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BILINGUALISM ACROSS THE ADULT LIFE-SPAN:

AGE AND LANGUAGE USAGE ARE CONTINUOUS VARIABLES

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DEDICATION

To David T. Burkert who, in addition to being an amazing husband and my Google, is my favorite copyeditor. A mis padres, Maite Zudaire Arana y Jose Maria Incera Martinez, que me enseñaron a volar lejos del nido, pero teniendo siempre un lugar seguro al que volver. To Dr. Conor T. M^{c}Lennan for being the best advisor del mundo, not only because it says so on his coffee mug (and beer stein!), but because his mentorship has helped me to develop in ways I did not know were possible. I also want to thank the rest of my dissertation committee members, Dr. Andrew Slifkin, Dr. Philip Allen, and Dr. Phillip Hamrick, for pushing me to my limits while helping me achieve my dreams. To soon-to-be Drs. Donaldson-Misener and Shelton, without whom this journey would not have been half as fun. Furthermore, a very special thank you to the International Women's Club of Hudson, for making the data collection process a fascinating journey with more questions than answers, and to Lisa Canterbury, for her invaluable help recruiting participants. Finally, to the great team of "LRLers" because working together, there is nothing we cannot achieve.

BILINGUALISM ACROSS THE ADULT LIFE-SPAN: AGE AND LANGUAGE USAGE ARE CONTINUOUS VARIABLES

SARA INCERA BURKERT

ABSTRACT

The purpose of this dissertation research was to analyze the effects of bilingualism and age on cognitive function. Specifically, I investigated the impact of bilingualism and age on two measures of executive control. The Stroop task is a measure of response inhibition, and the Flanker task is a measure of attention selection. Participants responded using a computer mouse. The mouse-tracking paradigm allowed me to examine the continuous dynamics of the responses as participants completed each trial. A better understanding of the impact of bilingualism and age on cognitive function has the potential to minimize cognitive decline in older age. The results showed that younger age was associated with better cognitive function in both tasks, but the positive effect of bilingualism was limited to the Stroop task. In response inhibition, the detrimental effect of age can be curtailed by the positive effect of bilingualism. Bilingualism offset approximately 60% of age-related cognitive decline in the current study. These results provide further support for the notion that bilingualism is one way of enhancing some aspects of cognitive function across the lifespan. The present study adds to the literature by studying these effects without dichotomizing bilingualism or age. It is important to measure continuous variables as such; varying degrees of the same construct have the potential to result in different levels of executive function.

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CHAPTER I

INTRODUCTION

The current study is designed to examine the effects of bilingualism and age on cognitive function. According to the Inhibition Deficit Theory (Hasher & Zacks, 1988), younger adults are better than older adults at inhibiting distracting information. According to the Bilingual Advantage Theory (Bialystok, 1999), bilinguals are better at ignoring distracting information than monolinguals, not only in language related tasks but also in non-verbal tasks (Bialystok & Martin, 2004). That is, younger and bilingual participants outperform older and monolingual participants on measures of executive function. It is possible that the effects of bilingualism and age are additive; that bilingualism has a stable positive effect across the entire life-span, and that there is a detrimental effect of aging regardless of level of bilingualism. An alternative possibility is that the effects of bilingualism and age interact with one another; if this is the case the positive impact of being bilingual could be larger in older age.

One novel aspect of the current study is conceptualizing bilingualism and age as continuous variables. I did not assign participants to categories: bilingual or monolingual, younger or older. I included age and bilingualism (language usage) as continuous variables in the statistical analyses. Bilingualism was measured as the percentage of time participants were "currently" and "on average" exposed to each language (from 0% to 50%). Participants who reported being exposed 50% of their time to each of their languages were considered high usage, participants who were exposed less to one language than the other (e.g., 20%-80%) were considered low usage, and monolinguals were rated as 0% bilingual usage. Importantly, by treating bilingualism and age as continuous variables, the research questions are no longer limited to obtaining (or failing to obtain) one or more significant effects. My goal is to better understand if varying degrees of the same construct (bilingualism or age) result in different levels of cognitive function.

Plasticity

In the last few years there has been an increase in publications using cognitive neuroscience to study the aging mind (Reuter-Lorenz & Park, 2010). Mechanisms found at the behavioral level have found support using brain-based methods, and brain-based studies of cognitive aging have broader human neuroscientific implications (Reuter-Lorenz & Park, 2010). Probably one of the most important contributions of this line of research is the increasing support for the concept of plasticity. It has been argued that the impact of bilingualism on executive function (especially in aging) should be reframed as a specific instance of neuroplasticity (Baum & Titone, 2014; Bialystok, 2014). As Reuter-Lorenz and Park (2010, p. 412) state: "From imaging, to animal models, to interventions, brain-based discoveries are revealing that psychological aging results from the combined effects of both

negative and positive plasticity. The capacity for positive plasticity and compensation are proving more prevalent and integral to the aging mind than previously recognized. Human neuroscience and genetic approaches hold great promise for discovering the bases for successful aging and new ways to promote positive plasticity."

A theory of the nature of the neural underpinnings of improved executive function in bilinguals has been proposed (Stocco, Yamasaki, Natalenko, & Prat, 2014). According to Stocco and colleagues, bilingualism trains a gating system in the striatum that flexibly routes information to the prefrontal cortex. These authors summarize the literature that establishes a relationship between fronto-striatal loops, executive function, and bilingualism. Furthermore, these authors argue that the striatal nuclei in the basal ganglia transfers information between cortical regions (Stocco et al., 2014). According to this theory, managing two languages at the same time imposes challenges and stimulates the basal ganglia circuit, in particular the striatum. In the present study, I quantified whether different levels of bilingualism would result in varying degrees of cognitive function (e.g., can bilingualism compensate for deficits due to age?). Bilingualism is one of multiple stimulating activities that can enhance cognitive reserve (Stern, 2002). According to several researchers (e.g., Bialystok, Craik & Freedman, 2007; Guzmán-Vélez & Tranel, 2014) the concept of cognitive reserve could explain how lifelong bilingualism helps maintain higher levels of cognitive function in old age.

Cognitive Reserve

Cognitive reserve is a construct at the forefront of research investigating how to prevent or slow cognitive decline. Stern (2002) defined cognitive reserve as the ability to

use alternate paradigms to approach a problem when the standard approach is no longer operational. According to the cognitive reserve hypothesis the brain is actively attempting to compensate for pathology, either by utilizing the brain networks more efficiently or by recruiting alternative networks (Stern 2002). A crucial idea in this proposal is that the brain of those with higher reserve is not anatomically different, and does not have more synapses, it just processes tasks in a more efficient manner (Stern, 2002).

Cognitive reserve is a mechanism for coping with brain damage that delays the onset of functional dementia (Sterns, 2002). Valenzuela and Sachdev (2006) reviewed data from more than 47,000 individuals and concluded that higher behavioral brain reserve was related to decreased longitudinal cognitive decline. These authors provide support for the idea that the link between behavioral brain reserve and incident dementia is due to fundamentally different cognitive trajectories rather than confounding factors. Furthermore, in a separate meta-analysis, Meng and D'Arcy (2012) studied a wide range of observational studies in diverse settings and concluded that there is robust support for the cognitive reserve hypothesis. Importantly, the cognitive reserve hypothesis opens the door to several opportunities for dementia prevention (Meng & D'Arcy, 2012).

Cognitive reserve builds up from extended experience with stimulating activities, such as speaking two or more languages. Many engaging activities have the potential to increase cognitive reserve. In the current study I used a validated questionnaire to measure cognitive reserve (CRIq; Nucci, Mapelli, & Mondini, 2012) in an effort to disentangle bilingualism from other beneficial activities (e.g., education, working, reading, using new technologies, etc.). Importantly, bilingualism appears to be one of many possible ways of enhancing cognitive reserve in order to minimize cognitive decline and delay the onset of

various types of dementia (Bialystok, Craik, & Freedman, 2010; Mekala et al., 2013). Guzmán-Vélez and Tranel (2014) reviewed the literature addressing the relationship between bilingualism and cognitive reserve. Growing scientific evidence suggests that lifelong bilingualism contributes to cognitive reserve and delays the onset of Alzheimer's disease symptoms (Bialystok et al., 2010; Guzmán-Vélez & Tranel, 2014; Mekala et al., 2013).

The potential for bilingualism to delay dementia was supported in a Canadian study in which bilinguals showed signs of dementia four years later than monolinguals (Bialystok et al., 2010). These findings have been replicated in India (Mekala et al., 2013), where bilinguals developed dementia five years later than monolinguals. Moreover, the effect was even larger when focusing on illiterate bilinguals and monolinguals; the illiterate bilinguals developed dementia six years later than the illiterate monolinguals. Level of education also influences the relationship between bilingualism and onset of Alzheimer's disease. Higher degrees of bilingualism were associated with increasingly later age-of-diagnosis (and age of onset of symptoms) of Alzheimer's disease, but only in participants with low education level (Gollan, Salmon, Montoya, & Galasko, 2011). Furthermore, the neurological basis of these findings have been investigated. Abutalebi and colleagues (2015) argued that bilingualism provides a neural reserve that protects against the cognitive decline that occurs during aging. This idea of a "neural reserve" or "brain reserve" has been integrated with

the concept of "cognitive reserve", where the brain of those with higher reserve is not anatomically different but processes tasks in a more efficient manner[1].

According to Perani and Abutalebi (2015) brain systems handling executive control and attention are more developed in bilinguals because speaking more than one language relies on these mechanisms. Interestingly, these neurocognitive benefits are even more prominent when second language proficiency and exposure are kept high throughout life (Perani & Abutalebi, 2015). One of my goals in this study is to understand how varying degrees of bilingualism influence cognitive function. Gollan et al. (2011) found that language proficiency is associated with later onset of dementia. Importantly, in Gollan's study, proficiency was measured across a continuum. Bilinguals with lower proficiency recruit more brain resources compared to highly proficient bilinguals (Leonard et al., 2011). Macnamara and Conway (2014) argued that the mechanism responsible for the bilingual advantage is the interplay between the magnitude of bilingual management demands and the amount of experience managing those demands. These findings are consistent with the idea that language usage (i.e., the percentage of time bilinguals use their two languages) has the potential to be an important factor.

Practical Implications

A report from the Alzheimer's Association, "Changing the Trajectory of Alzheimer's disease: A National Imperative" (2010) shows that "the cumulative costs of care for people with Alzheimer's from 2010 to 2050 will exceed $20 trillion, in today's

[1]Different levels of analysis can yield different results. It is possible to observe differences only at the neural level (brain reserve), only at the cognitive level (cognitive reserve), or at both levels of analysis.

dollars." This study highlights the practical (in addition to the personal and emotional) toll that this illness takes on the general population. A prevention effort or treatment breakthrough that delayed the onset of Alzheimer's disease would result in immediate benefits for our society. Given the current life expectancy, a five-year delay in the onset of the symptoms could cut the life of the disease in half (Alzheimer's Association, 2010).

Enhancing cognitive function in the general public is a noble goal, and there have been numerous attempts to prevent or delay the onset of dementia. For example, programs like "Lumosity" (Scanlon, Drescher, & Sarkar, 2007) have supported the claim that implementing training routines improves performance in specific tasks. Nevertheless, it is important to keep in mind that it is not clear how well these effects transfer to other circumstances. Most of these training programs include a series of exercises that have no direct connection to the user's everyday activities. One hypothesis is that training in the use of a second language could have more profound beneficial effects, while simultaneously increasing the user's proficiency in a useful skill with real world applications (e.g., traveling, job opportunities, personal growth, metacognition, etc.).

A limitation of brain training (e.g., Lumosity) has been that it is very domain specific; the benefits do not generalize to other domains. Importantly, bilingual practice includes internal control of switching between similar tasks, top-down resistance to interference, and dual tasking (Stocco et al., 2014). Because of the wide range of cognitive processes that are necessary to manage two languages at the same time, training in the use of a second language can be a way of obtaining general cognitive benefits. Lifelong bilinguals have developed symptoms dementia approximately five years later, on average, than monolinguals (Bialystok et al., 2010; Mekala et al., 2013). Bilingual patients are

several years older than comparable monolinguals at both age of symptom onset and date of first clinic visit (Bialystok, Craik, Binns, Ossher, & Freedman, 2013). In Bialystok's study, performance in the first testing occasion was comparable, and no differences were found in the rate of decline. Moreover, bilingual patients with Alzheimer's disease exhibit substantially greater amounts of brain atrophy than monolingual patients in areas traditionally used to distinguish Alzheimer's disease patients from healthy controls (Schweizer, Ware, Fischer, Craik, & Bialystok, 2012). Specifically, the radial width of the temporal horn and the temporal horn ration. This effect emerged with monolingual and bilingual patients matched on level of cognitive performance and years of education (Schweizer et al., 2012).

These results highlight the main idea of the cognitive reserve hypothesis, the mismatch between brain damage and cognitive performance. When bilinguals finally showed symptoms of dementia (a few years later than their monolingual counterparts), they had more brain damage. Bilinguals had been able to sustain more brain damage without showing symptoms of decline because of their increased levels of cognitive functioning. Diagnostic tools that aim for an early detection of Alzheimer's disease might need to rely on cues other than symptoms of dementia (e.g., olfactory deficits; Rezek, 1987) in order to accurately diagnose participants with high levels of cognitive functioning, including (at least some types of) bilinguals.

My main argument is that the impact of bilingualism on cognitive function will be found across the continuum of bilingualism (Suarez, Gollan, Heaton, Grant, & Cherner, 2014). I do not think that only lifelong bilinguals will benefit from this cognitive advantage. I argue that different levels of bilingualism will result in different levels of cognitive

function. Participants could improve their cognitive function by speaking two or more languages. If so, an extension of this research would be to examine whether the advantage that emerges from bilingualism can be found when implemented in a training program. The present research can help develop research-based intervention programs by determining: (1) if the beneficial effect of bilingualism emerges across the lifespan, (2) if there is a threshold of bilingualism for participants to show improved cognitive function, and (3) whether or not the effects of bilingualism and age interact.

Bilingualism and Aging

In a cross-sectional study, bilinguals performed better than monolinguals in executive function tasks, with some evidence for larger language group differences in older participants (Bialystok, Craik & Luk, 2008; Bialystok, Craik, Klein, & Viswanathan, 2004). Nevertheless, in a longitudinal study, bilingualism was associated with better memory and executive function at baseline but was not independently associated with rates of cognitive decline or dementia conversion (Zahodne, Schofield, Farrell, Stern, & Manly, 2014). In another longitudinal study, no interaction with age was found, indicating that the rate of change across ages was similar for bilinguals and monolinguals, although bilinguals outperformed monolinguals both in episodic memory recall and in letter fluency (Ljungberg, Hansson, Andres, Josefsson, & Nilsson, 2013). Taken together, these studies suggest that the bilingualism by age interaction is an artifact due to cohort effects. I argue that bilingualism influences the overall level of cognitive performance, delaying the onset of dementia, but it does not alter the rate of cognitive decline. Cross-sectional studies that have found an interaction between bilingualism and age are measuring a cohort effect.

Older cohorts benefit more from bilingualism because they have less cognitive reserve to begin with (similar to the illiterate bilinguals).

Since it is not possible to randomly assign participants to a certain age or level of bilingualism, the question remains: Were bilinguals different to begin with? Bak, Nissan, Allerhand, and Deary (2014) examined the effect of bilingualism on later-life cognition while controlling for childhood intelligence. These authors concluded that bilinguals performed significantly better than predicted from their baseline cognitive abilities, with strongest effects on general intelligence and reading. Interestingly, the positive effect of bilingualism on later-life cognition was also found for those who acquired their second language in adulthood (Bak et al., 2014). Pelham and Abrams (2014) found that late bilinguals generally performed like early bilinguals, experiencing the same degree of executive function benefits. This is excellent news for training programs, according to these findings adults can also benefit from learning a new language.

Research has shown that the bilingual advantage is reinforced by the use of a third language, and modulated by the duration of immersion in a second language environment (Heidlmayr, Moutier, Hemforth, Tanzmeister, & Isel, 2014). In trilinguals, areas of the brain related to domain-general inhibition are more activated for switches to the second and third language (Bruin, Roelofs, Dijkstra, & FitzPatrick, 2014). In the oldest old (Kave, Eyal, Shorek, & Cohen-Mansfield, 2008), the number of languages spoken contributed to the prediction of cognitive test scores beyond the effect of other demographic variables, such as age, gender, place of birth, age at immigration, or education. Moreover, those who are most fluent in a language other than their mother tongue score higher on average than those whose mother tongue is their best language (Kave et al., 2008). Taken together, these

results indicate that higher levels of usage and proficiency in your second or third language have beneficial effects on cognitive function.

Emmorey, Luk, Pyers, and Bialystok (2008) investigated whether the bilingual advantage stems from a general effect of bilingualism (the representation of two languages) or from a modality constraint (auditory vs. visual) that forces language selection. Only bimodal bilinguals (e.g., those that sign and speak) can use their two languages at the same time. Emmorey and colleagues (2008) concluded that the bilingual advantage in cognitive control emerges from the unimodal's bilingual experience of controlling two languages in the same modality. Nevertheless, Macnamara and Conway (2014) challenged these results by following a group of bimodal bilinguals (signed language – spoken language) for two years. These authors found that after gaining experience managing high bilingual management demands (becoming translators) bimodal participants outperformed their own previous test. These results support the idea that cognitive control outcomes for bilinguals vary as a function of the mechanisms recruited during bilingual management and the amount of experience managing the bilingual demands (Macnamara & Conway, 2014).

The cognitive demands from the environment are a crucial factor in shaping cognitive function. There is a growing consensus in the literature supporting the idea that the two languages of a bilingual are continuously active (Grainger & Beauvillain, 1987; Grainger, 1993; Marian & Spivey, 2003; Dijkstra, 2005; Schwartz & Kroll, 2006; Libben & Titone, 2009). The amount of cognitive effort necessary to manage both languages at the same time is likely to be at the root of this enhancement in cognitive function. Furthermore, the level of cognitive effort may be influencing the level of cognitive reserve. For example, when a person is immersed in a foreign language and the cognitive effort

required to communicate is relatively high, it is likely that the cognitive benefit is also maximized. When someone experiences a "language headache" (a headache that comes from the exhaustion of trying to understand a foreign language or from the effort of translating between two languages), it is likely that cognitive function is enhanced. If one goal is to enhance cognitive function in the general population, it is important to understand the ways in which the bilingual advantage can be maximized.

The Bilingual Mind

Researching how bilingualism affects cognitive function has not only practical, but also theoretical implications. A better understanding of how bilingualism influences cognitive function can result in important insights regarding how the brain functions. Meta-analytic reviews of the literature (e.g., Guzmán-Vélez & Tranel, 2014) have supported the beneficial effects of bilingualism on cognitive function. Nevertheless, some authors have challenged the generalizability of these benefits. Costa and Sebastián-Gallés (2014, p. 342) argued that "serious concerns have been raised about the robustness and reliability of the reported cognitive effects of bilingualism." Some authors go as far as to conclude that "the research findings testing for bilingual advantages in executive processing do not provide coherent and compelling support for the hypothesis that the bilingual experience causes improved executive processing" (Paap & Greenberg, 2013, p. 256).

According to De Bruin, Treccani, and Della Sala (2014), publication bias favoring studies with positive results might be generating a false sense of reliability for this effect. De Bruin et al. (2014) reported that studies challenging the bilingual advantage are less likely to be published. These authors reviewed conference abstracts from 1999 to 2012,

and did not find differences in sample size, tests, or statistical power between the published and unpublished studies. The crucial determinant to getting published was whether or not the results supported the bilingual advantage. Nevertheless, this work has been severely criticized by Bialystok, Kroll, Green, MacWhinney, and Craik (2015) because of three errors in reasoning. First, the relation between conference abstracts and published articles; bad research (in addition to null results) is less likely to get published. Second, the difference between null and negative findings (compared to null results, negative and positive findings should be equally likely to be found). Third, the differential effects of bilingualism on verbal and nonverbal task performance (bilingualism influences different tasks in different ways). De Bruin, Treccani and Della Sala (2015) responded to these criticisms by emphasizing that we should consider all the data.

Paap and colleagues have repeatedly argued against the bilingual advantage (Paap, 2014; Paap & Greenberg, 2013). Furthermore, other researchers agree with this argument, Duñabeitia and Carreiras (2015, p.2) stated "generalized and generalizable bilingual advantages in executive function do not exist." Paap and Greenberg (2013) reported three studies comparing bilinguals and monolinguals on 15 indicators of executive processing. In particular, in Experiment 3 these researchers used the flanker task and did not find a significant effect of bilingualism or a Group by Flanker interaction (Paap & Greenberg, 2013). Furthermore, Paap (2014) criticizes Kroll and Bialystok's argument that managing two languages leads to a reorganization of the neural circuits involved in language and cognitive processing and that there is a bilingual advantage in executive functioning (Kroll & Bialystok, 2013). According to Paap (2014), bilingual advantages are difficult to

replicate, and the effects are not reliable because of the small sample sizes and a confirmation bias to report positive findings.

In contrast, Kroll and Bialystok (2013) argue that studies of executive function have repeatedly demonstrated a bilingual advantage. These authors further stated that the adult mind and brain are open to experience in ways that create profound consequences for both language and cognition. According to Kroll and Bialystok, the tendency to consider bilingualism as a unitary phenomenon, and setting up the hypotheses in a categorical manner (there is an advantage or not) as opposed to a continuous manner (under which circumstances the advantage emerges), has created a controversy that hides the importance of the findings. The current study could help bring together these apparent contradictory findings by studying the boundary conditions under which the beneficial effects of bilingualism emerge.

I argue that the cognitive benefits come from the cognitive effort invested in dealing with two or more languages. More cognitive effort (e.g., when initially learning a language, when constantly switching between two languages, etc.) would result in higher levels of cognitive function. The end goal of this study is to understand under which circumstances bilingualism results in enhanced cognitive function.

Continuous Measures

Traditionally, researchers have measured bilingualism and age as dichotomous variables. A common practice is to compare four different groups: younger monolinguals, younger bilinguals, older monolinguals, and older bilinguals. Nevertheless, despite being pervasive in the literature, this practice can lead to a loss of information of the individual

differences. From a theoretical point of view, it is better to consider bilingualism as a continuous construct with different dimensions (e.g., proficiency, usage, etc.). Luk and Bialystok (2013) concluded that "bilingualism is not a categorical variable" and "the criteria that determine an individual's designation as monolingual or bilingual are fuzzy at best." A recent study (Suarez et al., 2014) has argued that variability within bilinguals can account for differences in inhibitory control. Suarez and colleagues (2014) found that greater degrees of English fluency predicted better speed on the incongruent trials of a Stroop task administered in Spanish. Therefore, it is important to conceptualize bilingualism as a continuum, in order to account for differences due to characteristics of the bilingual experience.

Age, a continuous variable, has also been dichotomized in the literature. Researchers typically compare younger and older adults with an age range specified for each group. The rationale is that in order to investigate an effect, it is useful to start with the extremes. Nevertheless, this approach has the implicit assumption that the relationship between age and the studied variables is linear, in which case comparing the extremes of the continuum would maximize any differences under investigation. However, the relationship may not be linear. If there is a curvilinear relationship, hypothesizing about middle age based on older and younger adults would be erroneous. Crucially, by comparing the extremes of the continuum (e.g., 18 and 75 years old) a great deal of important information is missing.

From a methodological point of view, dichotomizing variables has been heavily criticized. According to Maxwell and Delaney (1993) dichotomization of continuous variables not only results in loss of power (Type II error), but it can also increase the

probability of Type I errors. Therefore, two types of mistakes are possible when dichotomizing a continuous variable: it is possible to miss a real effect or to find an effect that is not real. Even though there are many instances in the literature where continuous measures of individual differences have been dichotomized, this practice is rarely justified from either a conceptual or statistical perspective (MacCallum, Zhang, Preacher, & Rucker, 2002). By measuring bilingualism and age as continuous variables, my goal is to maximize power and avoid the potentially serious negative consequences of dichotomization.

In the current study, I measured age and language usage as continuous measures. Instead of the traditional understanding of bilingualism and age as dichotomous measures, I want to observe cognitive function across the continuum. This conceptualization of bilingualism and age as a continuum has theoretical importance. Instead of asking whether it is better to be bilingual or younger, my research questions are whether varying degrees of bilingualism and/or age result in different levels of executive function. Moreover, understanding age as a continuum allowed me to measure if developmental changes are quantitative (continuous changes over time) or qualitative (periods without changes followed by periods with intense change). The goal is to increase our understanding of the magnitude the bilingual effect on cognitive function across the entire lifespan. In addition, a strength of the current design is the inclusion of a baseline measure. Participants had to click on the response button where the word "Here" appeared (top right or left corners of the screen). Including this baseline measure of participants' mouse performance is an efficient way of statistically controlling for individual differences. Doing so will lead to more accurate measurements of the overall effects of bilingualism and age.

Cognitive Function

Cognitive function concerns processing capacity, reasoning, memory, attention, language, and knowledge. The Transmission Deficit Theory (Mackay & Burke, 1990, Burke, MacKay & James, 2000) has been proposed as a way to explain cognitive decline in old age. This theory is a powerful alternative framework to understand some contradictory findings in the literature. There are some asymmetries in processing that need to be addressed at the theoretical level. For example, there are differences between phonological and semantic information (word meaning is better maintained in old age), as well as differences between comprehension and production (speech production is better maintained in old age). According to the transmission deficit account there are different mechanisms for retrieving existing representations than for learning new skills. Age differences increase when new connections are necessary, but are minimized when already established connections are sufficient to accomplish the task. The Transmission Deficit Theory (Mackay & Burke, 1990) and the Cognitive Reserve Hypothesis (Stern, 2002) are remarkable easy to integrate. If the deficit with age is based on the deterioration of certain connections (transmission deficit), then stimulating activities that make those connections more efficient (cognitive reserve) would delay cognitive decline.

Selection of information is maintained in old age, but the process of inhibition has been proposed as a potential source of age-related changes (Hasher & Zacks, 1988). The cognitive lives of older adults are characterized by stability, decline, and improvement. In other words, some cognitive abilities are maintained while others are enhanced or suffer declines. Importantly, despite the cognitive deficits observed in laboratory settings, everyday life of older adults does not seem to be dramatically affected. As we age, mental

processes can change, but compensation and external resources also come into play helping older adults to function very well in familiar environments. There is evidence to suggest that processes that were automatized when individuals were younger tend to remain intact in older age (Park & Schwarz, 2000). Previously acquired automatic processes are very important for the maintenance of functioning in older age. Different aspects of one's lifestyle can influence how well cognitive processes are maintained. Cognitive function is crucial to the performance of everyday activities and to have a good quality of life. Importantly, different levels of cognitive function can result in quantitative or qualitative differences in performance.

The present experiment includes two attentional tasks (Stroop and Flanker) that are used as indicators of executive functioning and cognitive control. Friedman and Miyake (2004) used a latent-variable analysis to study the relations among inhibition and interference control functions. These authors concluded that attention selection and response inhibition are closely related, but these two constructs are not exactly the same. These authors caution that the term inhibition has been overextended and it is necessary to be specific when discussing related effects. According to Friedman and Miyake's classification, the Stroop task measures "prepotent response inhibition" while the Flanker task measures "resistance to distractor interference." Therefore, if bilingualism and aging have an effect on both tasks, it would be possible to argue that the effects extend across different aspects of cognitive function. If not, it would be important to learn which aspect of cognition is influenced by each variable.

In the present study the control, congruent, and incongruent trials were randomly presented in order to maximize conflict monitoring (see the measures section below for a

detailed account of the tasks and a description of what is meant by congruent and incongruent trials). According to the Conflict Monitoring Hypothesis (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999), the anterior cingulate cortex is a brain area involved in cognitive control that responds to situations of conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001). Interestingly, bilingualism has been shown to enhance the anterior cingulate cortex, a structure that has been related to domain-general executive control functions (Abutalebi, Della Rosa, Green, Hernandez, Scifo, Keim, ... & Costa, 2011). Practice managing two languages results in enhancements of the anterior cingulate cortex, a brain structure that helps resolve conflict in domain-general cognitive tasks (Abutalebi et al., 2011). Costa, Hernandez, Costa-Faidella and Sebastian-Galles (2009) observed an effect of bilingualism in overall reaction times only in high monitoring conditions. These authors did not find differences between bilinguals and monolinguals in the low monitoring conditions, when the trials were of just one type (either congruent or incongruent). In the present experiment, I used a high monitoring version of the tasks (where congruent and incongruent trials are evenly distributed) in order to maximize the bilingual advantage.

While the Flanker and the Stroop tasks are widely used in the field to measure executive function, it is important to acknowledge the limitations of only using two tasks to measure domain-general abilities (even when both tasks measure conflict monitoring). One of the main criticisms is the absence of consistent cross-task correlations, which undermines the interpretation that these are valid indicators of domain-general abilities (Paap & Greenberg, 2013). It is possible that these two tasks measure two different constructs within the umbrella of cognitive function. It is also possible that cognitive function is not unidimensional, but a conglomerate of different mechanisms that work

together. According to Valian (2015, p. 3) "executive function is a complex set of cognitive processes, the components of which are sometimes minimally correlated with each other." In the current study I used two tasks to measure executive function across the life-span. The assumption is that these tasks provide useful information about participants' cognitive function, independently of the unidimensional or multidimensional understanding of this construct.

The Flanker and the Stroop are both attentional tasks. Attention involves two main processes: (1) the selection of some information and (2) the active inhibition of other information (Park & Schwarz, 2000). The Bilingual Advantage Theory (Bialystok, 1999), based on the Inhibitory Control Model (Green, 1998), proposed inhibition as the mechanism at the root of the bilingual differences. Abutalebi and Green (2007) argued that bilinguals' ability to select the intended language is the consequence of a dynamic process involving cortical and subcortical structures that make use of inhibition. Recent accounts have expanded the mechanisms at the root of these benefits beyond inhibition. Costa, Hernandez and Sebastián-Gallés (2008) found that bilingual participants were more efficient at resolving conflicting information, and thus when the task recruits sufficient monitoring resources bilinguals outperformed monolinguals. Bialystok (2010) found a bilingual advantage in tasks that require executive processing components for conflict resolution, including switching and updating, even when no inhibition was involved.

Experts

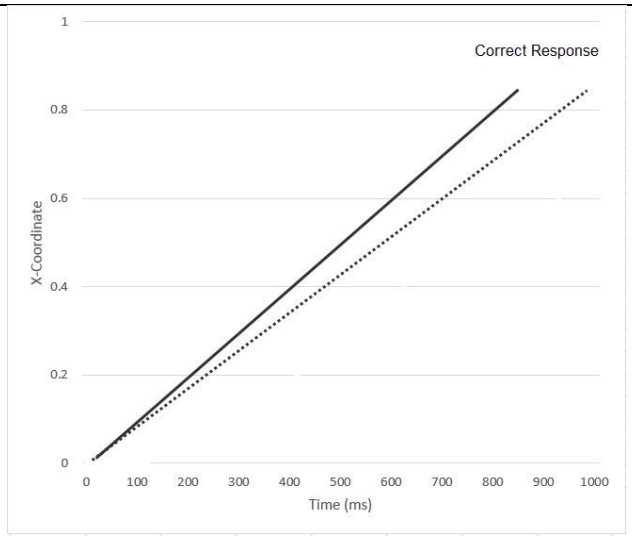
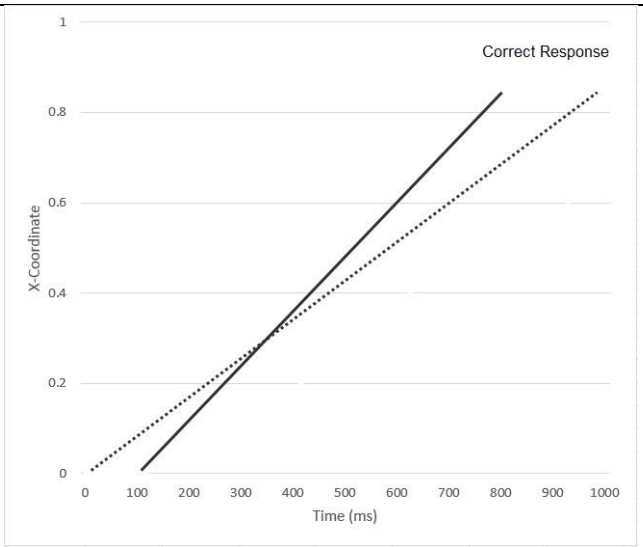
In the bilingual literature there has been numerous references to the idea that bilinguals are experts. For example, "… bilinguals are experts in resolving competition…"

(Kroll, 2008, p 106), or "…bilinguals are experts in cognitive control…" (de Groot, 2014, p 256). Importantly, Incera and M^{c}Lennan (2016a) provided empirical evidence that bilinguals "behave like experts." Bilinguals responded in a qualitatively (not quantitative) different way than monolinguals. A quantitative difference would entail bilinguals being overall faster than monolinguals, but a qualitative difference refers to bilinguals having a different way of performing the tasks (a different allocation of timing). Bilinguals waited longer to initiate a response, but then responded more efficiently (Incera & M^{c}Lennan, 2016a), supporting the "qualitatively different" approach. This processing style (take a moment to start, then perform better) has been found in other domains across the literature on expertise (Kobus, Proctor & Holste, 2001; Ranganathan & Carlton, 2007; Sanchez, Sicilia, Guerrero & Pugnaire, 2005; Shank & Haywood, 1987; Sim & Kim, 2010).

The two executive function tasks in the current dissertation (Flanker and Stroop) were presented using the mouse-tracking paradigm (Spivey, Grosjean, & Knoblich, 2005). The mouse-tracking paradigm makes it possible to measure participants' mouse movements over time. The position of the mouse on the screen (*x*-coordinate) is measured as the responses to these two executive control tasks unfold over time (Freeman & Ambady, 2010). A higher *x*-coordinate means that the participant is closer to the correct response. A steeper slope indicates that participants have covered more space (*x*-coordinate) for a set amount of time (see Table 1). Bilinguals are experts at ignoring irrelevant information. Therefore, the cognitive benefits of bilingualism should result in qualitative (not quantitative) differences (see Table 1). Both arguments (qualitative and quantitative) predict steeper slopes for bilingual participants; but only the expertise argument (qualitative differences) predicts longer initiation times for bilinguals. That is, I

predict that bilinguals take longer to initiate their mouse movements (longer initiation times), but then move more efficiently towards the correct response (steeper slopes of the trajectory).

Table 1. Competing predictions.

Overall Speed -No differences on Initiation Times -Steeper trajectories (i.e., faster movements towards the correct response) for bilinguals (continuous line) than monolinguals (dotted line)	
Expertise -Longer initiation times for bilinguals (continuous line) than monolinguals (dotted line) - Steeper trajectories for bilinguals (continuous line) than monolinguals (dotted line)	

Qualitative differences in performance have been found across many different domains by researchers that focus on expertise. In these experiments the quality of the

performance (i.e., accuracy) has been used to define who is an expert (higher performance) and who is a novice (lower performance). Then, the differences between these two groups have been studied in detail. Professional baseball hitters take longer to initiate a swing (Shank & Haywood 1987), but once they do so, their swing is faster than novice hitters (Ranganathan & Carlton, 2007). This implicit mechanism of delaying the onset of a response has been shown to improve performance in a number of other settings. In golf putting there were marked variations in timing between experts and novices: movement times of experts were longer at the beginning, and shorter later on (Sim & Kim, 2010). Moreover, expert soccer goalkeepers waited longer before initiating a response and appeared to spend longer periods of time fixating on the non-kicking leg (Sanchez, Sicilia, Guerrero, & Pugnaire, 2005). Finally, in a dynamic tactical scenario, expert marines took longer to assess the situation, but then the selection of a course of action was significantly faster (Kobus, Proctor, & Holste, 2001).

I argue that bilinguals are experts in the context of dealing with conflicting input, and this expertise is at the root of the bilingual advantage. I suspect that bilinguals' and monolinguals' performance is qualitatively different, as the bilingual expertise theory predicts. I argue that bilinguals take longer to initiate the response (initiation times), but once they respond they move faster towards the correct response (*x*-coordinates over time, the slope of the trajectory). If bilinguals perform like experts, the bilingual advantage should result in (1) longer initiation times and (2) faster movements towards the correct response.

Predictions

The current study adds to the literature in two novel ways. First, I measured the effects of bilingualism and age as continuous variables within a single study. Studies that have analyzed the impact of bilingualism and age on cognitive function have dichotomized these variables (e.g., Bialystok, Craik, & Luk, 2008). Moreover, studies that have considered bilingualism or age as continuous (e.g., Suarez et al. 2014; Hertzog, Kramer, Wilson, & Lindenberger, 2008) have not studied them in combination. To my knowledge, this is the first study to analyze the combined effects of bilingualism and age on cognitive function while conceptualizing these variables as continuous. Understanding these constructs across a continuum allows for new research questions (e.g., Do varying degrees of bilingualism/age result in different levels of executive function?). Second, I used mouse tracking to measure the time course of these effects. Mouse-tracking data allowed me to evaluate the continuous dynamics of the response (response style), rather than solely relying on traditional end-point measures, such as reaction time (RT) or accuracy. This methodology makes it possible to observe the time course of these effects.

(A) Bilingualism will positively impact cognitive function (Bilingual Advantage Theory).

(B) Age will negatively impact cognitive function (Inhibition Deficit Theory).

(C) Varying degrees of bilingualism/age will result in different levels of cognitive function.

(D) There will be no bilingualism-by-age interaction.

(E) Cognitive reserve and English proficiency will contribute to the model.

CHAPTER II

METHOD

Participants

I recruited 180 participants from Northeast Ohio (see Figure 1), including the Cleveland State University community, the Department of Psychology participation pool and volunteers from ResearchMatch.org, a recruiting website where participants can sign up for research experiments. All participants were 18 years old or older. First, the sample has sufficient age variation to observe changes in cognitive function. I recruited more than 20 participants per decade: 18-19, 20-29, 30-39, 40-49, 50-59, and 60+. Second, the sample varies in participants' level of bilingualism. I recruited 90 participants toward the "monolingual" end of the continuum, and 90 participants toward the "bilingual/multilingual" end of the continuum. Participants answered a language experience and proficiency questionnaire (see measures below), which allowed me to place them on the bilingual continuum. Including bilinguals with different language backgrounds

facilitated recruitment across all ages. Moreover, the amount of cognitive reserve has not been linked to speaking a particular combination of languages. It seems unlikely that the specific language spoken substantially influences the age of Alzheimer's disease diagnosis (Guzmán-Vélez & Tranel, 2015)[2].

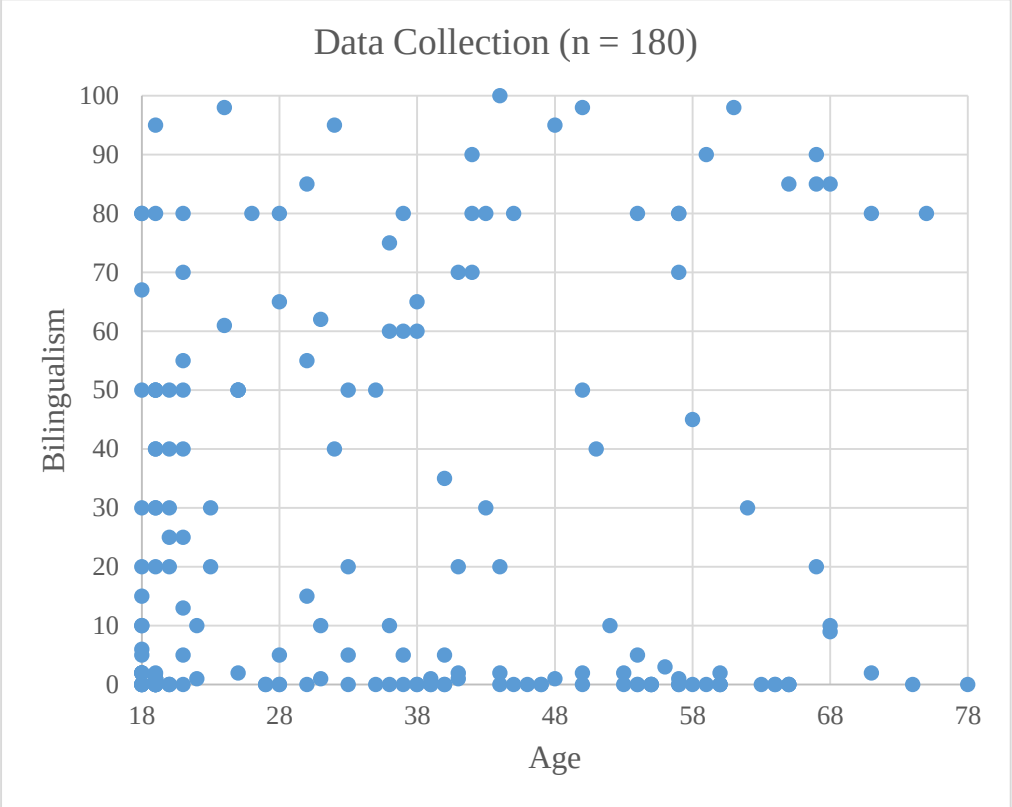


Figure 1. Data collection. Age is reported in years, and bilingualism is the percentage of time participants speak in their non-native language.

[2]Future research should investigate if the similarity between the two languages plays a role in these effects (e.g., Spanish and Portuguese are much more similar than Spanish and English). First, it is possible that languages that are very different stimulate more brain growth (more connections are necessary). Second, an alternative possibility is that languages that are very similar enhance inhibitory processes, because it is necessary to work harder to distinguish them.

Mouse Tracking

In the current experiment, I used the dynamic mouse-tracking paradigm (Spivey et al., 2005) to study the effect of bilingualism and aging on the slopes of the mouse trajectories. Spivey et al. (2005) reported evidence to "support the claim that continuous temporal dynamics in the brain are being reflected in the continuous temporal dynamics of motor output" (p. 10398). In 2010, Freeman and Ambady introduced MouseTracker, software designed to examine real time processing. Using mouse tracking, I observed directly each particular response over time, a detailed measure of the time courses. Participants responded to the two measures of executive control (Flanker and Stroop) by moving the mouse toward the correct response.

MouseTracker records the trajectory of the mouse every 13 to 17 milliseconds (ms). Three pieces of information are recorded (Freeman & Ambady, 2010): raw time (how many ms have elapsed), the *x*-coordinate of the mouse (in pixels), and the *y*-coordinate of the mouse (in pixels). According to Freeman and Ambady (2010), all trajectories are rescaled into a standard coordinate space. The top left corner of the screen corresponds to [-100, 150], and the bottom right corner corresponds to [100, 0], leaving the starting location of the mouse (the bottom center) with the coordinates [0, 0]. MouseTracker provides many measures that can be interpreted in different ways. In the present paper I focused on three of all the possible measures: Initiation Time, Reaction Time, and *x*-Coordinate. Initiation time is the duration between the onset of the target stimulus and the initiation of mouse movement; and *x*-coordinate over time is a continuous measure that can be analyzed in multiple ways. Growth curve analysis (Mirman, 2014) was used to analyze the impact of bilingualism and age on the slopes of the mouse trajectories.

In the current experiment participants responded to two measures of executive control: a verbal (Stroop) and a nonverbal (Flanker) cognitive task. In order to obtain a baseline measure of mouse trajectories, participants first responded to 16 trials where they were instructed simply to click on one of the two response alternatives (see Figure 2).

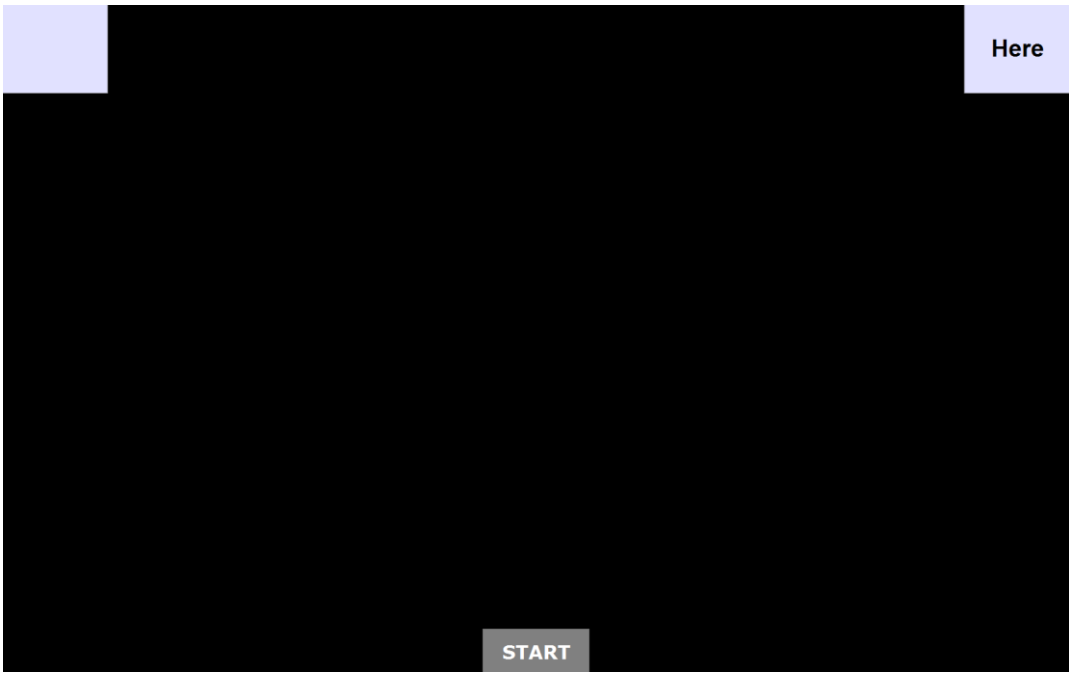


Figure 2. Baseline trial.

Measures

I collected data using five different measures. The independent variables (bilingualism and age) were obtained through questionnaires[3], while the dependent variables (verbal and non-verbal executive function) were measured using mouse tracking. First, participants answered two questionnaires: (1) LEAP-Q, a self-report measure of

[3]I want to thank my committee members for the addition of several relevant questions (see Appendices) from the Language History Questionnaire (LHQ).

language experience and proficiency, and (2) CRIq, a self-report measure of cognitive reserve. Furthermore, participants performed two tasks[4] using mouse tracking: (3) the Flanker task, a non-verbal measure of attention selection, and (4) the Stroop task, a verbal measure of response inhibition. Finally, participants responded to the (5) MINT test, an objective measure of English vocabulary.

(1) LEAP-Q

The Language Experience and Proficiency Questionnaire (LEAP-Q) is a reliable and valid questionnaire of bilingual language status (Marian, Blumenfeld, & Kaushanskaya, 2007). It is an efficient tool for assessing healthy older adults in research settings. Importantly, it provides an extensive array of measures, and can be completed by the bilingual independently (Marian et al., 2007). The estimated time to complete the questionnaire is 15 min for speakers of two languages (5-min increments for each additional language). The questionnaire records information about the participants' dominance, order of acquisition, percentage of time exposed to each language, language performance, etc. Interestingly, self-reported reading proficiency is a predictor of first-language performance, while self-reported speaking proficiency is a better predictor of second-language performance (Marian et al., 2007). I obtained my measure of language usage by computing the relative percentages of each language in Question 3 of this questionnaire.

[4]I decided not to counterbalance the order of the tasks, all participants responded to the Flanker task first.

The bilingual experience is dynamic, which makes it challenging to measure its dimensions accurately (Luk & Bialystok, 2013). No single measure provides a complete assessment of bilingual language proficiency, but self-ratings are probably based on a wider range of abilities (Gollan, Weissberger, Runnqvist, Montoya, & Cera, 2012). The numerous questions in the LEAP-Q questionnaire load in eight different factors: L1 Competence, Late L2 Learning, L2 Competence, L1 Maintenance, Late L2 Immersion, Media-Based Learning, Non-Native Statues and Balanced Immersion (Marian et al., 2007). Objective measures that present pictures and ask participants to name them (e.g., see MINT questionnaire below) may reflect only the ability to retrieve picture names (Gollan et al., 2012). I selected this self-report measure of bilingualism because I expect cognitive reserve to benefit from a range of language skills (e.g., lexical retrieval ability, formulation of syntactic structures, knowledge of colloquial expressions, range of registers, etc.). Finally, the questionnaire was presented in English; Delgado, Guerrero, Gogging, and Ellis (1999) reported that language of self-assessment does not influence bilinguals' proficiency rating.

(2) CRIq

The *Cognitive Reserve Index Questionnaire* (CRIq; Nucci, Mapelli, & Mondini, 2012) is the second questionnaire that participants answered. Nucci et al. (2012) validated this measure with a sample of 588 healthy individuals from 18 to 102 years old. These authors concluded that the questionnaire is a standardized measure of the cognitive reserve accumulated by individuals through their lifespan. This questionnaire measures the amount and intensity of the stimulating activities that participants have engaged in throughout their lifespan. The CRIq includes 20 items grouped into three sections: education, working activity, and leisure time. The reliability of the test was $\alpha = 0.62$, 95% CI [0.56, 0.97].

(3) Friendly Fish Flanker Task

The *Flanker* task (Eriksen & Eriksen, 1974) is a non-verbal measure of attention selection. Using a non-verbal task is crucial; an important aspect of the bilingual advantage is that it is not confined to linguistic processing (Bialystok, 2010). In the present experiment I used a modified version of the Flanker task. The Friendly Fish Flanker task[5] has been successfully utilized with children (Pontifex, Saliba, Raine, Picchietti, & Hillman, 2012; Voss et al., 2011). Researchers have observed that children as young as 4 years old can successfully complete the flanker task using these stimuli (see Figure 3). The stimuli have been obtained through the Health Behaviors and Cognition Laboratory, at Michigan State University.

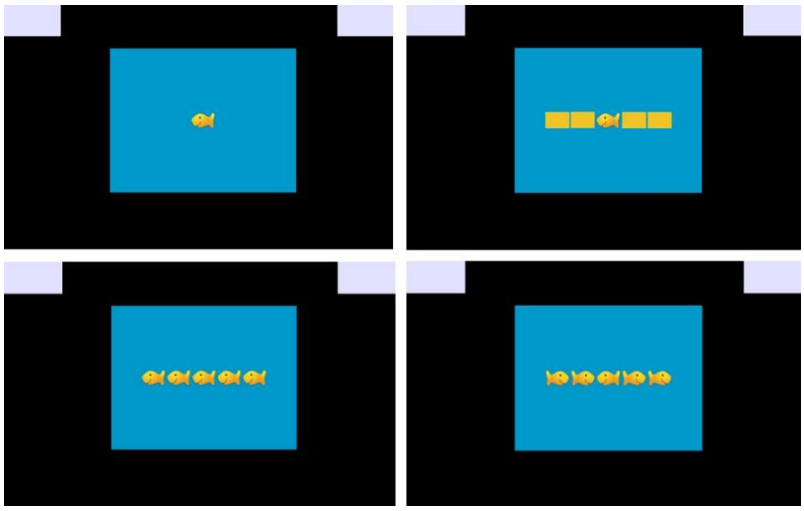


Figure 3. Flanker task: practice, control, congruent, and incongruent trials.

[5]In a separate line of research, I am investigating the effects of bilingualism on children's cognitive skills. In order to allow for more direct comparisons across populations, I selected the Friendly Fish Flanker task that has been used with pediatric samples.

Using MouseTracker (Freeman & Ambady, 2010), participants were asked to click on a location on the screen (top right or left corners) corresponding to the side of the screen the "fish" in the center is facing (see Figure 3). In this "flanker-ignoring" task, participants responded more slowly and less accurately when the surrounding fish were looking in the opposite direction (incongruent condition – bottom right corner) compare to when all the fish were looking in the same direction (congruent condition – bottom left corner). This effect — the so-called Flanker effect, has been used extensively in the literature since the 1970s. When control, congruent, and incongruent trials are presented randomly, the Flanker task is a good measure of resistance to distractor interference.

(4) Stroop task

The *Stroop* task (Stroop 1935) is a well-known measure of prepotent response inhibition. Stroop's (1935) article is one of the most influential studies in experimental psychology. In Experiment 2 of Stroop's original study, he introduced the "naming color test", a task in which participants were presented with a color word (e.g., blue) and were instructed to respond to its ink color. In this color-naming task, participants responded more slowly and less accurately when the ink color and word meaning were incongruent (e.g., blue in green ink) compared to when the name of the color appeared in black ink. This effect — the so-called Stroop effect — is a widespread measure of executive function across many fields (e.g., Ashley, Honzel, Larsen, Justus, & Swick, 2013; Cohn, Dustman, & Bradford, 1984; Grégoire, Perruchet, & Poulin-Charronnat, 2013; Hutchison, Smith, & Ferris, 2013; Mattia, Heimberg, & Hope, 1993; Vidoni et al., 2013).

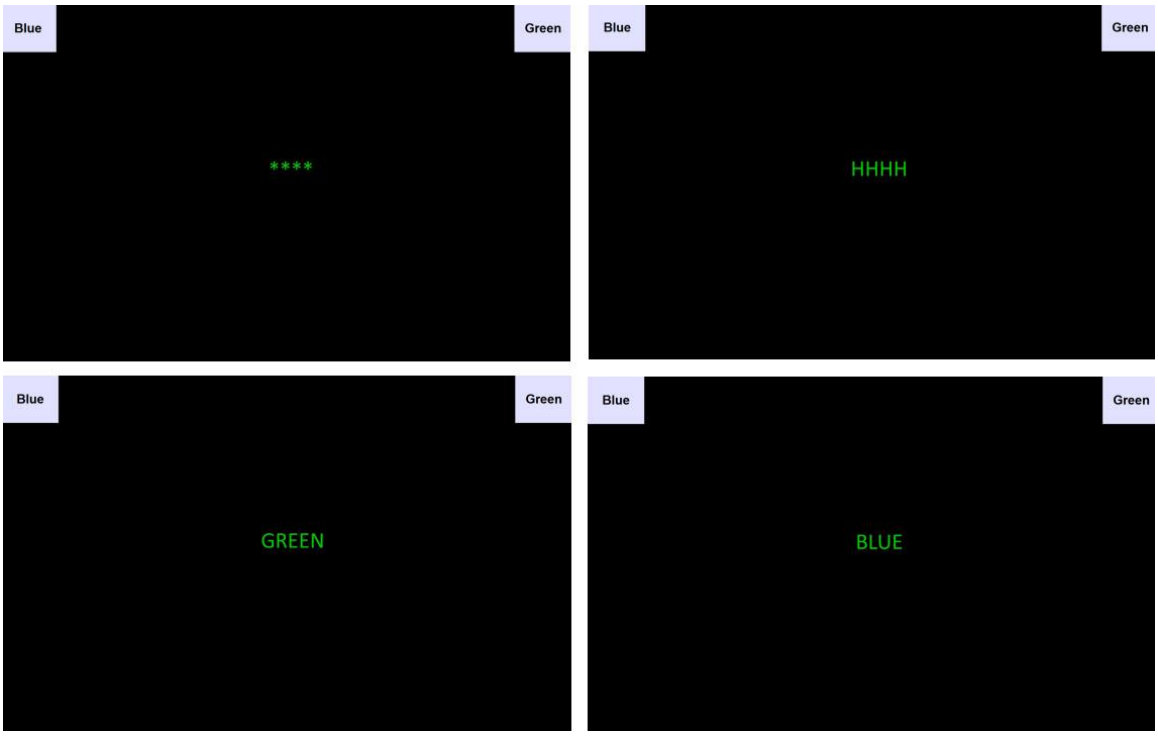


Figure 4. Stroop task: practice, control, congruent, and incongruent trials.

In the Stroop task a stimulus (e.g., *blue* in green ink, see Figure 4) was displayed as soon as participants click START, and remained on the screen until participants clicked one of the two response alternatives (one correct and one incorrect). The response alternatives (e.g., "Blue" and "Green" in Figure 4) appeared in the top left and right corners of the screen. Out of all possible combinations, the following six responses alternatives were used: "Blue" and "Green"; "Red" and "Blue"; "Yellow" and "Blue"; "Green" and "Red"; "Yellow" and "Green"; and "Red" and "Yellow". These combinations were used in this order in six sections of the experiment, each containing a practice block and an experimental block where control, congruent, and incongruent trials were randomly presented. I used a high monitoring version of the Stroop task (where control, congruent, and incongruent trials were evenly distributed) in order to maximize the bilingual

advantage. When control, congruent and incongruent trials are presented randomly, the Stroop task is a good measure of prepotent response inhibition.

(5) MINT

The *Multilingual Naming Test* (MINT: Gollan, Weissberger, Runnqvist, Montoya & Cera, 2012) is the last test participants responded to in this study. This test is an objective measure of vocabulary in which participants named 68 pictures presented on the screen. The MINT was used to objectively measure the level of English proficiency in the sample. Importantly, the MINT has been validated in a sample of older adults (Gollan et al., 2012). The test was only presented in English, since this is the only language that all participants had in common. According to Gollan and colleagues (2012), self-rated English proficiency correlates with proficiency measured in an oral interview (r = .281, p = .043) and with proficiency measured by the MINT (r = .460, p = .001). Importantly, the discrepancies between subjective and objective measures of language proficiency do not necessary reveal which measure is more appropriate. In the present experiment I studied language proficiency using both methodologies, self-report and picture naming, in an effort to present a comprehensive picture of the participants' bilingual experience.

Design

There was a baseline task and two experimental tasks (Flanker and Stroop) with three target conditions (control, congruent, and incongruent). For each task, participants responded to the practice trials, and then to 36 target trials (12 per condition). Congruent, incongruent, and control trials were randomly presented. As stated previously, participants first responded to the Baseline, then to the Flanker task, and finally to the Stroop task. A

challenge when studying bilingualism or age effects is that true experiments are not possible because age (or bilingualism) cannot be randomly assigned (Salthouse, 2004). Importantly, some statistical analyses (like those utilized in this dissertation research) can help control for the lack of randomization.

Despite the apparent simplicity of this design (180 participants responding to two questionnaires and two tasks), the current study is very efficient. Traditionally, an investigation searching for the same answers as the current experiment would involve at least a 6-way mixed ANOVA to perform the analysis: 4 (Condition) X 2 (Language Usage) X 5 (Age Groups) X 2 (Cognitive Reserve) X 2 (English Proficiency) X 5 (Timebins). One strength of the current study is that advanced statistical tools (e.g., growth curve analysis) allow for the examination of the effects of many variables simultaneously. The dataset derived from the current study could be used for many potential analyses. Not only does mouse tracking provide many dependent variables (e.g., *x*-coordinates, initiation times, reaction times, area under the curve, etc.), but the mouse trajectories can be analyzed as a function of many independent variables: task (baseline, verbal, and non-verbal), condition (congruent, incongruent, and control), bilingualism (e.g., language proficiency, language usage, language preference, dominance, age/order of acquisition, culture, immigration, accent), and cognitive reserve (education, working activity and leisure time).

Procedure

Participants were tested individually, either at the Language Research Laboratory (LRL) or in a quiet setting (e.g., public library). Finding a quiet setting outside the university was particularly relevant for less accessible populations like some older

bilinguals. All participants responded to the tasks using a laptop from the LRL. First, participants signed the consent form (Appendix 1) and answered the Participant Information Form (Appendix 2). The participant information form included six questions from the LHQ (Language History Questionnaire) in order to measure some language usage constructs not included in the LEAP-Q. Second, participants answered the LEAP-Q (Appendix 3) and the CRIq (Appendix 4) questionnaires. Third, participants responded to the baseline, Flanker and Stroop tasks using MouseTracker (Freeman & Ambady, 2010). At the beginning of each trial "START" appeared at the bottom-center, and the response options appeared in the top left and right corners of the screen. Upon clicking "START", the stimuli appeared in the center. Participants were instructed to begin moving the mouse immediately after clicking "START." If a participant took more than 500ms to initiate a mouse movement, a warning appeared at the end of that trial instructing the participant to start moving the mouse earlier on future trials, consistent with other mouse-tracking studies (Incera et al., 2013, Incera, 2014). Finally, participants responded to the English version of the MINT (Appendix 5) and received a debriefing form (Appendix 6).

Analysis Plan

For each task (Stroop and Flanker), I measured the effect of Bilingualism and Age on Initiation Times, Reaction Times, and *x*-Coordinates. In the results section I first present the results for the Stroop task, followed by the results for the Flanker task. I used mixed models to evaluate the improvement on model fit, and to calculate the parameter estimate for each effect. I studied the effects of Condition (predicting that performance in the incongruent condition would be worse), Bilingualism (predicting that higher levels of bilingualism would result in better performance), Age (predicting that younger age would

result in better performance), Condition by Bilingualism (predicting that the positive effect of bilingualism would be more pronounced in the incongruent condition), Condition by Age (predicting that the positive effect of younger age would be more pronounced in the incongruent condition), and Condition by Bilingualism by Age (to evaluate whether a 3-way interaction would emerge). I ran additional models that included the baseline, cognitive reserve, and English proficiency as covariates. The independent variables (Bilingualism, Age, Reserve, Proficiency, and Time) were mean centered. The effect of participants and all repeated measures (Condition and Time) were included as random effects. In order to avoid the problem of multiple comparisons and reduce Type I error, an effect was interpreted only when (1) it improved model fit, (2) the comparison was significant, and (3) the estimate was in the predicted direction (e.g., positive for bilingualism and positive for younger adults).

Growth curve analysis (Mirman, 2014) was used to analyze the impact of bilingualism and age on mouse trajectories. I selected a linear model to fit the data, because the quadratic and cubic models failed to converge. All participants started and finished in the same location of the screen (within the START button and within the Response button respectively); there was insufficient variability in the trajectories to fit the originally proposed cubic model. My analysis focused on the intercept and linear (slope) terms of the trajectory. If a trajectory has a high intercept or a steeper slope, participants are covering more space (*x*-coordinates) in less time than if a trajectory has a lower intercept or a flatter slope. Therefore, faster movements toward the correct response would result in higher trajectories and more pronounced slopes. Faster movements toward the correct response in the incongruent condition of the Stroop or Flanker tasks (as a function of different levels

of age, bilingualism, or both) correspond to less interference, which is a good proxy for cognitive function. Participants with higher cognitive function should be better at inhibiting the distraction (e.g., ignoring the automatic reading or not looking at the surrounding fish) and selecting the appropriate response (e.g., focusing on the color of the word or on the center fish).

CHAPTER III

RESULTS

As discussed in the Introduction, I analyzed bilingualism and age as continuous variables. Bilingualism was operationally defined as the percentage of time that participants speak in their two languages (from 0% to 50%), and age was measured in years. I predicted better performance for those with higher levels of bilingualism (more balanced usage of their languages). I further predicted that performance would decline with increasing age.

Data Screening

There were 12 trials per condition (baseline, Flanker congruent, Flanker control, Flanker incongruent, Stroop congruent, Stroop control, Stroop incongruent) for a total of 84 target trials per participant. There was a grand total of 15,120 trajectories across the 180 participants. Incorrect responses, trials with initiation times greater than 500 ms, and trials

with reaction times greater than 5,000 ms were discarded. Consistent with previous research (Incera, Markis, & M^{c}Lennan, 2013; Krestar, Incera & M^{c}Lennan, 2013, Incera & M^{c}Lennan, 2016b), more than 90% of the trials were included in the final analyses (see Table 2). By analyzing the first one second of each trajectory (50 bins of 20 ms), the dataset included 401,650 data points in the Stroop task, and 389,500 in the Flanker task[6].

Table 2. Final percentage of trials included in the analyses.

		Stroop			*Flanker*		
	Baseline	*Congruent*	*Control*	*Incongruent*	*Congruent*	*Control*	*Incongruent*
Final % Included	94%	97%	95%	86%	95%	95%	76%
Initiation Times	84	168	172	171	158	163	161
Reaction Times	1,203	1,263	1,316	1,594	1,213	1,208	1,382

Baseline

Before exploring the effects of bilingualism and age on the two experimental tasks, I evaluated if there were differences in *x*-coordinates at baseline. There was a significant main effect of age ($\chi^2_{(1)} = 58.50$, $p < 0.001$) and a bilingualism by age interaction ($\chi^2_{(3)} =$

[6]It is important to highlight that 16 participants (out of 180) did not have any correct trials in the incongruent condition of the Flanker task. The Flanker task was presented first and it is possible that this subset of participants did not fully comprehend the instructions. The instructions read "Your task is to ignore the surrounding fish to simply **click on the response on the screen** (right or left square) corresponding to the side of the screen **the fish in the center is facing.**" These participants were systematically clicking on the side of the screen the majority of the fish (surrounding fish) were facing. If responding at random, approximately 50% of their trials should have been correct. Fortunately, mixed models are able to handle these missing data without difficulty (each trial is a separate row), so no data were excluded from the analysis.

15.47, $p = 0.001$) at baseline. First, aging had a significant impact on the baseline trajectory. Younger participants moved the mouse faster toward the correct response than older participants. In Figure 5, I plotted the baseline trajectories for participants in each decade. It is easy to observe the pattern in which younger participants (clearer lines) moved the mouse faster. This effect is likely to be a cohort effect. In general, younger adults are more familiar - and have had more practice - with computers than older adults.

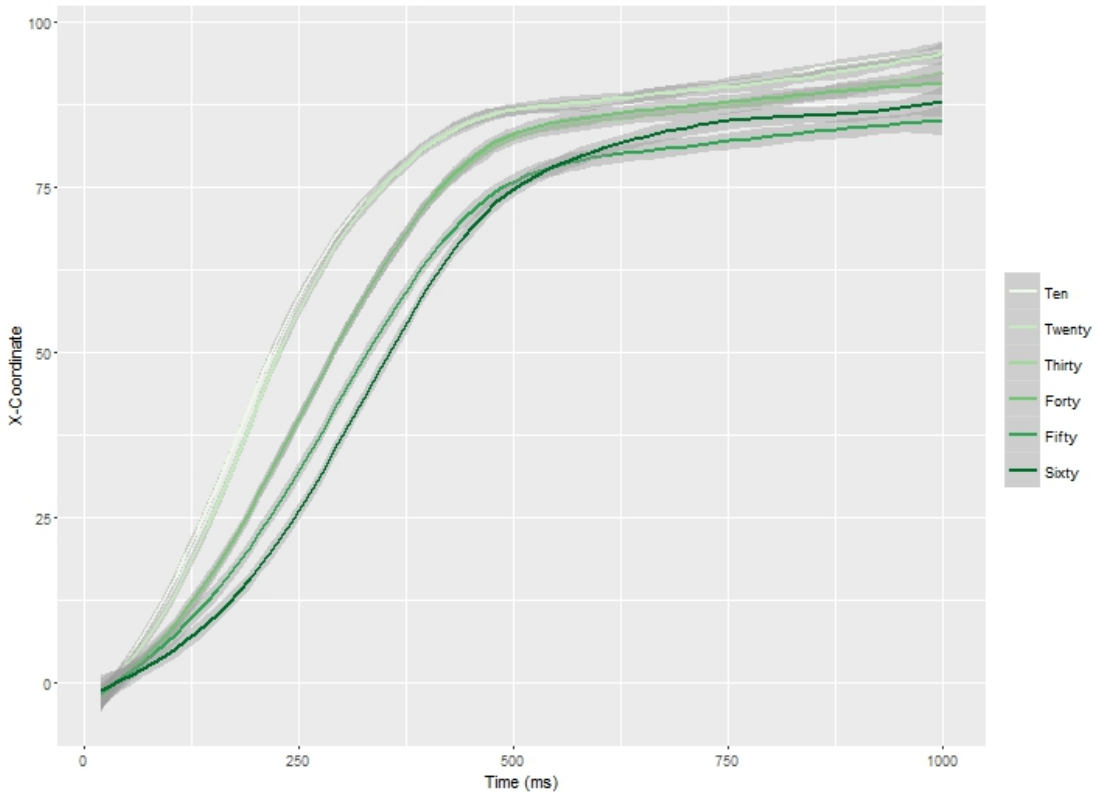


Figure 5. The initial one second of the baseline trajectories across six decades (Teens 18-19, Twenties 20-29, Thirties 30-39, Forties 40-49, Fifties 50-59, Sixties 60+). The shaded band is the 95% confidence interval.

Second, at baseline younger monolinguals moved faster toward the correct response than younger bilinguals, but this effect was not significant in older adults. In Figure 6, for

illustration purposes, I plotted the baseline trajectories for these four groups by dichotomizing the continuous variables bilingualism and age with a median split. The trajectories for bilinguals (Yes – Blue) and monolinguals (No – Red) are virtually on top of each other for older adults, but younger monolinguals moved faster toward the correct response. In conclusion, these significant effects at baseline suggest that it is most appropriate to focus on the interactions (the relative effects when comparing to participants' own baseline) for the following analyses in the experimental conditions.

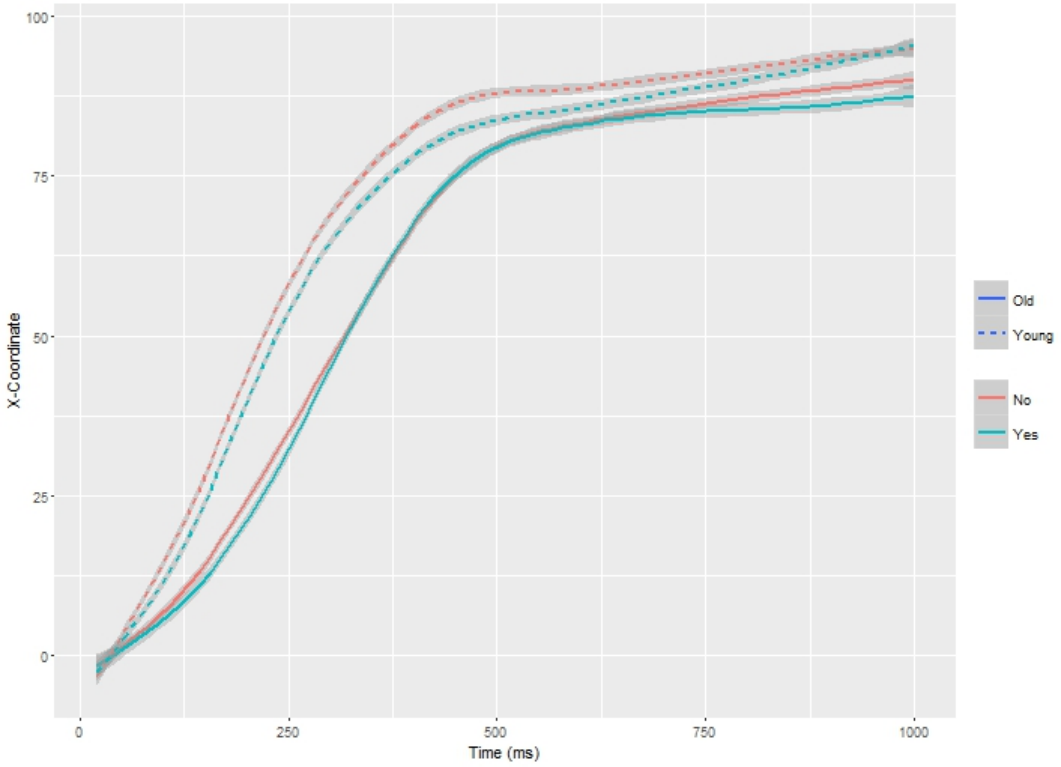


Figure 6. The initial one second of the baseline trajectories comparing younger (discontinuous lines) and older (continuous lines) adults, and bilinguals (blue lines) and monolinguals (red lines). The shaded band is the 95% confidence interval.

Stroop Task

Initiation Times

As reported in Table 3, there was no effect of Bilingualism, Age, or significant interactions for initiation times in the Stroop task.

Table 3

Model Comparison Results Evaluating Effects of Adding Parameters on Model Fit. Parameter Estimates for Analysis of Effects of Condition, Age, and Bilingualism on Initiation Times.

	Model Fit			*Comparisons*		
	χ^2	df	*p*	Estimate	SE	*t*
Condition	0.30	2	0.858	-1.47	8.70	-0.17
Bilingualism	0.06	1	0.802	3.17	6.28	0.51
Condition X Bilingualism	0.19	2	0.908	-1.20	8.88	-1.14
Age	0.84	1	0.357	5.53	6.21	0.86
Condition X Age	0.23	2	0.891	-2.50	8.87	-0.28
Condition X Bilingualism X Age	0.06	3	0.996	-0.61	10.24	-0.06

Reaction Times

In line with my predictions, there was a significant main effect of Condition and significant main effect of Age (see Table 4). Participants' reaction times were 334 ms longer in the incongruent condition. Older participants' reaction times were 237 ms longer than younger participants' reaction times. There was no significant main effect of Bilingualism and no significant interactions in the Stroop task.

Table 4

Analysis of Effects of Condition, Age, and Bilingualism on Reaction Times.

	Model Fit			*Comparisons*		
	χ^2	df	*p*	Estimate	SE	*t*
Condition	66.93	2	< 0.001	334	31	10.72*
Bilingualism	8.07	1	0.004	8.45	22.15	0.38
Condition X Bilingualism	0.51	2	0.778	-16.48	31.35	-0.52
Age	312	1	< 0.001	237	22	10.73*
Condition X Age	4.63	2	0.099	66.29	31.57	0.61
Condition X Bilingualism X Age	0.79	3	0.851	27.62	37.47	0.74

x-Coordinates

As discussed in the Methods section, the mouse-tracking paradigm provides the *x*-coordinates of the mouse position over time (ms). I analyzed the initial one second (50 bins of 20 ms) of the mouse trajectories over time using growth curve analysis (Incera & McLennan, 2016a; Mirman, 2014). This methodology allowed me to determine which variables improve model fit, and the influence of Bilingualism and Age on the mouse trajectories in the Stroop task.

The Model

In line with my predictions, there was a significant main effect of Condition, a significant Condition by Bilingualism interaction, and a significant main effect of Age (see Table 5). Participants' trajectories were less steep in the incongruent condition (Estimate = -17). Moreover, in the incongruent condition bilingual participants moved more directly to the correct response (Estimate = 2) than monolingual participants. Finally, younger

participants moved more directly to the correct response (Estimate = -3) than older participants.

Table 5

Model Comparison Results Evaluating Effects of Adding Parameters on Model Fit. Parameter Estimates for Analysis of Effects of Condition, Age, and Bilingualism on x-Coordinate.

	Model Fit			*Comparisons*		
	χ^2	df	*p*	Estimate	SE	*t*
Condition	319	4	< 0.001			
Intercept				-19.04	1.34	-14.26*
Slope				-17.31	0.94	-18.41*
Bilingualism	0.003	1	0.954			
Intercept				-1.27	0.95	-1.34
Slope				-0.75	0.67	-1.13
Condition X Bilingualism	11.00	5	0.051			
Intercept				2.29	1.34	1.70
Slope				1.99	0.94	2.11*
Age	62.57	1	< 0.001			
Intercept				-6.89	0.95	-7.26*
Slope				-2.97	0.67	-4.45*
Condition X Age	96.37	5	< 0.001			
Intercept				0.17	1.35	0.12
Slope				-1.05	0.95	-1.10
Condition X Bilingualism X Age	1.84	6	0.934			
Intercept				0.27	1.61	0.17
Slope				0.02	1.13	0.02

Including the Baseline Condition

After controlling for the baseline condition, there was a main effect of Condition, a Condition by Bilingualism interaction, a main effect of Age, and a Condition by Age interaction (see Table 6). First, participants' trajectories were not as steep in the incongruent condition (Estimate = -12). Second, in the incongruent condition bilingual participants' trajectories moved more directly to the correct response (Estimate = 3)

compared to monolingual participant's trajectories. Third, young participants' mouse trajectories moved more directly to the correct response than older participants' mouse trajectories (Estimate = -6). Finally, in the incongruent condition younger participants' trajectories moved more directly to the correct response (Estimate = -5) than older participants' trajectories.

Table 6

Analysis of Effects of Condition, Age, and Bilingualism on x-Coordinate after Including the Baseline condition.

	Model Fit			*Comparisons*		
	χ^2	df	*p*	Estimate	SE	*t*
Condition	1276	6	< 0.001			
Intercept				-46.06	1.28	-36.07*
Slope				-12.29	0.86	-14.26*
Bilingualism	0.27	1	0.602			
Intercept				-2.16	0.91	-2.38*
Slope				0.10	0.61	0.17
Condition X Bilingualism	13.92	7	0.052			
Intercept				3.17	1.28	2.47*
Slope				1.13	0.86	1.31
Age	154	1	< 0.001			
Intercept				-6.06	0.91	-6.68*
Slope				1.14	0.61	1.86
Condition X Age	166	7	< 0.001			
Intercept				-0.67	1.29	-0.51
Slope				-5.17	0.87	-5.92*
Condition X Bilingualism X Age	4.09	8	0.848			
Intercept				1.78	1.53	1.16
Slope				0.50	1.04	0.48

Controlling for Cognitive Reserve

After controlling for Cognitive Reserve, there was a main effect of Condition, a Condition by Bilingualism interaction, a main effect of Age, and a Condition by Age interaction (see Table 7). First, participants' trajectories were not as steep in the

incongruent condition (Estimate = -5). Second, in the incongruent condition bilingual participants' trajectories moved more directly to the correct response (Estimate = 3) compared to monolingual participants' trajectories. Third, young participants' mouse trajectories moved more directly to the correct response than older participants' mouse trajectories (Estimate = -6). Finally, in the incongruent condition younger participants had steeper trajectories (Estimate = -5) than older participants.

Table 7

Analysis after Controlling for Cognitive Reserve.

	Model Fit			*Comparisons*		
	χ^2	df	*p*	Estimate	SE	*t*
Cognitive Reserve				-3.01	0.003	-0.11
Condition	1344	6	< 0.001			
Intercept				-4.61	1.28	-36.07*
Slope				-1.23	0.86	3.07
Bilingualism	7.21	1	0.007			
Intercept				-2.16	0.91	-2.38*
Slope				1.04	0.61	0.17
Condition X Bilingualism	14.42	7	0.044			
Intercept				3.17	1.28	2.48*
Slope				1.13	0.86	1.31
Age	57.93	1	< 0.001			
Intercept				-6.01	0.98	-6.10*
Slope				1.14	0.61	1.87
Condition X Age	166	7	< 0.001			
Intercept				-6.64	1.29	-0.51
Slope				-5.17	0.87	-5.92*
Condition X Bilingualism X Age	4.10	8	0.848			
Intercept				1.78	1.53	1.16
Slope				0.50	1.03	0.48

Controlling for English Proficiency

After controlling for English Proficiency, there was a main effect of Condition, a Condition by Bilingualism interaction, a main effect of Age, and a Condition by Age

interaction (see Table 8). First, participants' trajectories were less steep in the incongruent condition (Estimate = -12). Second, in the incongruent condition bilingual participants' trajectories moved more directly to the correct response (Estimate = 3) compared to monolingual participants' trajectories. Third, younger participants' mouse trajectories moved more directly to the correct response than older participants' mouse trajectories (Estimate = -6). Finally, in the incongruent condition younger participants had steeper trajectories (Estimate = -5) than older participants.

Table 8

Analysis after Controlling for English Proficiency.

	Model Fit			*Comparisons*		
	χ^2	df	*p*	Estimate	SE	*t*
English Proficiency				0.12	0.050	2.35*
Condition	1276	6	< 0.001			
Intercept				-46.05	1.27	-36.09*
Slope				-12.29	0.86	-14.26*
Bilingualism	0.30	1	0.580			
Intercept				-1.81	0.92	-1.97
Slope				0.11	0.61	0.18
Condition X Bilingualism	13.92	7	0.052			
Intercept				3.18	1.28	2.48*
Slope				1.13	0.87	1.31
Age	158	1	< 0.001			
Intercept				-6.19	0.91	-6.82*
Slope				1.14	0.61	1.87
Condition X Age	167	7	< 0.001			
Intercept				-0.65	1.29	-0.50
Slope				-5.17	0.87	-5.92*
Condition X Bilingualism X Age	4.11	8	0.847			
Intercept				1.79	1.53	1.17
Slope				0.50	1.03	0.48

In summary, the significant effects were quite stable when comparing the general model to the models in which I controlled for baseline, cognitive reserve, and English proficiency. There was a strong Stroop effect (-19, -46, -5, -46), that was most reduced by controlling for cognitive reserve. There was a Condition by Bilingualism interaction (2, 3, 3, 3), which supports the claim that bilingualism has a positive impact on executive function. The bilingual effect was not reduced by controlling for cognitive reserve. There was a significant main effect of Age (-7, -6, -6, -6), older participants' trajectories were farther from the correct response when compared to younger participants' trajectories. Finally, after controlling for baseline a reliable Condition by Age interaction emerged (-1, -5, -5, -5), which supports the claim that younger adults performed better on the incongruent condition of the Stroop task. The main effect of Age was the only effect that emerged in the slope of the trajectories. Younger adults were not only faster overall, but the differences between younger and older adults were bigger at the end of the trajectory. The remaining effects (Condition, Bilingualism, and the interactions) emerged on the intercept of the trajectory, indicating that performance was better overall, but the effect size did not increase as time unfolded throughout each trial.

Flanker Task

Initiation Times

As reported in Table 9, there was no effect of Bilingualism, Age, or significant interactions for initiation times in the Flanker task.

Table 9

Analysis of Effects of Condition, Age, and Bilingualism on Initiation Times.

	Model Fit			*Comparisons*		
	χ^2	df	*p*	Estimate	SE	*t*
Condition	0.20	2	0.905	-0.82	8.80	-0.41
Bilingualism	0.70	1	0.402	2.62	6.24	0.42
Condition X Bilingualism	0.24	2	0.886	1.44	9.04	0.16
Age	0.06	1	0.802	3.28	6.23	0.53
Condition X Age	0.29	2	0.864	-5.60	9.08	-0.62
Condition X Bilingualism X Age	0.34	3	0.952	-4.38	10.52	-0.41

Reaction Times

There was a significant main effect of Condition and a significant main effect of Age (see Table 10). Participants' RTs were 200 ms longer in the incongruent condition. Younger participants' RTs were 211 ms faster than older participants' reaction times. There was no significant main effect of Bilingualism and no significant interactions in the Flanker task.

Table 10

Analysis of Effects of Condition, Age, and Bilingualism on Reaction Times.

	Model Fit			*Comparisons*		
	χ^2	df	*p*	Estimate	SE	*t*
Condition	28.01	2	< 0.001	200	30	6.60*
Bilingualism	1.64	1	0.200	5.98	21.54	0.28
Condition X Bilingualism	0.40	2	0.816	27.66	31.18	0.89
Age	253	1	< 0.001	211	21.51	9.82*
Condition X Age	0.73	2	0.694	14.61	31.32	0.47
Condition X Bilingualism X Age	1.86	3	0.601	38.87	36.31	1.07

x-Coordinates

The Model

In line with my predictions, there was a significant main effect of Condition, a significant main effect of Age, and a significant Condition by Age interaction (see Table 11). First, participants' trajectories were not as steep in the incongruent condition (Estimate = -6). Second, younger participants moved more directly to the correct response than older participants (Estimate = -2). Finally, in the incongruent condition younger adults moved more directly to the correct response (Estimate = -1) compared to older adults.

Table 11

Analysis of Effects of Condition, Age, and Bilingualism on x-Coordinate.

	Model Fit			*Comparisons*		
	χ^2	df	*p*	Estimate	SE	*t*
Condition	144	4	< 0.001			
Intercept				-13.87	1.08	-12.84*
Slope				-6.30	0.63	-9.91*
Bilingualism	0.40	1	0.527			
Intercept				-1.56	0.76	-2.05*
Slope				-0.46	0.45	-1.03
Condition X Bilingualism	1.64	5	0.896			
Intercept				0.24	1.11	0.21
Slope				-0.96	0.65	-1.47
Age	37.59	1	< 0.001			
Intercept				-6.27	0.76	-8.21*
Slope				-2.47	0.45	-5.51*
Condition X Age	130	5	< 0.001			
Intercept				2.34	1.11	2.11*
Slope				-1.41	0.65	-2.15*
Condition X Bilingualism X Age	8.07	6	0.233			
Intercept				-0.08	0.51	-0.15
Slope				-1.24	0.76	-1.64

Including the Baseline Condition

After controlling for the baseline condition there was a main effect of Condition, a significant main effect of Age, and a significant Condition by Age interaction (see Table 12). First, participants' trajectories were not as steep in the incongruent condition (Estimate = -6). Second, younger participants' mouse trajectories moved more directly to the correct response than older participants' mouse trajectories (Estimate = -6). Finally, in the incongruent condition trajectories moved more directly to the correct response for younger adults (Estimate = -5). No effects of bilingualism emerged.

Table 12

Analysis of Effects of Condition, Age, and Bilingualism on x-Coordinate after Including the Baseline condition.

	Model Fit			*Comparisons*		
	χ^2	df	*p*	Estimate	SE	*t*
Condition	1062	6	< 0.001			
Intercept				-13.87	1.08	-12.84*
Slope				-6.30	0.63	-9.91*
Bilingualism	1.59	1	0.207			
Intercept				-2.58	0.77	-3.34*
Slope				-0.05	0.44	-0.11
Condition X Bilingualism	2.18	7	0.949			
Intercept				1.25	1.12	1.12
Slope				-1.34	0.63	-2.14*
Age	126	1	< 0.001			
Intercept				-6.46	0.77	-8.39*
Slope				1.03	0.43	2.37*
Condition X Age	170	7	< 0.001			
Intercept				2.55	1.12	2.27*
Slope				-4.90	0.63	-7.74*
Condition X Bilingualism X Age	11.79	8	0.161			
Intercept				0.98	1.30	0.76
Slope				-0.55	0.73	-0.74

Controlling for Cognitive Reserve

After controlling for cognitive reserve there was a main effect of Condition, a significant main effect of Age, and a significant Condition by Age interaction (see Table 13). First, participants' trajectories were not as steep in the incongruent condition (Estimate = -36). Second, younger participants moved more directly to the correct response than older participants (Estimate = -7). Finally, in the incongruent condition younger adults moved more directly to the correct response than older adults (Estimate = -5). No effects of bilingualism emerged.

Table 13

Analysis after Controlling for Cognitive Reserve.

	Model Fit			*Comparisons*		
	χ^2	df	*p*	Estimate	SE	*t*
Reserve				0.004	0.003	1.49
Condition	1091	6	< 0.001			
Intercept				-35.57	1.09	-32.71*
Slope				3.66	0.62	5.93
Bilingualism	9.73	1	0.002			
Intercept				-2.51	0.77	-3.25*
Slope				-0.05	0.44	-0.11
Condition X Bilingualism	2.31	7	0.941			
Intercept				1.25	1.11	1.12
Slope				-4.90	0.63	-7.74*
Age	66.39	1	< 0.001			
Intercept				-7.10	0.88	-8.08*
Slope				1.03	0.43	2.37*
Condition X Age	170	7	< 0.001			
Intercept				2.55	1.12	2.28*
Slope				-4.90	0.63	-7.74*
Condition X Bilingualism X Age	11.86	8	0.157			
Intercept				0.98	1.29	0.76
Slope				-0.55	0.73	-0.74

Controlling for English Proficiency

After controlling for English proficiency there was a main effect of Condition, a significant main effect of Age, and a significant Condition by Age interaction (see Table 14). First, participants' trajectories were not as steep in the incongruent condition (Estimate = -36). Second, younger participants moved more directly to the correct response than older participants (Estimate = -7). Finally, in the incongruent condition younger participants moved more directly to the correct response than older participants (Estimate = -5). No effects of bilingualism emerged.

Table 14

Analysis after Controlling for English Proficiency.

	Model Fit			*Comparisons*		
	χ^2	df	*p*	Estimate	SE	*t*
English Proficiency				0.19	0.62	5.93*
Condition	1063	6	< 0.001			
Intercept				-35.62	1.08	-32.98*
Slope				3.66	0.62	5.93*
Bilingualism	0.52	1	0.469			
Intercept				-2.03	0.78	-2.59*
Slope				-0.05	0.44	-0.11
Condition X Bilingualism	2.18	7	0.950			
Intercept				1.23	1.12	1.11
Slope				-1.36	0.63	-2.15*
Age	137	1	< 0.001			
Intercept				-6.69	0.76	-8.74*
Slope				1.03	0.43	2.37*
Condition X Age	169	7	< 0.001			
Intercept				2.50	1.11	2.25*
Slope				-4.90	0.63	-7.74*
Condition X Bilingualism X Age	11.74	8	0.163			
Intercept				-0.78	0.51	-1.55
Slope				-0.55	0.74	-0.75

In summary, the significant effects were quite stable when comparing the general model to the models in which I controlled for baseline, cognitive reserve, and English proficiency. The effects of Flanker and Age emerged in the slope of the trajectories. There was a strong Flanker effect (-14, -14, -36, -36) across all models that was maximized when controlling for cognitive reserve and English proficiency. There were no significant effects of Bilingualism[7]. There was a significant main effect of Age (-6, -6, -7, -7), younger participants' trajectories moved more directly to the correct response compared to older participants' trajectories. This main effect of age was equivalent across the Stroop and Flanker tasks. Finally, there was a reliable Condition by Age interaction across all models (-1, -5, -5, -5), that replicates the pattern for results from the Stroop task (a weaker interaction before controlling for baseline).

[7]When combining both tasks a significant Task X Bilingualism interaction emerged. Higher levels of bilingualism resulted in better performance in the Stroop task (*Estimate* = 2.91, *SE* = 1.23, *t* = 2.36*), but not in the Flanker task (*Estimate* = 1.01, *SE* = 1.23, *t* = 0.82).

CHAPTER IV

DISCUSSION

When comparing the results across both tasks it is possible to observe that the significant 3-way interaction (Condition by Bilingualism by Age) does not emerge[8]. The model that best fits the data is the one that accounts for the contribution of Bilingualism and Age separately. The fact that these two factors influence cognitive function without interacting with one another has practical implications. First, there is an effect of aging across all levels of bilingualism; even those who are highly balanced bilinguals will experience cognitive decline during their adult life-span. Second, the positive effect of bilingualism can have an impact at any point during the life-span. It is not the case that the

[8]It is possible that in the present study I did not have sufficient power to detect the Condition X Bilingualism X Age interaction. An alternative (and more plausible, in my opinion) possibility is that the 3-way interaction only emerges in samples that include pre-clinical/clinical populations of older adults.

advantages of speaking more than one language are greater in older adults. All ages are likely to benefit equally.

A Bilingualism by Age interaction emerged at baseline; therefore, I will not focus on interpreting the main effects of these constructs. Instead, I will discuss the Condition by Bilingualism interaction (is the positive effect of bilingualism bigger in the incongruent condition?) and the Condition by Age interaction (is the negative effect of age bigger in the incongruent condition?). By controlling for each participants' baseline, these interactions can better explain the effects of bilingualism and age on cognitive function. Having a baseline trajectory is a strength of the present study. Including the baseline trajectory in the analyses makes it possible to control for individual differences in mouse movements.

First, a reliable Condition-by-Age interaction emerged across all models. The difference between younger and older adults was greatest in the incongruent trajectories. This interaction supports the Inhibition Deficit Theory (Hasher & Zacks, 1988), according to which older adults are impaired when inhibiting irrelevant information (for a detailed theoretical discussion of this interaction in mouse tracking see Incera, Krestar, Markis, McLennan, & Allard, 2016). Second, a reliable Condition-by-Bilingualism interaction emerged in the Stroop but not in the Flanker task. In the Stroop task, a measure of response inhibition, the Condition-by-Bilingualism interaction was reliable, even after controlling for cognitive reserve and English proficiency. Bilingualism was positively associated with performance in the incongruent condition of the Stroop task. The fact that no significant effect of bilingualism emerged in the Flanker task warrants a detailed explanation. Even though previous studies have obtained a positive effect of bilingualism in the Flanker task

(e.g., Abutalebi et al., 2015), there have been studies that failed to replicate this effect (e.g., Paap & Greenberg, 2013).

One explanation for the null effect of bilingualism in the Flanker task is that the advantage of bilingualism is only relevant – or more relevant – to response inhibition (a construct captured in the Stroop task), but not – or less so – to attention selection (the construct measured by the Flanker task). In the present study the same participants completed the Stroop and Flanker tasks but the bilingual advantage only emerged in the Stroop task. These results support the idea that these two tasks are sensitive to different components of cognitive function. Bilinguals are constantly managing their two languages (inhibiting one while using the other) so the bilingual experience might be more closely aligned with response inhibition than attention selection. Even though both tasks might be measuring a type of inhibition, the present results challenge a unitary account of executive function (for a discussion of this topic see Incera, Benson, & M^{c}Lennan, 2016). In a recent paper, my coauthors and I evaluated the time course of response inhibition and attention selection using verbal and non-verbal stimuli (Incera, Benson, & M^{c}Lennan, 2016). We reported that the effect of attention selection is weaker - and emerges later in the trajectory - than the effect of response inhibition. Importantly, these trends were stable regardless of stimuli type (verbal or non-verbal).

An alternative explanation is that the positive effect of bilingualism only emerges under difficult conditions. If this is the case, it would be possible to observe the bilingual advantage in a difficult version of the Stroop or Flanker task, but not in an easy version of either of these tasks. This argument is supported by evidence that the bilingual advantage is greater in conditions with higher working memory demands (Bialystok, Craik, Klein, &

Viswanathan, 2004). Moreover, this idea is closely related to that of the conflict monitoring hypothesis (Botvinick et al., 1999), according to which the effect of bilingualism only emerges in high monitoring conditions. If this is the case, the Flanker task used in the present experiment might have been too easy[9] to capture the benefits of being bilingual. In addition to the mouse-tracking experiment mentioned above (Incera, Benson, & McLennan, 2016), support for this argument comes from RT measures in the present study. The mean RT for the incongruent condition in the Stroop task was 1,594 ms, compared to 1,382 ms in the Flanker task (the control condition in the Stroop task was 1,316). Within the same sample of participants, the effect of bilingualism emerged in the Stroop task (a relatively challenging task with longer RTs) but not in the Flanker task (a much easier task designed for children). Therefore, the difficulty of the task has the potential to play a role regarding the bilingual advantage. Future studies should manipulate the difficulty of the task to determine the extent to which difficulty influences these effects.

A final possibility is that different analyses capture different aspects of cognitive function. Abutalebi et al. (2015) found the bilingual advantage in the Flanker task by performing an ex-Gaussian analysis, while Paap and Greenberg (2013) reported a null effect after analyzing mean RTs. Researchers should consider analyzing different aspects of the distribution (parameters such as mu, sigma, and tau) before concluding that there is a null effect. In addition, it is also important to be clear on the definition of bilingualism. For the analyses reported in this document I operationalized bilingualism as "language

[9]I selected a children's version of the Flanker task ("Friendly Fish") in order to compare cognitive function across the full lifespan. While this task was sufficiently sensitive to observe significant bilingual effects in children, it might have been too easy for the bilingual advantage to emerge in adults.

usage", the percentage of time participants speak in their different languages. Different aspects of the bilingual experience (e.g., proficiency, number of languages, similarity between the languages, age of acquisition…) could yield different results. Researchers need to be very clear when defining what they mean by bilingualism (Luk & Bialystok, 2013).

According to Paap and Greenberg (2013), in order to clarify whether or not there are genuine bilingual advantages, compelling evidence should follow several guidelines. First, "identify the specific component(s) of executive processing that should be enhanced by managing two languages." This dissertation research sheds some light on this issue by comparing attention selection and response inhibition. Measuring the same sample of individuals in both tasks, the bilingual advantage only emerged in response inhibition. As argued above, these two constructs might be less related than previously thought. Second, "show a bilingual advantage in an indicator of that component across two different tasks." If the bilingual advantage emerges in response inhibition (but not attention selection) a non-verbal response inhibition task (e.g., Simon task) would be a good task to use in order to replicate these effects. Bialystok et al. (2004) found that bilingualism was associated with smaller Simon effects costs for middle age and older adults. I considered the Simon task for the present study, but in this task the stimuli are presented in different locations on the screen (right or left), which could present a challenge when using the mouse-tracking paradigm. Third, "show that the indicators correlate with one another and have some degree of convergent validity." Friedman and Miyake (2004) made an important contribution to the literature regarding this topic, but future studies should further evaluate the degree of convergent validity between different measures of executive function. Finally, "show no

differences between the two groups on a pure block of easy choice-RT trials", "match the groups on SES", and "minimize cultural differences between the groups". In the present study, various demographic variables were measured and were statistically controlled for. The Stroop X Bilingualism interaction remained intact after controlling for cognitive reserve, a composite that included education, reading, work activity, and leisure activities[10] (Incera & M^{c}Lennan, 2016c). In summary, these guidelines are helpful suggestions for future research; the present investigation is a crucial first step in this direction.

An important advantage of using the mouse-tracking paradigm is the potential to evaluate the time course of these effects. In order to compare the effects of bilingualism and age, I focused on the incongruent condition of the Stroop task (see Figure 7). In Figure 7 it is easy to observe that the effect of aging emerges earlier in the trajectory and is much more pervasive than the effect of bilingualism. Nevertheless, as discussed in the results' section, this pattern is difficult to interpret because of the group differences at baseline. Incera and M^{c}Lennan (2016a) found that the effect of bilingualism in younger adults emerged as early as 200 ms. In terms of the size of the estimates (the relative difference with their own baseline), the detrimental effect of age (*Estimate* = -5) is greater than the positive effect of bilingualism (*Estimate* = +3). Despite the fact that the positive effect of bilingualism is not sufficiently large to completely offset the effect of aging, it is important to keep in mind that in the present experiment bilingualism can still offset 60% of age-

[10]A more detailed analysis of the influence of these additional variables on cognitive function was presented as a poster at the 2016 Cognitive Aging Conference.

related cognitive decline. Future work should study the time course of the relative differences in these trajectories.

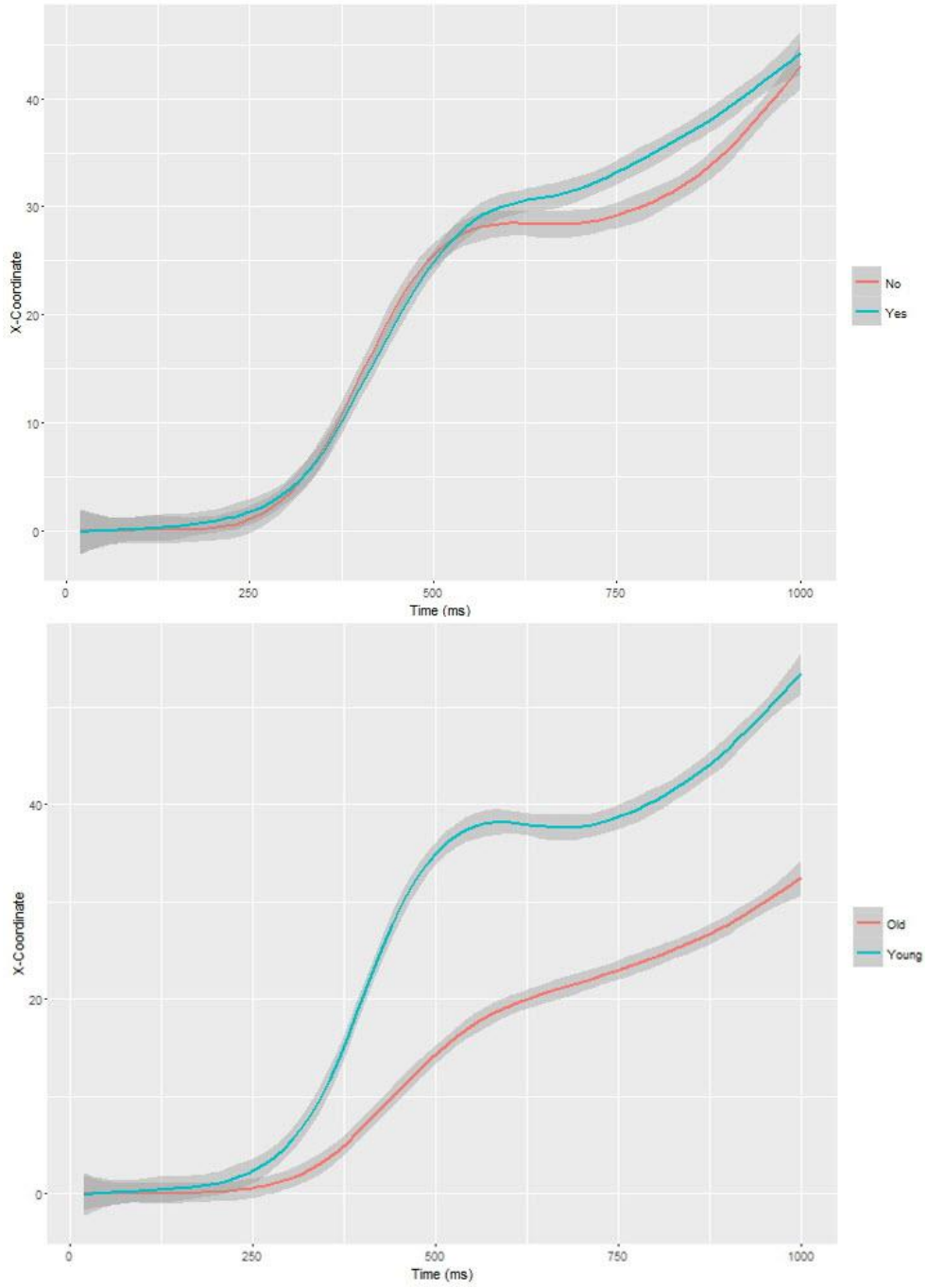


Figure 7. The initial one second of the mean trajectories comparing the main effects of bilingualism (top) and age (bottom). The shaded band is the 95% confidence interval.

The purpose of the current study was to analyze the effects of bilingualism and age (as continuous measures) on cognitive function. Previous studies have made inferences based on the dichotomization of bilingualism and age (e.g., bilinguals/monolinguals, young/old). Dichotomization of a continuous variable not only has negative consequences at the statistical level (Maxwell & Delaney, 1993; MacCallum et al., 2002), but dichotomization limits the questions to: Does bilingualism impact cognition? Does aging impact cognition? My data support the idea that varying degrees of the same construct (bilingualism or age) result in different levels of cognitive function. It is not the case that age-related decline emerges at age 60; instead, my data show a steady decline with every decade. Moreover, different levels of language usage also resulted in different levels of cognitive function. Mouse-tracking data provided a richer analysis of the responses, making it possible to observe differences in the time course of these effects. The question is no longer "if" bilingualism or aging impacts cognition, but "under which circumstances" are effects of bilingualism and aging likely to emerge.

An important contribution of the present study is studying the effect of bilingualism on a continuum. As depicted in Figure 8, in the Stroop task bilinguals not only outperformed monolinguals, but more balanced bilinguals (language usage closer to 50-50%) outperformed those who were less balanced (language usage closer to 20-80%). Furthermore, a detailed analysis of which aspects of bilingualism impact cognitive function is necessary to better understand the types of intervention that would be most likely to succeed. For example, if usage is at the root of these effects, classic instructional environments, where participants do not use their two languages in their everyday lives, are likely to have a smaller benefit on cognitive function. If usage – how much you use the

two languages – is at the root of the cognitive advantage, immersion settings (e.g., travel abroad programs) would be a better way to maximize these effects. Future studies need to determine which aspects of the bilingual experience play the biggest role in increasing cognitive function.

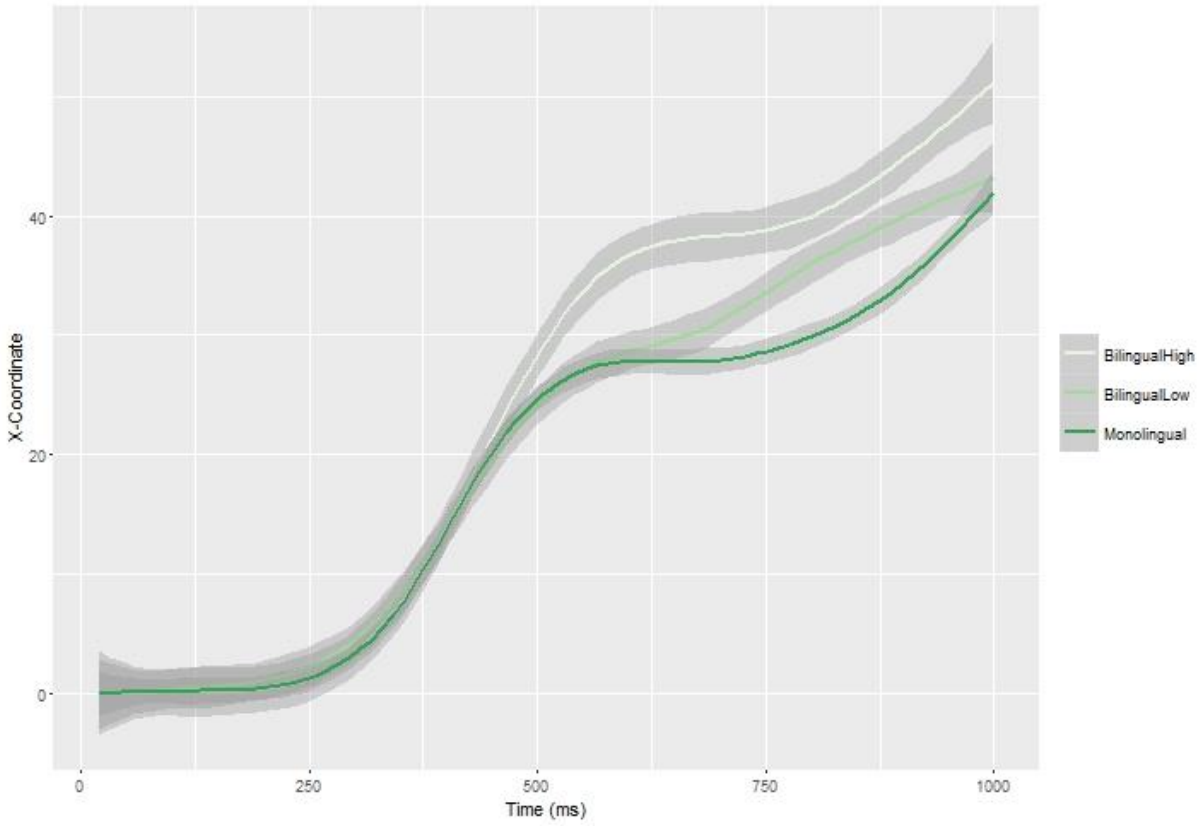


Figure 8. The initial one second of the trajectories comparing three levels of bilingualism in the incongruent condition of the Stroop task. The shaded band is the 95% confidence interval.

The Transmission Deficit Theory (Mackay & Burke, 1990, Burke, MacKay & James, 2000) proposes that age differences increase when new connections are necessary. Engaging in stimulating activities can increase the number of connections and prevent

cognitive decline. Being bilingual is presumably associated with having a higher number of connections and results in more efficient processing across the life-span. Leaning a new language can create new connections in the brain that may delay cognitive decline. Speaking more than one language is one of a number of stimulating activities that can enhance cognitive reserve, a protective factor against cognitive decline across the adult life-span. Understanding the circumstances under which bilingualism maximizes cognitive function should contribute to the development of new training programs or clinical interventions (for prevention, treatment, or both).

In the present study I did not obtain the expertise pattern that I predicted (Incera & M^{c}Lennan, 2016a). The study where we found expertise effects was particularly challenging because it included randomized English and Spanish trials in the same Stroop task. Moreover, it is possible that the current Stroop task was less difficult because it followed a Flaker task that gave participants practice at ignoring irrelevant information. In line with the argument stated above regarding the impact of task difficulty – or lack thereof – in finding the bilingual advantage, it is possible that the tasks presented here were not sufficiently challenging to elicit the expertise pattern.

The present research has limitations. First, the current dissertation research is a cross-sectional study; therefore, I cannot distinguish between age and cohort effects. Nevertheless, cognitive decline is typically smaller within participants (age effect) than across participants (cohort effect), so the cognitive advantage of being bilingual could offset an even bigger proportion of the decline due to normal aging. Cross-sequential studies (e.g., Schaie, 1996) have shown that the differences between generations (cohort differences), are greater than the decline a single person experiences across his or her own

life (age differences). If I am overestimating the real effect of aging (by adding cohort effects), the proportion of age-related decline that the effect of bilingualism could curtail has the potential to be bigger than the 60% reported here. Second, language usage was obtained through self-report[11], which might be different than objective measures of the same construct. As discussed in the Introduction, self-report has the advantage of including a wide range of sources of information, but the disadvantage of being an off-line measure of metalinguistic knowledge. Future research should develop more detailed and statistically sound measures of the bilingual experience to overcome this limitation. Finally, despite my best efforts to collect a large and diverse sample, to statistically control for differences at baseline and for other relevant variables (e.g., education, work, reading, etc.), it is possible that spurious variables are influencing these results. Future research should recruit larger and more diverse samples to investigate the role that any such differences may have contributed to the results obtained in the current study.

More attention has been paid to cognitive aging in the last few decades because of the increasing age of the population. Understanding how environmental aspects that are modifiable and can be trained, such as bilingualism, might affect cognitive function has strong practical and theoretical implications. Recent research has supported the idea that the adult brain is capable of plastic change, an important theoretical revolution for interventions. Experience and training can alter the course of cognitive aging (Greenwood, 2007). The potential of behavior to influence levels of cognitive functioning has been reviewed by Hertzog, Kramer, Wilson, and Lindenberger (2008). These authors argued

[11] Language proficiency measured with the MINT (an objective measure) did not predict cognitive function.

that maintaining an intellectually engaged and physically active lifestyle promotes successful cognitive aging. The question remains, what constitutes an active lifestyle? Findings from the present dissertation research could influence future work by emphasizing the need to be precise in defining the degree of engagement necessary. If the goal is to maximize cognitive function, it is crucial to understand "how active" your lifestyle needs to be.

In conclusion, bilingualism offset approximately 60% of age-related cognitive decline in the current study. Crucially, I measured the effects of bilingualism and age as continuous variables. This conceptualization allowed for better statistical analyses (more power) and it provided answers to new questions. I strongly recommend researchers to measure continuous variables as such, and to include categorical variables only when using an experimental manipulation (e.g., learning or not a second language) or when adding truly categorical variables (e.g., language type, country of origin). Importantly, this study increased our theoretical understanding of the bilingual advantage, while providing detailed information that can be used to develop better interventions. Interventions that increase cognitive function can significantly impact our society by increasing well-being and delaying the onset of dementia.

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Cleveland State University
engagedlearning

PARTICIPANT CONSENT FORM: LANGUAGE ACROSS THE LIFESPAN

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Sara Incera is a doctoral student working under Dr. McLennan's supervision. Dr. McLennan is an Associate Professor in the Department of Psychology at Cleveland State University. The goal of the present experiment is to learn more about the relationship between language and cognition at different ages.

First, you will answer a language history questionnaire. Second, you will be given two tasks on a laptop. In these tasks, you will see words or pictures on a computer screen, and you will respond by clicking on a response with a computer mouse. Finally, you will be asked to name some pictures in English.

The questionnaire will take about 20 minutes. The tasks will also take about 20 minutes. You will participate for a maximum of 1 hour. You can ask questions at any time. In order to make sure your identity is confidential, we will assign you a number. All of your information will be coded with that number instead of your name.

You will receive **1 credit** of research participation or **$20** for your participation. You may stop participating in the experiment at any time. You will be excused without loss of credit or money. The 1 credit or $20 will be given to you even if you decide to discontinue or withdraw.

The direct benefits of this experiment are 1 credit or $20. Participation in this experiment involves no known risks beyond those associated with daily living. Your participation is voluntary. There are two copies of this informed consent form, one for the researchers and one for you to keep for your own records.

Thank you!

"I am 18 years or older, and I understand this consent form. I understand that if I have any questions about my rights as a research subject, I can contact the Cleveland State University Institutional Review Board at (216) 687-3630."

_____ _____
Signature of Participant *Date*

_____
Name of Participant (PLEASE PRINT) *E-mail address* *Telephone Number*

_____ _____
Signature of Researcher *Date*

QUESTIONNAIRE: LANGUAGE ACROSS THE LIFESPAN
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FOR LRL USE:
Room #_____
Participant #_____
_____ (credits) OR $_____
Experiment _____
Date _____
Experimenter _____

Please fill in the following information:

A. Date of Birth: _____ Place of birth (City):_____

Gender: _____ Current Job:_____

B. Are you (circle one): right-handed left-handed ambidextrous

C. Write down the name of the language(s) used by your teachers for general instruction (e.g. history, math, science) at each schooling level. If you switched language within a given school level, write a note such as "switched from X language to Y language at Grade Y".

- Primary/Elementary School: _____
- Secondary/Middle School: _____
- High School: _____
- College/University: _____ Major: _____

D. Your country of origin: _____

Place of Longest Residence (City): _____

Your country of current residence: _____

How long have you been in the country of your current residence?

_____ (years) _____ (months)

E. Would you like to be added to (or remain on) our "Paid Participants Database" so that we can notify you in the future of paid experiments for which you are eligible to participate? _____

F. If you have lived or travelled in other countries for more than three months, please indicate the name(s) of the country or countries, your length of stay, the language(s) you learned or tried to learn, and the frequency of your use of the language while in that country according to the following scale (circle the number in the table):

Never *Rarely* *Occasionally* *Sometimes* *Frequently* *Very Frequently* *Always*
1 _____ 2_____ 3_____ 4_____ 5_____ 6_____ 7_____

Country	Length of Stay (cumulative)	Language	Frequency of Use
			1 2 3 4 5 6 7
			1 2 3 4 5 6 7
			1 2 3 4 5 6 7
			1 2 3 4 5 6 7

G. Do you mix words or sentences from two languages in your own speech (e.g. saying a sentence in one language but use a word or phrase from another language in the middle of the sentence)?

__ Yes

__ No

H. How often do you use your languages for the following activities? Circle the number in the table according to the scale below.

Never *Rarely* *Occasionally* *Sometimes* *Frequently* *Very Frequently* *Always*
1 _____ 2_____ 3_____ 4_____ 5_____ 6_____ 7_____

Language	Arithmetic (e.g. count, add, multiply)	Remember numbers (e.g. student ID, telephone)	Dream	Think	Talk to yourself	Express anger or affection
	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7
	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7
	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7
	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7

Northwestern Bilingualism & Psycholinguistics Research Laboratory
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Adapted to pencil-and-paper version by Marilyn Logan

Language Experience and Proficiency Questionnaire (LEAP-Q)

Participant Code		**Study Code**		Today's Date	
Age		Date of Birth		Male ☐	Female ☐

(1) Please list all the languages you know **in order of dominance**:

1	2	3	4	5

(2) Please list all the languages you know **in order of acquisition** (your native language first):

1	2	3	4	5

(3) Please list what percentage of the time you are *currently* and *on average* exposed to each language. (*Your percentages should add up to 100%*):

List language here:					
List percentage here:					

(4) When choosing to read a text available in all your languages, in what percentage of cases would you choose to read it in each of your languages? Assume that the original was written in another language, which is unknown to you. *(Your percentages should add up to 100%*):

List language here:					
List percentage here:					

(5) When choosing a language to speak with a person who is equally fluent in all your languages, what percentage of time would you choose to speak each language? Please report percent of total time. (*Your percentages should add up to 100%*):

List language here					
List percentage here:					

(6) Please name the cultures with which you identify. On a scale from zero to ten, please rate the extent to which you identify with each culture. (Examples of possible cultures include US-American, Chinese, Jewish-Orthodox, etc.):

Culture: _____

0 1 2 3 4 5 6 7 8 9 10

No identification | Very low identification — Moderate identification — Complete identification

Culture: _____

0 1 2 3 4 5 6 7 8 9 10
No identification | Very low identification — Moderate identification — Complete identification

Culture: _____

0 1 2 3 4 5 6 7 8 9 10
No identification | Very low identification — Moderate identification — Complete identification

Culture: _____

0 1 2 3 4 5 6 7 8 9 10
No identification | Very low identification — Moderate identification — Complete identification

Culture: _____

0 1 2 3 4 5 6 7 8 9 10
No identification | Very low identification — Moderate identification — Complete identification

(7) How many years of formal education do you have? _____

Please check your highest education level (or the approximate US equivalent to a degree obtained in another country):

- ☐ Less than High School
- ☐ High School
- ☐ Professional Training
- ☐ Some College
- ☐ College
- ☐ Some Graduate School
- ☐ Masters
- ☐ Ph.D./M.D./J.D.
- ☐ Other:

(8) Date of immigration to the USA, if applicable _____

If you have ever immigrated to another country, please provide name of country and date of immigration here.

_____

(9) Have you ever had a vision problem☐, hearing impairment☐, language disability☐, or learning disability ☐? (Check all applicable).

If yes, please explain (including any corrections):

_____

Language:

This is my (**native second third fourth fifth**) language.

(1) Age when you…

began acquiring this language:	*became fluent in this language*:	*began reading in this language*:	*became fluent reading in this language*:

(2) Please list the number of years and months you spent in each language environment:

	Years	Months
A country where this language is spoken		
A family where this language is spoken		
A school and/or working environment where this language is spoken		

(3) Please circle your *level of* ***proficiency*** in speaking, understanding, and reading in this language:

Speaking

0 1 2 3 4 5 6 7 8 9 10

None Very low Low Fair Slightly less than adequate Adequate Slightly more than adequate Good Very good Excellent Perfect

Understanding spoken language

0 1 2 3 4 5 6 7 8 9 10

None Very low Low Fair Slightly less than adequate Adequate Slightly more than adequate Good Very good Excellent Perfect

Reading

0 1 2 3 4 5 6 7 8 9 10

None Very low Low Fair Slightly less than adequate Adequate Slightly more than adequate Good Very good Excellent Perfect

(4) Please circle how much the following factors contributed to you learning this language:

Interacting with friends

0 1 2 3 4 5 6 7 8 9 10

Not a contributor Minimal contributor Moderate contributor Most important contributor

Interacting with family

0 1 2 3 4 5 6 7 8 9 10

Not a contributor Minimal contributor Moderate contributor Most important contributor

Reading

0 1 2 3 4 5 6 7 8 9 10

Not a contributor Minimal contributor Moderate contributor Most important contributor

Language tapes/self-instruction

0 1 2 3 4 5 6 7 8 9 10

Not a contributor Minimal contributor Moderate contributor Most important contributor

Watching TV

0	1	2	3	4	5	6	7	8	9	10
Not a contributor	Minimal contributor				Moderate contributor					Most important contributor

Listening to the radio

0	1	2	3	4	5	6	7	8	9	10
Not a contributor	Minimal contributor				Moderate contributor					Most important contributor

(5) Please circle to what extent you are currently exposed to this language in the following contexts:

Interacting with friends

0	1	2	3	4	5	6	7	8	9	10
Never	Almost Never				Half of the time					Always

Interacting with family

0	1	2	3	4	5	6	7	8	9	10
Never	Almost Never				Half of the time					Always

Watching TV

0	1	2	3	4	5	6	7	8	9	10
Never	Almost Never				Half of the time					Always

Listening to radio/music

0	1	2	3	4	5	6	7	8	9	10
Never	Almost Never				Half of the time					Always

Reading

0	1	2	3	4	5	6	7	8	9	10
Never	Almost Never				Half of the time					Always

Language-lab/self-instruction

0	1	2	3	4	5	6	7	8	9	10
Never	Almost Never				Half of the time					Always

(6) In your perception, how much of a foreign accent do you have in this language?

0	1	2	3	4	5	6	7	8	9	10
None	Almost none	Very light	Light	Some	Moderate	Considerable	Heavy	Very heavy	Extremely heavy	Pervasive

(7) Please circle how frequently others identify you as a non-native speaker based on your <u>accent</u> in this language:

0	1	2	3	4	5	6	7	8	9	10
Never	Almost Never				Half of the time					Always

CRIq

Cognitive Reserve Index questionnaire

M. Nucci, D. Mapelli & S. Mondini

Instructions: The CRIq can be administered by a family member or the caregiver when the participant cannot be interviewed due to attested or suspected cognitive decline. Check the appropriate box at the bottom of the questionnaire.

Surname: ..... Name: .....

Date of birth: ...../...../..... Place of birth: ..... Age: .....

Place of residence: ..... Nationality: .....

Civil status: single ☐ married ☐ divorced ☐ widowed ☐

CRI-*Education*

Instructions: Count 1 for each year of education. Count 0.5 for every 6-month period of vocational training courses taken.

	Years
1. Years of education (including postgraduate studies and any specialization)	.....
2. Vocational training (0.5 for every 6 months)	.....

CRI-*WorkingActivity*

Instruction: Indicate working years rounded off on on a five-year scale (0-5-10-15-20, etc.; e.g., if a person has been working for 17 years, write down 20). The degree of intellectual involvement and personal responsibility discriminates between the 5 levels of working activity. Report on all working activities, even in the case of simultaneously held multiple jobs.

	Years
1. Low skilled manual work (agricultural worker, gardener, house keeping (hotel), waiter, driver, mechanic, plumber, call center operator, electrician, etc.)	.....
2. Skilled manual work (craftsman, clerk, cook, shop assistant, tailor, nurse, professional soldier, barber/hair dresser, etc.)	.....
3. Skilled non manual work (shopkeeper, white-collar worker, priest or monk/nun, sales representative, real estate agent, nursery school teacher, musician, etc.)	.....
4. Professional occupation (CEO of a small company, qualified freelancer, teacher, contractor, lawyer, engineer, etc.)	.....
5. Highly responsible or intellectual occupation (CEO of a large company, judge, university professor, top manager, politician, surgeon, etc.)	.....

CRI-*LeisureTime*

Instructions:

- Each item refers to activities carried out regularly throughout adult life (i.e. from 18 years onwards).
- All paid activities are excluded from this section (for paid activities, return to CRI-WorkingActivity).
- Register answers according to the frequency mentioned for each activity (e.g., weakly, monthly, annual).
- The column Years refers to the number of years in which the mentioned activity has been carried out Often/Always, overstating according to a scale of 5 to 5 years (5-10-15-20, etc.). For example, whether a person regularly reads a newspaper for 27 years, will be registered Often/Always for 30 years, even if he/she has stopped reading for many years.
- If the activity has never or seldomly been carried out (option Never/Rarely) the number of years need not be indicated.
- If over the participants lifespan the activity changed in frequency in a significant manner, only the period (in number of years) of the highest frequency is to be considered. For example, if a person drove a car every day for 40 years, but in the following 15 years he/she did so only once or twice a week, than the answer is Often/Always for 40 years.

1. ACTIVITIES WITH WEEKLY FREQUENCY

	less or equal then 2 times in a week	more or equal then 3 times in a week	Years
1. Reading newspapers and magazines	☐ Never/Rarely	☐ Often/Always	.....
2. Housework activities (cooking, washing, ironing, etc.)	☐ Never/Rarely	☐ Often/Always	.....
3. Driving (not biking)	☐ Never/Rarely	☐ Often/Always	.....
4. Leisure activities (sports, hunting, dancing, cards, bowling, etc.)	☐ Never/Rarely	☐ Often/Always	.....
5. Using new technologies (digital camera computer, Internet etc.)	☐ Never/Rarely	☐ Often/Always	.....

2. ACTIVITIES WITH MONTHLY FREQUENCY

	less or equal then 2 times in a month	more or equal then 3 times in a month	Years
1. Social activities (parties/going out with friends, local community events, etc.)	☐ Never/Rarely	☐ Often/Always	.....
2. Cinema, theater	☐ Never/Rarely	☐ Often/Always	.....
3. Gardening, handicraft, knitting, embroidery, etc.	☐ Never/Rarely	☐ Often/Always	.....
4. Taking care of children or elderly	☐ Never/Rarely	☐ Often/Always	.....
5. Volunteering	☐ Never/Rarely	☐ Often/Always	.....
6. Artistic activities (playing an instrument, painting, writing, etc.)	☐ Never/Rarely	☐ Often/Always	.....

3. ACTIVITIES WITH ANNUAL FREQUENCY

	less or equal then 2 times in a year	more or equal then 3 times in a year	Years
1. Exhibitions, concerts, conferences	☐ Never/Rarely	☐ Often/Always	.....
2. Holidays (lasting at least several days)	☐ Never/Rarely	☐ Often/Always	.....
3. Reading books	☐ Never/Rarely	☐ Often/Always	.....

4. ACTIVITIES WITH FIXED FREQUENCY

1. Children	☐ No	☐ Yes number .....

			Years
2. Pet care	☐ Never/Rarely	☐ Often/Always	.....
3. Managing one's bank account(s)	☐ Never/Rarely	☐ Often/Always	.....

Questionnaire administered by: participant ☐ family/caregiver ☐ .....

Date: ...../...../..... Interviewer: .....

RESULTS

CRI-Education .....

CRI-WorkingActivity .....

CRI-LeisureTime .....

CRI .....

☐	☐	☐	☐	☐
low	medium-low	medium	medium-high	high
≤ 70	70 : 84	85 : 114	115 : 130	≥ 130