X Participant Group interaction effect were tested using the multivariate criterion of Wilks's lambda (Λ). The Trial Type main effect was significant, $\Lambda = .80$, $F(1, 34) = 8.58$, $p = 0.006$, $\eta^2 = .201$. Both groups were more accurate in responding to compatible trials (Monolingual: $M = 98.9\%$, $SD = 3.2\%$; Bilinguals: $M = 99.4\%$, $SD = 1.7\%$) than incompatible trials (Monolingual: $M = 97.0\%$, $SD = 3.7\%$; Bilinguals: $M = 96.8\%$, $SD = 3.8\%$). The Trial Type X Participant Group interaction effect was however insignificant, $\Lambda = .99$, $F(1, 34) = 0.26$, $p = 0.615$, $\eta^2 = .008$, indicating no statistical differences between participant groups across trial types in percentage accuracy. The univariate test associated with the Participant Group main effect was also insignificant, $F(1, 34) = 0.074$, $p = 0.787$, $\eta^2 = .002$, indicating no statistical differences between participant groups in percentage accuracy.

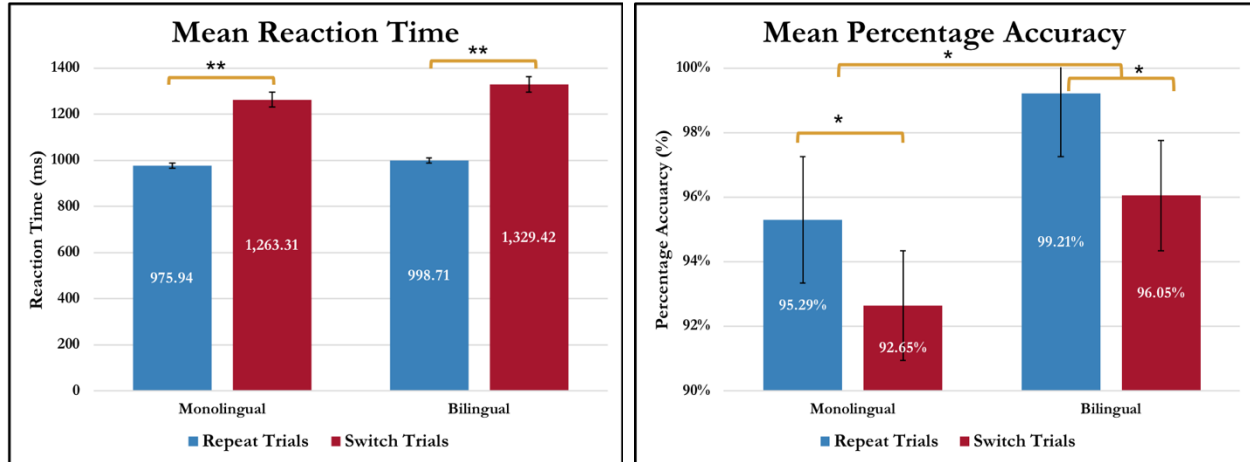
Letter-Number Switching Task

Fig. 13. Mean reaction time and percentage accuracy for Letter-Number Switching task between monolinguals and bilinguals across type of trials (repeat vs. switch)

Note: The error bars at each bar indicate standard errors of means.

Figure 13 shows the data comparison computed by using the mean reaction time and percentage accuracy of the Letter-Number Switching task and separating the data into two groups: monolinguals and bilinguals across two types of trials: repeat and switch. For both tasks, a two-way mixed ANOVA was conducted to evaluate the hypothesis that bilinguals have a cognitive advantage on monolinguals in shifting skills. The primary dependent variables were the mean reaction time and mean percentage accuracy.

For reaction time, the within-subjects factors were type of trials with two levels (repeat and switch) and the between-subjects factors were the participant groups with two levels (monolinguals and bilinguals). The Trial Type main effect and Trial Type X Participant Group interaction effect were tested using the multivariate criterion of Wilks's lambda (Λ). The Trial Type main effect was significant, $\Lambda = .45$, $F(1, 34) = 42.92$, $p < .001$, $\eta^2 = .558$. Both groups required more reaction time in responding to switch trials (Monolingual: $M = 1263.31$, $SD = 289.84$; Bilinguals: $M = 1329.42$, $SD = 326.84$) than repeat trials (Monolingual: $M = 975.94$, $SD = 152.43$; Bilinguals: $M = 998.71$, $SD = 171.46$). The Trial Type X Participant Group interaction

effect was however insignificant, $\Lambda = 1.0$, $F(1, 34) = 0.211$, $p = 0.649$, $\eta^2 = .006$, indicating no statistical differences between participant groups across trial types in reaction time. The univariate test associated with the Participant Group main effect was also insignificant, $F(1, 34) = 0.429$, $p = 0.517$, $\eta^2 = .012$, indicating no statistical differences between participant groups in reaction time.

For percentage accuracy, the within-subjects factors were type of trials with two levels (compatible and incompatible) and the between-subjects factors were the participant groups with two levels (monolinguals and bilinguals). The Trial Type main effect and Trial Type X Participant Group interaction effect were tested using the multivariate criterion of Wilks's lambda (Λ). The Trial Type main effect was significant, $\Lambda = .80$, $F(1, 34) = 7.52$, $p = 0.01$, $\eta^2 = .181$. Both groups were more accurate in responding to repeat trials (Monolingual: $M = 95.3\%$, $SD = 7.6\%$; Bilinguals: $M = 99.2\%$, $SD = 1.9\%$) than switch trials (Monolingual: $M = 92.7\%$, $SD = 8.3\%$; Bilinguals: $M = 96.1\%$, $SD = 5.7\%$). The univariate test associated with the Participant Group main effect was also significant, $F(1, 34) = 4.113$, $p = 0.05$, $\eta^2 = .108$. On average, bilinguals (repeat: $M = 99.2\%$, $SD = 1.9\%$; switch: $M = 96.1\%$, $SD = 5.7\%$) were more accurate than monolinguals (repeat: $M = 95.3\%$, $SD = 7.6\%$; switch: $M = 92.7\%$, $SD = 8.3\%$) in responding to both types of trials. The Trial Type X Participant Group interaction effect was however insignificant, $\Lambda = 1.0$, $F(1, 34) = 0.058$, $p = 0.811$, $\eta^2 = .002$, indicating no statistical differences between participant groups across trial types in percentage accuracy.

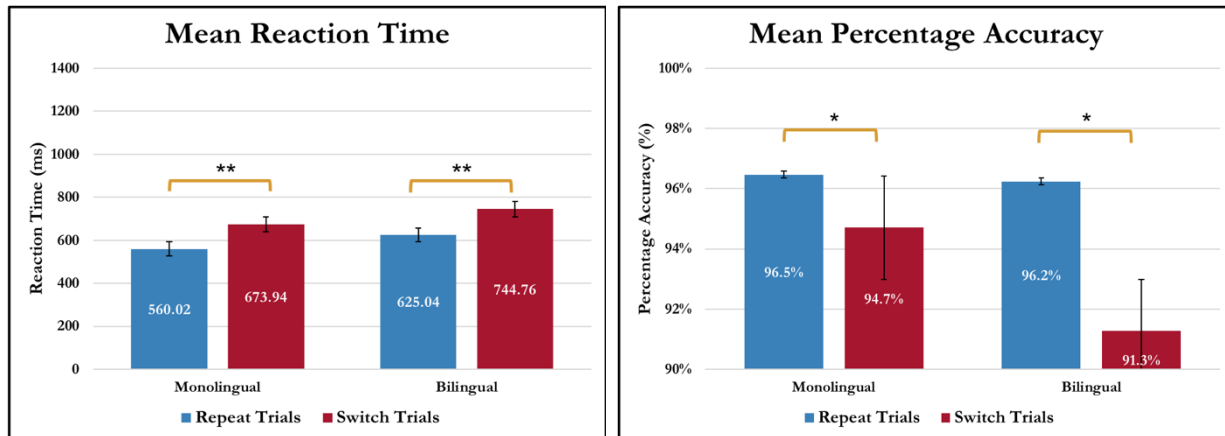
Color-Shape Switching (Cued) Task

Fig. 14. Mean reaction time and percentage accuracy for Color-Shape Switching (Cued) task between monolinguals and bilinguals across type of trials (repeat vs. switch)

Note: The error bars at each bar indicate standard errors of means.

Figure 14 shows the data comparison computed by using the mean reaction time and percentage accuracy of the color-shape switching (cued) task and separating the data into two groups: monolinguals and bilinguals across two types of trials: repeat and switch. For both tasks, a two-way mixed ANOVA was conducted to evaluate the hypothesis that bilinguals have a cognitive advantage on monolinguals in shifting skills. The primary dependent variables were the mean reaction time and mean percentage accuracy.

For reaction time, the within-subjects factors were type of trials with two levels (repeat and switch) and the between-subjects factors were the participant groups with two levels (monolinguals and bilinguals). The Trial Type main effect and Trial Type X Participant Group interaction effect were tested using the multivariate criterion of Wilks's lambda (Λ). The Trial Type main effect was significant, $\Lambda = .42$, $F(1, 33) = 46.22$, $p < .001$, $\eta^2 = .583$. Both groups required more reaction time in responding to switch trials (Monolingual: $M = 673.94$, $SD = 195.24$; Bilinguals: $M = 744.76$, $SD = 147.34$) than repeat trials (Monolingual: $M = 565.82$, $SD = 134.28$; Bilinguals: $M = 625.04$, $SD = 98.84$). The Trial Type X Participant Group interaction

effect was however insignificant, $\Lambda = 1.0$, $F(1, 33) = 0.01$, $p = 0.928$, $\eta^2 < .001$, indicating no statistical differences between participant groups across trial types in reaction time. The univariate test associated with the Participant Group main effect was also insignificant, $F(1, 33) = 1.566$, $p = 0.220$, $\eta^2 = .045$, indicating no statistical differences between monolinguals and bilinguals in reaction time.

For percentage accuracy, the within-subjects factors were type of trials with two levels (compatible and incompatible) and the between-subjects factors were the participant groups with two levels (monolinguals and bilinguals). The Trial Type main effect and Trial Type X Participant Group interaction effect were tested using the multivariate criterion of Wilks's lambda (Λ). The Trial Type main effect was significant, $\Lambda = .89$, $F(1, 33) = 46.22$, $p < .001$, $\eta^2 = .583$. Both groups required more reaction time in responding to switch trials (Monolingual: $M = 673.94$, $SD = 195.24$; Bilinguals: $M = 744.76$, $SD = 147.34$) than repeat trials (Monolingual: $M = 565.82$, $SD = 134.28$; Bilinguals: $M = 625.04$, $SD = 98.84$). The univariate test associated with the Participant Group main effect was however insignificant, $F(1, 34) = 3.606$, $p = 0.066$, $\eta^2 = .096$, indicating no statistical differences between monolinguals and bilinguals in percentage accuracy. The Trial Type X Participant Group interaction effect was also insignificant, $\Lambda = 0.92$, $F(1, 34) = 2.93$, $p = 0.096$, $\eta^2 = .079$, indicating no statistical differences between participant groups across trial types in percentage accuracy.

Discussion

Our current study was designed to explore the effects of bilingualism on executive function skills, specifically inhibition and shifting skills. We hypothesized that the group of bilinguals would outperform the group of monolinguals on the cognitive tasks measuring inhibition and shifting skills administered in this study. The current study failed to reject the null hypothesis

given that the cognitive task performances that were analyzed using reaction time and percentage accuracy between the two groups across trials were inconsistent across tasks.

Results with the measure of reaction time revealed that both participant groups required additional time to respond to incompatible and switch trials than compatible and repeat trials in all tasks. However, all tasks except the Simon task revealed no significant main effect or interaction effect between participant groups across trials. Most importantly, performance results from the Simon task showed contrasting findings compared to previous studies suggesting a bilingual advantage (Bialystok et al., 2004; Bialystok et al., 2008; Marton et al., 2017; Woumans et al., 2015). In particular, monolinguals outperformed bilinguals in both types of trials in the Simon task in our study.

In terms of percentage accuracy, results showed that both participant groups had higher accuracy scores in compatible or repeat trials than incompatible or switch trials in all tasks except the Simon task. A significant interaction effect was also found in the Simon task, indicating that the difference in accuracy between the two types of trials were larger in monolinguals than in bilinguals. In addition, bilinguals achieved significantly higher percentage accuracy scores than monolinguals in the letter-number switching task.

Similar to previous studies (Bialystok et al., 2004; Bialystok et al., 2008; Desjardins & Fernandez, 2018; Kousaie et al., 2014; Marton et al., 2017; Moradzadeh et al., 2015; Paap & Greenberg, 2013; Prior & Gollan, 2011; Prior & MacWhinney, 2010; Scaltritti, 2017; Seçer, 2016; Woumans et al., 2015; Wiseheart et al., 2016), the current study selected reaction time as our primary dependent measure. Moreover, our study also selected similar tasks in attempt to replicate results found in previous studies examining inhibition and shifting skills in bilinguals. This included the Simon task (Bialystok et al., 2004; Bialystok et al., 2008; Desjardins &

Fernandez, 2018; Kousaie et al., 2014; Paap & Greenberg, 2013; Woumans et al., 2015), Stroop task (Bialystok et al., 2008; Kousaie et al., 2015) and the color-shape switching (cued) task (Paap & Greenberg., 2013; Prior & Gollan., 2011; Prior & MacWhinney., 2010).

Despite the similarities, our current study also differed from previous studies in important ways. Firstly, given that previous research has suggested that music training could enhance executive function skills (Bialystok & DePape, 2009; DePape, 2007; Moradzedeh et al., 2015), we anticipated that the additional control on music background would help avoid music background becoming a confounding variable and would subsequently help us obtain more reliable results.

Secondly, though past studies attempted to control for the age of second language acquisition, most studies (Bialystok et al., 2008; Desjardins & Fernandez, 2018; Kousaie et al., 2014; Marton et al., 2017; Paap & Greenberg, 2013; Prior & Gollan, 2011; Scaltritti et al., 2017; Seçer, 2016; Wiseheart et al., 2016; Woumans et al., 2015) often used self-reported data obtained from the language background questionnaires instead of controlling this variable at the beginning of recruitment by implementing an inclusion criteria. Furthermore, previous research has shown that the differences in the age of second language acquisition (e.g., from birth or at the age of 3) may have an impact on the effects of bilingualism on cognitive control in children (Struys et al., 2015). If this variable resulted in task performance differences in Struys and colleagues' (2015) study with children, it could also potentially impact the results of this study with adults. Therefore, in order to control for the age of second language acquisition, the current study implemented an inclusion criteria where bilingual participants had to acquire their second language before the age of five.

Thirdly, the format of our Simon task was also different from previous studies. Specifically, although our Simon task was similar to the original Simon task (Simon & Ruddell, 1967), most of the Simon tasks in past bilingual studies used stimuli such as arrows (Bialystok et al., 2008; Kousaie et al., 2014) or colored figures (dots – Woumans et al., 2015; squares – Bialystok et al., 2004; Desjardins & Fernandez, 2018). In addition, we also administered an additional letter-number switching task, a task that is less frequently used in bilingual studies, to examine shifting skills.

Lastly, accuracy was often minimally discussed in previous studies. In particular, accuracy was often examined to omit outliers (Paap & Greenberg, 2013; Prior & Gollan, 2011) or analyze error rates (Bialystok et al., 2004; Bialystok et al., 2008; Scaltritti et al., 2017; Wiseheart et al., 2016; Woumans et al., 2015). However, percentage accuracy was used as a primary dependent measure in our study.

Though the current study replicated and further refined the experimental design in reference to previous studies, our results still revealed inconsistent findings with most of the evidence indicating no relation between bilingualism and executive function skills. Therefore, we discussed the following factors to help interpret our current results.

In the Simon task, written words (e.g., “right”, “left”) were used as stimuli, which indicated that all participants would have to process an English word prior to responding to each trial. Similarly, in the Stroop and color-shape switching (cued) task, participants also had to process English words as a stimulus (e.g., “green”) and as a cue (e.g., “color”) respectively. Wang and his colleagues (2016) conducted a study examining word recognition speed of bilinguals in the Stroop task. Their study revealed that low-proficient Chinese-English bilinguals had weaker inhibition control and were slower at recognizing English words in the Stroop task compared to

the more equally proficient bilinguals. Given that unequal proficiency levels in speaking were found in the current study's bilingual group (Refer to Figure 3), we suggest that the bilingual participants in this study could be unbalanced bilinguals. If that is the case, the reduced word processing speeds in these unbalanced bilinguals may have attributed to the reaction time differences between groups in the Simon task. In addition, the effects of the bilingual advantage and reduced word processing speeds could have potentially been canceled out and thus resulted in the null results obtained in the Stroop and color-shape switching (cued) task. Therefore, we propose that the potential reduced word processing speed in unbalanced bilinguals could have affected the results obtained in these tasks and the use of linguistic information or stimuli in cognitive tasks should be taken into consideration in future bilingual studies.

Additionally, as previously explained, the letter-number switching task consisted of a continuous sequential pattern that was not made explicit to participants. However, we suggest that the predictable pattern in this task may have triggered the activation of implicit learning, allowing the participants to implicitly learn of the task's sequential pattern, thus improving task performance. Specifically, past studies have indicated that bilinguals may have better implicit learning skills than monolinguals in word learning (Marton et al., 2014; Escudero et al., 2016; Onni et al., 2018). Given the evidence shown for enhanced implicit learning skills in word learning, bilinguals may potentially also have similar enhanced skills in pattern learning. Therefore, we suggest that implicit learning skills could have affected the results obtained in the letter-number switching task and future studies should have better control of this testing aspect.

Besides that, it is important to note that explicit explanations on the definition of a consonant and a vowel were more frequently given to bilinguals than monolinguals during testing. This was to help them differentiate and identify the two types of letters. In Bialystok and colleagues'

(2004) study, they presented evidence indicating that bilinguals tend to be weaker in lexical retrieval than monolinguals. Therefore, the fact that bilinguals had to retrieve the meanings of the words, “consonant” and “vowel”, and identify between the two types of letters during testing suggests that the linguistic factor may have also impacted the bilinguals’ performance in the letter-number switching task. Thus, future bilingual studies should also consider the type of linguistic information that is required to be understood receptively in cognitive tasks.

Our current study is limited by the lack of information on first and second language use in bilinguals. Although our study has attempted to control for the percentage of language exposure (see Figure 2) and proficiency levels (see Figure 3-5), it is unknown as to whether the bilingual participants were consistently using both languages daily. As Bialystok (2017) has emphasized, the extensive use of language is what activates the brain in the linguistic and cognitive domains in order to generalize the effects of bilingualism beyond language to executive function skills. Moreover, the results from Xie and colleagues’ (2014) study also suggested that language-switching frequency and second language use may be more important as a contributing factor to enhanced shifting skills than second language proficiency. Therefore, the frequency and amount of first and second language use in bilinguals would be crucial to investigate as an additional variable. For that reason, we suggest that future studies should include a more comprehensive language background questionnaire to obtain additional information on each participant’s first and second language use. This would allow us to obtain a better picture on the extent of the effects of bilingualism on executive function skills.

Conclusion

In conclusion, results from the present study offered insufficient support to the hypothesis that bilinguals would perform better than monolinguals in cognitive tasks measuring inhibition

and shifting skills. Given that the current study implemented a similar yet refined experimental design compared to previous studies, our results added to the literature by providing data consistent with no cognitive advantage in Mandarin-English bilinguals using computer-based cognitive tasks to measure executive function skills. Future investigations should consider including a comprehensive language background questionnaire and modified cognitive tasks with controls for linguistic information and predictable patterns to have a better understanding of the relation between bilingualism and executive function skills.

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