The Association Between Multilingualism and Executive Function in the Canadian Longitudinal Study on Aging: Results from the Baseline Comprehensive Cohort

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Background: Identifying factors that protect against cognitive impairment is key to healthy aging. Cognitive stimulation through multilingualism may be protective against cognitive impairment, such as low executive function. Evidence of a multilingual advantage on executive function tasks is mixed, and very few studies have examined the role of language similarity on cognition.

Objectives: To examine the association of: 1) the number and 2) the similarity of spoken languages with executive function in Canadians aged 45–85 years.

Methods: Baseline cross-sectional data from the Canadian Longitudinal Study on Aging's Comprehensive cohort were used for analyses of the number (n=22,249) and similarity (n=20,440) of languages. Language similarity was examined in bilinguals, where similar bilingualism referred to individuals whose two spoken languages were within the same Indo-European language family subgroup. Low executive function was derived from five executive function tests, where raw scores were converted to z-scores, summed, and then dichotomized based on a cut-point of ≥1.5 SD below the mean of the overall score in a weighted cognitively healthy subsample. Weighted multivariable logistic regression models were adjusted for sociodemographic, general health, health behaviours/lifestyle, and cognitively stimulating covariates. The fully adjusted model was stratified by participation in cognitive leisure activities.

Results: The number of languages spoken was significantly associated with executive function in a dose-response manner: compared to those who spoke one language, individuals who spoke up to, and including, four languages had lower odds of low executive function. The association between language similarity and low executive function was not significant. When stratified by cognitive leisure activities, the same conclusions held in those who participated in these cognitive activities infrequently, but not every day or several time a week.

Conclusion: The number of languages spoken is protective against low executive function, with peak protection occurring at four languages, but the similarity of spoken languages does not provide any protective effect. Therefore, an individuals may benefit from learning *any additional* Indo-European language. Moreover, protection against low executive function can be achieved through different combinations of cognitively stimulating activities, but language learning would be particularly beneficial for persons who engage infrequently in traditional cognitive activities. (350 words)

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List of Abbreviations

AD	Alzheimer's Disease
AFT	Animal Fluency Test
APOE	Apolipoprotein E gene
AUC (ROC)	Area Under the Receiver Operating Characteristic Curve
BWE	Backwards Elimination
CI	Confidence Interval
CIHR	Canadian Institutes of Health Research
CIND	Cognitive Impairment - No Dementia
CLSA	Canadian Longitudinal Study on Aging
COWAT	Controlled Oral Word Association Test
DCS	Data Collection Sites
DSM-5	Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition
EPMT	Event-based Prospective Memory Test
MAT	Mental Alternation Test
MCI	Mild Cognitive Impairment
MMSE	Mini-Mental State Examination
NuAge	The Québec Longitudinal Study on Nutrition and Aging
OR	Odds Ratio
PHAC	Public Health Agency of Canada
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RDD	Random Digit Dialing
SD	Standard Deviation
Stroop	Stroop Neurological Screening Test
Stroop-V	Stroop Neurological Screening Test – Victoria Version
TPMT	Time-based Prospective Memory Test
VIF	Variance Inflation Factor
WHO	World Health Organization
3MS	Modified Mini-Mental State Examination

1.0 Literature Review

1.1 Cognitive Function

Cognitive function refers to the many mental abilities that people require to complete simple activities and complex tasks in their daily lives (Glisky, 2019). Age-related changes in cognitive function can be a normal part of human aging. For example, cognitive abilities, such as processing speed and memory, typically decline with age; however, certain cognitive deficits not related to regular age-related change can be a sign of more severe illness or an age-related disease, such as dementia (Harada et al., 2013; Hugo & Ganguli, 2014). To aid in the diagnosis of cognitive disorders, cognitive function can be classified into six neurocognitive domains according to the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5): Perceptual-motor function, language, learning and memory, social cognition, complex attention, and executive function (Sachdev et al., 2014). Using these domains, cognitive function may be assessed globally (i.e., by considering all domains) or by specific domain, such as executive function (Glisky, 2019).

1.1.1 A Domain of Cognitive Function: Executive Function

Executive function, also referred to as executive control, is the domain of cognitive function responsible for the top-down mental processing that is required to concentrate, plan and monitor behaviours to reach a goal or solve a problem (Diamond, 2013). Further, executive functions are essential for managing complex tasks and juggling multiple tasks simultaneously. Although there is little consensus regarding the components of executive function, Diamond (2013) suggests that three core functions — inhibition, working memory, and mental flexibility — encapsulate the roles and responsibilities of this domain.

Inhibition is defined as the ability to control thoughts, behaviours, and emotions to override strong internal or external stimuli and instead behave appropriately. Inhibition consists of response inhibition (i.e., inhibition of behaviours) and interference control (i.e., selective attention or inhibition of thoughts). Tests to assess the inhibition domain of executive function include the Stroop Neurological Screening test (Stroop) and the Simon task. *Working memory* is the ability to hold thoughts in the mind while simultaneously manipulating information. This capability is distinct from short-term memory, which simply holds information in the mind. To examine this domain, tests often include a backward-span digit task, and the ability to repeat and reorder actions given by an interviewer. *Mental flexibility*, the third core executive function, is built on both working memory and inhibition. It is the ability to adjust to changing priorities and take advantage of sudden and unexpected changes. Popular tests for mental flexibility include letter fluency tasks such as the Controlled Oral Word Association Task (COWAT) (Tuokko et al., 2017), or tasks measuring task-switching ability such as the Wisconsin Card Sorting Task (Diamond, 2013).

Executive functions are housed in the brain's prefrontal cortex (Suchy, 2009). As the prefrontal cortex is vulnerable to age-related change, variations in executive function, such as declines in inhibition, are often considered a part of normal aging (Diamond, 2013; West, 1996). Since executive function is responsible for integrating information across cognitive domains and coordinating behaviours, deficits in executive function (e.g., low or poor executive function performance) may impact an individual's ability to appropriately respond and regulate behaviour (Diamond, 2013; West, 1996). For example, impairments in executive function can negatively impact planning, multi-tasking, processing information and problem-solving abilities (Diamond, 2013; Murman, 2015). Deficits in executive function have also been linked to an increased falls risk and a decline in the ability to successfully multi-task — a skill often required to complete activities of daily living and ultimately maintain independence (Fraser & Bherer, 2013). Importantly, decline in the executive function domain in older adults has been found to predict the development of overall dementia and Alzheimer's disease (AD) (Clark et al., 2012; Guarino et al., 2019).

1.1.2 Cognitive Impairment

Unlike the subtle or less severe changes in cognition that may accompany normal aging, cognitive changes indicative of dementia are progressive and have an insidious onset (Public Health Agency of Canada [PHAC], 2019). Specifically, dementia includes the experience of cognitive decline, cognitive impairment, and changes in behaviour that are significantly different from the individual's normal functioning. Importantly, these cognitive changes can be severe enough to impact everyday life (PHAC, 2019). Dementia is often preceded by mild cognitive impairment (MCI), that is, the experience of a slight but notable decline in cognitive function that does not necessarily impact simple daily activities; however, the boundary between these two cognitive states is a grey area (Livingston et al., 2017; Petersen, 2016). As mild cognitive changes grow more severe, the ability to complete daily activities becomes an increasing challenge and progression to dementia may occur (Petersen, 2016).

Often when symptoms of cognitive impairment become apparent, a clinical diagnosis of dementia is sought (Livingston et al., 2017). Modest impairments in some domains, such as executive function, can be indicative of the prodromal stages of the disease (Clark et al., 2012; Sachdev et al., 2014). Thus, promptly identifying impairment of specific cognitive functions, such as executive function, may help to delay the progression of more severe dementia symptoms and thus maintain an individual's autonomy (Clark et al., 2012; Guarino et al., 2019; Suchy, 2009). Specifically, early diagnosis or identification of dementia may allow for the opportunity to seek treatment that can help to delay symptoms (PHAC, 2019; Wicking Dementia Research and Education Centre University of Tasmania, n.d.). As many tests of executive function are both sensitive and specific to cognitive changes due to cognitive impairment (Tuokko et al., 2017), it has been suggested that combined tests of executive function may be a valuable tool to identify early changes in cognition due to dementia before severe symptoms arise (Suchy, 2009). For example, those with poor cognitive performance on tasks of executive function at baseline may be more likely to experience cognitive decline and develop more severe forms of cognitive impairment and dementia at follow-up (e.g., Clark et al., 2012; Guarino et al., 2019). Given the relationship between executive function deficits and later development of dementia, insight into the specific changes in executive function may provide an indication of older adults at higher risk of further decline from MCI or the development of dementia. Moreover, as there is no cure for dementia, the identification of high-risk individuals is key to developing treatment plans and strategies with family members to improve quality of life as the disease progresses (Livingston et al., 2017; PHAC, 2019; Wicking Dementia Research and Education Centre University of Tasmania, n.d.).

1.1.3 Factors that Influence the Risk of Cognitive Impairment

There are several non-modifiable factors that can influence an individual's risk of cognitive impairment. Discussed here are the impacts of age, sex and immigration status.

1.1.3.1 Non-modifiable Factors. It is well established that age is a risk factor for change in cognitive function and the development of cognitive impairment (for reviews see, e.g., Chen et al., 2009; Livingston et al., 2017). Change in cognition, such as declines in specific cognitive domains like executive function, do occur normally with age; these declines can be correlated with structural and functional changes (e.g., dysfunction in neuronal networks) occurring in the brain as persons age (for a review see, e.g., Murman, 2015). However, it should be noted that age is also the greatest known risk factor for dementia, which is not a part of normal aging (PHAC, 2019).

In addition to age, sex also has an impact on risk of cognitive impairment. Men and women show differences in cognitive function and development of cognitive impairment and dementia because of differences in biology (i.e., hormones and brain structure) (for a review see, e.g., Li & Singh, 2014). Further, previous literature examining cognition and sex has supported a higher prevalence of cognitive impairment and dementia in women due, in part, to longevity; however, this evidence is insufficient to explain differences in risk (Launer et al., 1999; Snyder et al., 2016). There may also exist differences in resilience to cognitive impairment based on sex (McCarrey et al., 2016); however, the evidence for a differential association between sex and cognitive resilience or reserve remains unclear (for a review, see, e.g., Li & Singh, 2014). Other factors such as educational level or academic performance may also confound the association between sex and cognition. It is well established that women have historically lower levels of education compared to men in Canada (Gaskell, 2014). As these women are now part of Canada's aging cohort, their greater prevalence of low education may impact current rates of dementia. That is, considering the well-established association between low education and dementia risk (e.g., Chen et al., 2009), it is likely that the lower levels of education experienced by these women place them at a high risk for dementia. Notably, however, in the most recent report by Statistics Canada on gender-based analysis, it was found that women compared to men currently have better academic performance in secondary school and account for the majority of recent post-secondary graduates in all provinces across Canada (Ferguson & Statistics Canada, 2016). With these rates in mind, it is possible that the risk of dementia in Canadian women may change in the future, particularly due to the reversal or reduction of gender differences in achievement of higher education.

Lastly, and relatively less explored in comparison to age and sex, is immigration status or related measures, such as country of birth. This factor has been shown to be related to an increased risk of cognitive impairment; however, the association between immigration and cognition is complex and may be influenced by other modifiable factors (i.e., lower levels of education or greater stress) (Bialystok et al., 2007; Moon et al., 2019; PHAC, 2019). Further the "healthy immigrant effect" may also play a role in how immigration status impacts cognition (Moon et al., 2019). This factor will be discussed in greater detail in section 1.3.3. where immigration status is discussed in the context of acting as an effect modifier.

1.1.3.2 Modifiable Factors. Unlike the above-mentioned non-modifiable factors, individuals can take measures to change their modifiable risk factors. Modifiable risk factors for cognitive impairment will be discussed in terms of: 1) sociodemographic factors, 2) general health factors, 3) health behaviours/lifestyle factors, and 4) cognitively stimulating activities.

Sociodemographic factors, such as urban/rural residence and household income, have been studied in association with cognition. First, living in a rural setting compared to an urban setting is related to an increased risk of AD (Jia et al., 2014; Weden et al., 2018). Granted, these findings may be related to the fact that urban residents are generally healthier than those living in rural locations (Weden et al., 2018). Second, low annual household income (Fischer et al., 2009) and lower socioeconomic status more generally have been linked to increased risk of dementia and cognitive impairment (Valian, 2015); however, these factors can be influenced by other social determinants of health, such as education.

General health factors associated with cognition and cognitive impairment have been fairly well established. The presence of chronic physiological health conditions, such as cardiovascular disease, diabetes, and obesity, as well as mental health disorders, namely depression, have well-known associations with dementia and its subtypes (for reviews, see, e.g., Chen et al., 2009; Livingston et al., 2017). Additionally, brain injuries, including traumatic brain injuries and loss of consciousness, have been linked to future impairments in prospective memory that are associated with executive dysfunction (Bedard et al., 2018). Research has also linked incident dementia and cognitive impairment to low self-rated general health (e.g., Montlahuc et al., 2011).

Health behaviours and lifestyle factors have also been studied in relation to cognitive function. For example, an increased risk of AD and dementia has been associated with tobacco use (Launer et al., 1999; Livingston et al., 2017; Tyas et al., 2000) and alcohol consumption (Chen et al., 2009). In addition, an individual's social support network may also influence their risk of dementia (Livingston et al., 2017; Pillemer & Holtzer, 2016). In particular, the experience of overall low social support has been found to be a risk factor for low global cognitive function (Oremus et al., 2019) and low executive function (Rutter, 2019) in middle-aged and older Canadians.

Cognitive stimulation may act as a protective factor against cognitive impairment and cognitive decline in later life as the sustained engagement in cognitively demanding activities can increase neural efficiency and build cognitive reserve (defined in section 1.1.4) (McDonough et al., 2015; for reviews see, e.g., Iizuka et al., 2019; Yates et al., 2016; Q. Bin Zhu et al., 2019). Although a high level of education is a well-established sociodemographic factor associated with reduced risk of dementia (Chen et al., 2009), it has also been found to be protective when examined as a cognitively simulating activity (Meng & D'Arcy, 2012). In their systematic review and meta-analysis, Meng & D'Arcy (2012) found that low education increased the risk of dementia and cognitive impairment but that higher education resulted in faster cognitive decline after diagnosis — a hallmark of cognitive reserve (Y. Stern, 2013). Similarly, frequent participation in cognitive leisure activities, such as puzzles, playing cards, trivia, sudoku and other similar activities, has been associated with better overall cognitive performance (Litwin et al., 2017; Mao et al., 2020;

X. Zhu et al., 2017) and executive function (Wang et al., 2013; Yates et al., 2016). Moreover, participation in cognitive activities reduces the risk of dementia by delaying the manifestation of clinical symptoms (Scarmeas et al., 2001; Stern & Munn, 2010) and has also been associated with a reduced risk of AD (Akbaraly et al., 2009; Sattler et al., 2012; Wilson et al., 2002). Besides leisure and education, multilingualism has also been associated with a reduced risk of dementia (for reviews, see, e.g., Baum & Titone, 2014; Valian, 2015; Ware et al., 2020). The effect of multilingualism on cognition will be discussed further in section 1.2.

Importantly, it has been suggested that a combination of cognitively stimulating factors, such as multilingualism, education, and cognitive leisure activities, may work together to protect against cognitive impairment, or *mutually compensate* against cognitive change. That is, these various cognitively stimulating factors may work together, through different combinations, to achieve the maximum level or "ceiling" of resilience against cognitive impairment. For example, "weak" factors may not contribute further to protection against cognitive impairment as the ceiling for protection may already have been reached by a dominating factor. However, if a person has no "strong" factors, the "weak" factors may combine with other "weak" cognitive activities to increase a person's protection against cognitive impairment. In support of this theory, studies examining the combination of education and cognitive leisure activities on cognition have found that only those with low levels of education have benefited from engagement in cognitive activities (e.g., Litwin et al., 2017; Park et al., 2019). Note, the "weak" and "strong" labels used here are for explanatory purposes only as it is not yet clear how these cognitive factors combine to form a protective effect.

1.1.4 Cognitive Reserve: Protection Against Cognitive Impairment

In addition to the many aforementioned modifiable and non-modifiable factors that impact the risk of dementia, the experience of dementia symptoms, such as cognitive impairment, can also be influenced by an individual's cognitive reserve capacity (PHAC, 2019). Proposed by Stern (2002), reserve theory, as a whole, is the combination of passive and active processes that together accounts for differences in how individuals cope and express change in cognitive function due to age or pathology, as in the case of dementia. The passive process, or brain reserve, argues that the physical features of the brain (e.g., whole brain size) can manage a certain level of neuropathological damage before a threshold is reached and symptoms of cognitive impairment are expressed. The active process, cognitive reserve, accounts for how individuals process cognitive tasks and respond to pathological change. Specifically, cognitive reserve is the brain's ability to buffer against the clinical expression of neuropathology through the efficient use of pre-existing neural networks or compensatory strategies. Steffener and Stern (2012) define efficiency as a change in neural activity that occurs when completing a task. Ultimately, higher levels of cognitive reserve result in maintenance of brain function despite pathology, allowing individuals to remain cognitively normal longer (Stern & Barulli, 2019). Thus, cognitive reserve reduces an individual's risk of dementia by buffering against symptom expression (Stern & Barulli, 2019). This has also been referred to as cognitive resilience (Arenaza-Urquijo & Vemuri, 2018). Exploring factors that build cognitive reserve capacity, such as multilingualism, is key to developing interventions that will protect against cognitive impairment (PHAC, 2019). Moreover, it is important to understand how language itself contributes to cognitive reserve as well as in combination with other factors, such as education and cognitive leisure activities, to examine any ceiling effects for cognitive reserve.

1.2 Multilingualism

Accumulating evidence exists to support that speaking at least one additional language protects against negative changes in cognition (e.g., Bialystok et al., 2007). This evidence concerning language and cognition is primarily focused on the influence of bilingualism, that is, speaking two languages. However, the field is inconsistent in their definitions and thus defines the term "bilingualism" differently across studies. For example, this term has been used ambiguously in the literature to refer to speakers of *at least* two languages or has been used when considering bilinguals as a group (i.e., bilinguals compared with speakers of three or more languages). In an attempt to add clarity to this area of research, "multilingualism" will be used in this review as an umbrella term to refer to speakers of at least two languages. When specifically referring to speakers of more than two languages (e.g., trilinguals) the number of languages spoken will be explicitly stated. Before exploring the literature concerning multilingualism and cognition, a potential mechanism of how multilingualism may build cognitive reserve and the supporting literature on multilingualism and cognitive reserve will be discussed.

1.2.1 Theoretical Mechanisms Linking Multilingualism and Cognitive Reserve

Multilingualism, as an action that involves consistent cognitive effort, has been shown to protect against cognitive impairment and dementia through its ability to build cognitive reserve capacity (Bialystok et al., 2012). Although there is no clear consensus regarding the underlying mechanism of how multilingualism increases cognitive reserve and thus protects against cognitive impairment, it is thought that reserve may arise from the strengthening and reorganization of neural networks due to neuroplasticity (Bialystok et al., 2012; Freedman et al., 2014). According to the *inhibitory control model* (Green, 1998), as "mental jugglers", multilinguals must actively engage their executive function to monitor their multiple known languages, respond with the current language, and inhibit the other(s) based on their environment. Essentially, multilinguals are "exercising" their executive functions, and cognitive control, almost constantly (Coderre et al., 2016; Freedman et al., 2014). This consistent use of executive control (i.e., executive function) is hypothesized to result in efficient networks and reorganization, thus contributing to cognitive reserve and hence protecting against cognitive impairment (Bialystok et al., 2012). Although the *inhibitory control model* has been widely accepted, Valian (2015) suggests that a single underlying mechanism may not exist to explain how language enhances reserve capacity. Further, instead of emphasizing one executive process, such as inhibition, they argue that the consistent exposure to cognitive stimulation may lead to better executive function globally. Results from a meta-analysis support this argument, finding that the bilingual experience results in a more efficient executive function system leading to generalized, global benefits, across a variety of cognitive tasks involving executive control (Hilchey & Klein, 2011). Ultimately, regardless of the mechanism, the use of multiple languages exercises executive function, which may help to build reserve and protect against cognitive impairment (Bialystok et al., 2012).

1.2.2 Evidence Supporting the Association of Multilingualism with Cognitive Reserve

Evidence supporting cognitive reserve in multilinguals can be found from neurofunctional studies investigating neural efficiency and processing during cognitive tasks. Several studies examining multilinguals have found functional neural activity differences in brain regions known to be involved in cognitive and executive control (Abutalebi et al., 2015; P. Li et al., 2014). For example, during tasks of executive function, fMRI results showed that multilinguals activate different pathways than monolinguals and that the pathways activated were not vulnerable to aging (Ansaldo et al., 2015; Berroir et al., 2017). Moreover, compared to monolinguals, speakers of another language in addition to English have been found to use fewer brain regions (Berroir et al.,

2017) and less neural activity (i.e., greater efficiency) to complete tasks involving executive function (Gold et al., 2013). These results support the existence of neural efficiency and alternate pathways, characteristics of cognitive reserve, in multilinguals during tasks of executive function, thereby suggesting that there is a potential for cognitive reserve in these individuals.

1.2.3 Characteristics of Language that May Impact Cognition

The efficient processing and executive control seen in multilinguals are sensitive to the nature of multilingualism itself (Li et al., 2014). Although no single study can control for all the possible characteristics of the multilingual experience (Bak, 2016), effort should be made to recognize the potential influence of these factors on cognitive function. In particular, there is evidence to suggest that the proficiency, frequency, first language learned, and age of second language acquisition play a role in the association between multilingualism and cognition (for a review see, e.g., Baum & Titone, 2014). For example, it has been suggested that bilinguals perform better on tests involving vocabulary, such as the Verbal Fluency Test, in their first language or when they are allowed to respond in both of their known languages (Celik et al., 2020). Nevertheless, it has also been suggested that these above-mentioned characteristics of language play no significant role (Lehtonen et al., 2018). Also, the language environment (i.e., living in a location where the primary language spoken is the individual's second or non-dominant language) may have an impact on cognition, as cognitive demand is more constant in a foreign environment; this has particular relevance for immigrant populations (Chertkow et al., 2010; Kousaie et al., 2014; Woumans et al., 2015).

In addition to the aforementioned traits, the role of the specific number of languages spoken and the similarity of language spoken is worth consideration (Bialystok et al., 2012). For example, speakers of three or more languages must juggle more than two languages, which would be expected to require greater cognitive control than juggling only two languages. This extra effort may provide additional benefit for cognition (e.g., Chertkow et al., 2010; Ihle et al., 2016). Also, the typological similarity (i.e., language distance) of a multilingual's spoken languages may affect cognition. For example, the linguistic commonalities between languages of the same family may require enhanced executive control, and greater suppression, to respond in the correct language while inhibiting the other (Bialystok et al., 2012). This is known as the *interference inhibition effect* (Antoniou & Wright, 2017). However, theories have also proposed that languages with more linguistic differences may be more cognitively challenging than languages that share multiple commonalities (Antoniou & Wright, 2017). These two characteristics, the number and type of spoken languages, will be further explored in section 1.3 where the association between multilingualism and cognitive function is discussed in greater detail.

1.3 Multilingualism and Cognitive Function

With the context that multilingualism, due to enhanced executive control, may be associated with greater cognitive reserve, the association between multilingualism and cognitive function will be explored regarding: 1) executive function, and 2) cognitive impairment. As the majority of the relevant literature has considered the effect of multilingualism with dementia and AD, these articles will be considered in addition to those examining executive function or global cognition as outcomes. The inclusion of all of these outcomes in this review will help to ensure a comprehensive understanding of the current body of literature.

1.3.1 Multilingualism and the Executive Function Domain

Commonly referred to as "multilingual advantage" and "multilingual disadvantage", language can produce advantages on some executive function tasks, but presents challenges on others.

1.3.1.1 Cognitive Advantages of Multilingualism: “The Multilingual Advantage”. Considering that multilinguals exercise their executive functions consistently as “mental jugglers,” it is reasonable that many studies have reported that multilingualism yields advantages in executive function tasks — the “multilingual advantage”. Several studies have found multilinguals to have an executive function advantage over monolinguals (e.g., Bialystok et al., 2008; Nielsen et al., 2019; Zahodne et al., 2014). Subanalyses of the Modified Mini-Mental State Examination [3MS] have shown that bilinguals’ higher cognitive scores, compared to monolinguals, are driven by executive function components (Padilla et al., 2016). Regarding specific executive function domains, multilinguals have been shown to outperform monolinguals on tasks of inhibition — Stroop (e.g., Bialystok, Poarch, et al., 2014), Simon (e.g., Cox et al., 2016), and Flanker tasks (Abutalebi et al., 2015; Del Maschio et al., 2018) — mental flexibility (i.e., task-switching) (e.g., Gold et al., 2013; Houtzager et al., 2017; López Zunini et al., 2019; Rieker et al., 2020), and working memory (Bialystok et al., 2004; Bialystok, Poarch, et al., 2014; Zahodne et al., 2014).

Regarding the impact of explicitly more than two languages spoken and the similarity of languages spoken, a dearth of studies exists examining these characteristics with executive function. Comparing performance on the Mini-Mental State Examination (MMSE), Japanese-Taiwanese-Mandarin trilinguals, compared to bilinguals, had better performance overall, and an analysis of the MMSE subcomponents suggested an executive function advantage (Liu et al., 2017). A study examining bilinguals of two similar languages, Dutch and Frisian, found these individuals performed better on task-switching than monolinguals; however, comparisons with other bilinguals were absent (Houtzager et al., 2017). When examining language type directly in bilinguals, the similarity of spoken languages was found to play a non-significant role in predicting cognitive performance overall (Sörman et al., 2019). However, when considered relative to monolinguals, it was only those bilinguals who spoke two similar languages, English-Swedish, that performed significantly better on a verbal fluency executive function task; speakers of dissimilar languages, Finnish-Swedish, did not significantly differ in performance from monolinguals (Ljungberg et al., 2020). Notably, although non-significant, a linear trend in overall task performance was found indicating better average performance for similar bilinguals compared to dissimilar bilinguals, and dissimilar bilinguals compared to monolinguals (Ljungberg et al., 2020).

While there are numerous studies supporting the existence of a multilingual advantage on tasks of executive function, there are also many studies that do not find evidence of this association (e.g., Anderson et al., 2017; Antón et al., 2016; Desjardins et al., 2020; Filippi et al., 2020; Kousaie et al., 2014; Kousaie & Phillips, 2012; Massa et al., 2020; Morrison & Taler, 2020; Nichols et al., 2020; Papageorgiou et al., 2019; Weyman et al., 2020). A recent population-based study of 11,041 participants found the bilingual effect to be explained by confounding factors such as education and age, and that *monolinguals* had experienced an executive function advantage on some tasks (Nichols et al., 2020). Criticism has been raised by Lehtonen et al. (2018), who suggest that the inconsistent definition of "bilingualism/multilingualism"; small sample size; and lack of consideration for confounding variables, such as socioeconomic status, comorbidities, or immigration status, have resulted in spurious findings in the literature. It has also been argued that the lack of consideration for other language factors such as age of acquisition, proficiency, language dominance and language environment in the definition of bilingualism may have resulted in inconsistent findings and an unclear picture of the bilingual advantage (de Bruin, 2019). Paap et al. (2015) argue that the evidence for a bilingual advantage can be attributed to publication and reporting biases, and state that a bilingual advantage does not exist or is restricted "to very specific undetermined circumstances". Further, they suggest that the small effect sizes, supportive of a bilingual advantage, found in recent meta-analyses could be explained by confirmation bias as the abnormalities across these studies point to this researcher bias. That is, the small but statistically significant advantage found for bilinguals would likely disappear if researcher bias was accounted for (Paap, 2019; Paap et al., 2020). On the contrary, it has been argued that publication bias, such as that found by Paap et al., is only found in specific circumstances, such as when using certain bias detection methods (Ware et al., 2020). Moreover, the small effect sizes from recent meta-analyses criticized by Paap are similar in size to those found for the impact of physical exercise on cognitive outcomes, an arguably uncontroversial effect (Bialystok, 2021).

In addition, it is suggested that the wide range of executive function tasks creates a challenge regarding the interpretation of a purely executive function advantage (Baum & Titone, 2014; Valian, 2015). A recent meta-analysis suggests that an executive function advantage for multilinguals is dependent on task and age, finding that bilinguals performed significantly better than monolinguals on four of the seven tasks that were analyzed, and that advantages were greater for older bilinguals (Ware et al., 2020). As well, the processing effort required for certain executive function tasks may play a role in finding a significant association, as some studies have shown that multilinguals present an advantage only when controlled, but not automatic, effort is required for task completion (Bialystok et al., 2004, 2006). Task difficulty may also result in null findings, as a multilingual advantage may only be found when challenging tasks are used (for a review, see Teubner-Rhodes, 2020). Still, another line of thought comes from electrophysiological studies that support a functional neural processing advantage for multilinguals compared to monolinguals, but not a behavioural task advantage (e.g., Berroir et al., 2017; Kousaie & Phillips, 2017). These findings relate to those discussed in section 1.2.2 regarding cognitive reserve and neural efficiency.

In summary, while there is support for a multilingual advantage in executive function, there is also a large body of literature that has found no such advantage. As discussed, there exists a variety of potential factors that could contribute to the null findings and inconsistencies in some studies. Despite these factors, the notion of a multilingual advantage is supported by some experts who believe that it is present despite null findings, and that the advantage may often be masked by other cognitively stimulating experiences (Valian, 2015). Overall, research in this area may benefit from some methodological consistency. For example, with inconsistent definitions of "bilingualism" it is hard to discern if the multilingual advantage is really, for example, a trilingual advantage. Clarity in this field regarding the number of languages spoken may help to untangle some uncertainty regarding the existence of a multilingual advantage. Ultimately, although no clear answer exists regarding the multilingual advantage, what is clear is that while the effects of language on executive function are inconsistent, they are generally positive when they do occur.

1.3.1.2 Cognitive Disadvantages of Multilingualism: "The Multilingual Disadvantage". Just as multilingualism can provide cognitive benefits, it can also result in disadvantages on certain tasks of executive function — the "multilingual disadvantage" (for a review see, e.g., Bialystok, 2009). Compared to monolingual controls, multilinguals experience more frequent tip-of-the-tongue states, poorer vocabulary, longer naming times on tasks, and reduced scores on verbal fluency tasks (Bialystok et al., 2008; Clare, Whitaker, Martyr et al., 2016; Friesen et al., 2015; Lehtonen et al., 2018). Although there is some debate as to why these disadvantages occur, a prevailing theory of language processing proposes that this disadvantage is largely due to a bilingual's parallel activation of both languages even when only one is in use (Bialystok et al., 2008; Coderre et al., 2016; Green, 1998; for a review see, e.g., Kroll et al., 2012). Reasonably, this notion could be extrapolated to speakers of more than two languages, where concurrent activation of many languages may exist and result in similar disadvantages. Notably, these aforementioned disadvantages may be specific to certain tasks. For example, although multilinguals generally perform worse on verbal fluency tasks compared to monolinguals, a few studies have shown this poor performance is more often found in categorical fluency tasks, which place a greater demand on semantic memory and vocabulary (Bialystok et al., 2008; Rosselli et al., 2000). However, there have been more recent instances when no difference is found on categorial fluency tasks (e.g., Friesen et al., 2015; Ljungberg et al., 2020). On letter (i.e., phonemic) fluency tasks multilinguals have been shown to perform similarly (Rosselli et al., 2000), if not better than monolinguals (Marsh et al., 2019; Ramakrishnan et al., 2017; Rosselli et al., 2000) since these tasks place a greater demand on executive control (Friesen et al., 2015; Marsh et al., 2019). Ultimately, studies using large executive function batteries to investigate the association between multilingualism and cognition should consider the potential for task-based bias (Anderson et al., 2017).

1.3.2 Multilingualism and Cognitive Impairment

Although some of the aforementioned evidence does support a multilingual advantage in executive function, and neuroimaging studies support a positive influence of language on neural processing and cognitive reserve, it is important to consider if these effects can be translated into protection against cognitive impairment, specifically: 1) global cognition and age-related cognitive decline, and 2) dementia (including AD).

1.3.2.1 Multilingualism, Global Cognition and Age-related Cognitive Decline. Speaking at least two languages has been associated with better global cognition (e.g., Padilla et al., 2016; Ramakrishnan et al., 2017) and protection against age-related cognitive decline (e.g., Bak et al., 2014) in some studies. When matched to speakers of two or more languages on brain health, monolinguals were found to have significantly poorer clinical outcomes related to cognitive health (Berkes et al., 2021). Further, speakers of two or more languages have been found to have significantly higher MMSE scores compared to monolinguals (Berkes et al., 2021). Examining multiple languages specifically, one study found that speaking more than three languages to be associated with better Katzman cognitive-screening test scores in all three waves of a 12-year study (Kavé et al., 2008). Further, a greater number of languages spoken was a significant predictor of cognitive state over time in those with low education (Kavé et al., 2008) and has been associated with high cognitive performance independent of cognitive leisure activities and physical occupation (Ihle et al., 2016; Kavé et al., 2008).

Multilingualism has also been found to protect against age-related cognitive decline (e.g., Bak et al., 2014; Padilla et al., 2016). Bak et al. (2014) found that speaking two languages was protective against cognitive decline independent of intelligence and could not explained by other variables such as gender and socioeconomic status. Examining an increasing number of languages, they also found that knowing three (or more) languages showed a stronger protective effect against cognitive aging than bilingualism. Similarly, Perquin et al. (2013) found lifelong trilinguals to be approximately three times less likely to have cognitive impairment no dementia (CIND) relative to bilinguals after adjusting for age and education; however, this protective effect reached a peak effect at three languages, as those who spoke four languages or more had a similarly reduced risk of CIND as trilinguals. The authors concluded that speaking three languages, as well as other cognitively stimulating activities, such as leisure and education, are likely contributing to cognitive reserve (Perquin et al., 2013).

1.3.2.2. Multilingualism and Dementia. In addition to better global cognition and protection against cognitive decline, there is considerable evidence of a protective effect of multilingualism on the risk of dementia; however, this effect often depends on study design and sample (for reviews, see, e.g., Antoniou & Wright, 2017; Klimova et al., 2017; Valian, 2015). The association between the number and similarity of languages spoken and dementia has been relatively less explored.

Several studies examining multilingualism and dementia have found a significant association between speaking at least two languages and the delay of dementia or AD symptoms, specifically in clinic-based populations (Bialystok et al., 2007; Bialystok, Craik, et al., 2014; Chertkow et al., 2010; Craik et al., 2010; Woumans et al., 2015) and retrospective study designs (Alladi et al., 2013; Bialystok et al., 2007; Craik et al., 2010; de Leon et al., 2020; for a review see, Mukadam et al., 2017). However, more recent prospective population-based studies have generally failed to find an association between speaking two languages and dementia (Hack et al., 2019; Yeung et al., 2014; Zahodne et al., 2014). For example, Zahodne et al. (2014) found that, although speaking both Spanish and English was associated with better executive function at baseline, it was not independently associated with incident dementia after adjustment for covariates including gender, age, education, and country of origin. Further, in their systematic review and meta-analysis, Mukadam et al. (2017) found the protective effect of multilingualism on dementia to be non-significant, and determined that retrospective, relative to prospective designs, were more likely to find a positive association between multilingualism and dementia. Since retrospective studies generally use clinic-based samples, it has been suggested that the positive findings from this design may be due to selection bias (Mukadam et al., 2017; Valian, 2015). Notably, clinic-based samples overlook those who remain cognitively healthy, they may carry bias related to health service use, and are less representative of the general population (Hack et al., 2019; Valian, 2015). Moreover, unlike some early studies (e.g., Bialystok et al., 2007), it is argued that more recent population-based studies are more appropriately controlling for covariates, which may help explain the recent null findings in this literature (Lehtonen et al., 2018).

In comparison, the association between the *specific* number of languages spoken (i.e., more than *at least* two languages) and dementia has been relatively less explored. Speaking three or more languages has been found to delay the onset of dementia symptoms and diagnosis (Chertkow et al., 2010). This association behaved in a dose-response manner, with a greater number of languages providing additional years of delay in dementia diagnosis in immigrant participants (Chertkow et al., 2010). Alternatively, a protective effect at four (or more) languages but not two or three has also been found; however, these results were attenuated by other characteristics of language, such as idea density (Hack et al., 2019). Other studies, either population-based or clinic-based, have failed to find an added benefit of speaking more than two languages on dementia (Alladi et al., 2013; Liu et al., 2017).

The role of language similarity on the risk of dementia has been studied very little. One study examined the impact of speaking similar languages, Cantonese and Mandarin, on the onset of AD symptoms. Relative to Cantonese monolinguals, Cantonese-Mandarin bilinguals experienced a delay in AD symptoms by 5.5 years (Zheng et al., 2018). Research into the role of language typology in protecting against cognitive impairment, including dementia, is needed (Antoniou & Wright, 2017; Bialystok et al., 2012).

1.3.3 The Role of Confounding Variables and Effect Modifiers

Although the general link between language and cognition has been discussed, the role of potential confounding variables and effect modifiers, such as age, immigration status, education, and cognitively stimulating activities, on this association has yet to be considered.

Many studies have examined the role of age and whether it influences the association between multilingualism and cognitive function, but the results are largely inconclusive. Notably, several studies support that older multilinguals have a greater advantage on tasks of executive function over older monolinguals as normal age-related decline is attenuated for these multilingual older adults (for a review, see, e.g., Lehtonen et al., 2018). The difference between monolinguals and multilinguals is also greater in older adults than young adults (e.g., Bialystok et al., 2008). However, this difference is not always true for middle-aged adults (e.g., Bialystok et al., 2004). Other studies have found no significant interactions between age and speaking at least two languages (e.g., Luo et al., 2013; Nichols et al., 2020).

Immigration status has also been considered as a potential covariate in several studies, as the influence of multilingualism may be due, in part, to the "healthy immigrant effect" (Fuller-Thomson, 2015) or, arguably may act to attenuate the "un-healthy immigrant effect" (i.e., the health disparities immigrant populations face over time) (Moon et al., 2019). As well, if immigrants live in a foreign language environment, this may act to place greater demands on their cognition, thereby building reserve (Woumans et al., 2015). Chertkow et al. (2010), in an analysis of their immigrant participant group, found that the number of languages spoken was associated with a delay in dementia diagnosis. Notably, this association was not found in their group of native Canadian multilinguals. However, other studies examining immigrant populations have found the association between language and cognition to be independent of immigration status (e.g., Alladi et al., 2013; Craik et al., 2010; Lawton et al., 2015).

The role of education and cognitively stimulating experiences has been explored in several studies (Ihle et al., 2016; Perquin et al., 2013; for a review see, e.g., Q.-B. Zhu et al., 2019). These characteristics are important to consider as some studies have failed to find an association between multilingualism and cognition that is independent of education (e.g., Massa et al., 2020; Mukadam et al., 2018). Further, Liu et al. (2017) have found better cognitive performance in trilinguals compared to bilinguals in individuals with little or no formal education. However, this is not supported by Alladi et al. (2013), who found the association to be independent of education. Regarding other cognitively stimulating experiences and multilingualism, Ihle et al. (2016), for example, found that a higher number of languages spoken predicted cognitive performance over and above leisure activities, physical occupation, and gainful activities, but not over and above the effect of education and cognitively demanding occupations in their sample of participants. The authors suggest that language may build cognition and thus cognitive reserve, but may be dependent on the other types of cognitive experiences individuals are engaged in. These findings support the idea of mutual compensation, that is, the benefits of multilingualism on cognition can be modified by other stimulating factors so that the benefits of language are invisible (i.e., a ceiling effect of resilience is reached, see section 1.2.3) (Y. Stern, 2013; Valian, 2015).

Also, worth revisiting, is the role that other characteristics of language such as the frequency of use, proficiency, age of acquisition, and language environment play in the association between multilingualism and cognition (for a review see, e.g., Baum & Titone, 2014). It has been suggested that to consider the role of multilingualism on cognitive function, multilingualism should be deconstructed; that is, considering the impact of language characteristics such as frequency of use and first language learned as potential key factors (Arce Renteria, 2021). For more details on how these factors may impact cognition, see section 1.2.3.

In summary, given the differences in how many studies address and adjust for several of these covariates and confounding factors, including aspects of the multilingual experience, it is reasonable that the literature concerning multilingualism and cognition is mixed. Uncertainty still exists in the field as to whether multilingualism is truly a protective factor against cognitive impairment. It may be that language is a protective factor for some individuals but not everyone.

1.4 Conclusion

This review has demonstrated that multilinguals as a population are highly variable, differing with respect to characteristics that can impact their executive function and neural processing. Factors such as age, immigration status, education, other cognitively stimulating activities (see sections 1.2.3 and 1.3.3), and characteristics of language such as frequency of use and first language spoken (see section 1.2.3), may also contribute to this complex association. Multilingualism has been positively associated with enhanced executive function, leading to greater cognitive reserve capacity and thus protection against cognitive impairment and dementia in some studies. However, there remains a large body of literature that does not support superior executive function or protective effects against dementia in multilinguals compared to monolinguals. Therefore, considering the limitations of existing studies and the differences in adjustment for key covariates and lack of adjustment for other aspects of the multilingual experience (e.g., language similarity) it is uncertain if knowing multiple languages is indeed protective against cognitive impairment. Work is needed to resolve inconsistencies in the literature, such as definitions of multilingualism and consideration of covariates, that may help to account for these mixed findings. These efforts may aid in clarifying the existence of an association between multilingualism and cognitive function. Further, this added clarity may help to inform individuals and language-based intervention strategies focused on the prevention of cognitive impairment and dementia.

2.0 Rationale and Objectives

The association of multilingualism with executive function is complex, resulting in a body of literature that is mixed in its support of the association. Inconsistencies in the definition of multilingualism (e.g., referring to speakers of *at least* two languages as “bilinguals”), is likely a contributing factor. Consequently, it is difficult to discern if additional languages are needed to protect against cognitive impairment, and further, if this association between the number of languages and cognition behaves in a dose-response manner such that a greater number of languages spoken is more protective. Even less explored has been the role of language similarity and how this factor may contribute to executive function. These characteristics need to be more fully examined as there is potential for these aspects of language to have protective effects on cognition based on the added complexity and executive control demands required to juggle more than two languages or multiple similar languages. This study addressed this gap by exploring the association of executive function with the specific number and similarity of languages spoken.

In addition to the role of language itself, previous studies have focused on clinic-based populations as opposed to representative population-based samples. These differences in study populations may have also contributed to inconsistencies in the literature. Clinic-based samples carry sampling bias as they are less likely to reflect the general population. Further, as this sample already has memory concerns, these studies may miss important findings regarding the risk of cognitive impairment by overlooking those who remain cognitively healthy (Hack et al., 2019). Moreover, these previous studies have been criticized for their small sample size and lack of control for key covariates, such as immigration status and socioeconomic status. Using the Comprehensive cohort from the Canadian Longitudinal Study on Aging (CLSA), a national population-based study of middle-aged and older Canadians, the current study will attempt to address these gaps. The CLSA offers the opportunity to examine the association between multilingualism and executive function in a population of Canadian participants. As well, the Comprehensive cohort's large sample size (n=30,097), provides the opportunity to adjust for many covariates, such as general health factors, health behaviours/lifestyle, and cognitively stimulating activities, many of which are not always considered in previous studies.

In summary, the current study aimed to fill the aforementioned gaps by examining the association of multilingualism, defined as the number and similarity of languages spoken, with executive function using the CLSA. The role of the above-mentioned covariates on this association was also explored.

The specific objectives of this study were to:

1) Examine the association between the number of languages spoken and low executive function at baseline in a population-based sample of Canadians aged 45 to 85 years.
2) Examine the association between the similarity of languages spoken and low executive function at baseline in a population-based sample of Canadians aged 45 to 85 years.

By considering these particular aspects of language, this thesis contributes to the existing literature on the association between multilingualism and cognition and provides evidence that may be used to inform language-based intervention strategies aimed at reducing the risk of cognitive impairment and dementia. As impairments in executive function have been linked to an increased falls risk and a decline in the ability to successfully multi-task (Fraser & Bherer, 2013) (i.e., key factors that negatively impact independence), the identification of modifiable factors, such as multilingualism, that protect against low executive function may also encourage older individuals to engage in learning a new language now in order to remain independent later. Further, describing the characteristics of individuals with poor executive function may also help to identify those who may be at risk for further cognitive decline and dementia, while also identifying protective and risk factors for intervention strategies. This is particularly salient as age-related diseases such as dementia are becoming an increasingly urgent public health priority given Canada's rapidly aging population (PHAC, 2019). With no known cure for dementia, identifying modifiable protective factors such as multilingualism is key to reducing dementia-related impacts on individuals, families and society as a whole (Livingston et al., 2017). Protection is key when there is no cure.

3.0 Methodology

3.1 Literature Search Strategy

To identify existing literature examining the association of multilingualism (the number and similarity of languages spoken) with cognitive function (reviewed in section 1.0), a systematic literature search was undertaken. Two electronic databases, PubMed (1950 to present) and PsycINFO (1850 to present), were initially searched in April 2020. The search strings included key concepts related to multilingualism, cognitive function, and age. For a detailed list of search terms and subject headings used, see Appendix A, Table A1 and Table A2. The search was restricted to studies published in English and was not restricted by date. This initial search returned a total of 1,128 articles, 715 from PubMed, and 413 from PsycINFO. After duplicates between the databases were removed, 862 articles remained for screening. The total number of peer-reviewed empirical articles included after applying exclusion criteria was 58.

To identify studies published within the last year, the original literature search was updated in April 2021, capturing publications from April 2020 to April 2021. Using the same aforementioned search concepts and databases, a total of 111 new publications were identified for this one year. After duplicates with the original April 2020 search were removed, 67 articles remained and were screened for eligibility. A total of 65 articles were included in the final review. See Appendix B for a detailed description of the search strategy and Figure B1 for a PRISMA diagram of the search results which includes the April 2021 update. For a summary of the included literature see Appendix C, Table C1.

3.2 Data Source: The Canadian Longitudinal Study on Aging

3.2.1 Background

The CLSA is a national, population-based, long-term study of aging that aims to improve the overall health and quality of life of aging Canadians (Raina et al., 2019). Examining aging as a dynamic process, the CLSA investigates factors that influence the process of aging from mid-life to older age. The data from the CLSA allow for an interdisciplinary and integrated perspective regarding the biological, physical, clinical, psycho-social, and societal factors that influence healthy aging.

3.2.2 Study Design

The CLSA was designed as a 20-year prospective cohort study, consisting of a national, stratified, random sample of approximately 50,000 Canadians aged 45–85 years at the time of recruitment. CLSA data include Canadians from all 10 provinces (Raina et al., 2019). The participants make up two study components: the Tracking cohort, who are interviewed by telephone, and the Comprehensive cohort, who are interviewed in person, take part in physical assessments and provide biospecimen samples. As the participants in the Comprehensive cohort undergo in-person interviews and cognitive assessments and complete a greater number of cognitive tests in comparison to the Tracking cohort (Tuokko et al., 2017), the current study utilized data from the Comprehensive cohort only. CLSA data collection is designed to occur in repeated waves every three years, for at least 20 years, or until participant withdrawal or death. Participant recruitment and baseline data collection were completed from 2010–2015. The first wave of follow-up was completed in 2018.

3.2.3 Sampling Frame, Eligibility and Data Collection

Three sampling sources were used for recruitment into the Comprehensive cohort: 1) provincial health registration database mailouts, 2) Random Digit Dialing (RDD) of landline telephones, and 3) the Québec Longitudinal Study on Nutrition and Aging (NuAge) (Canadian Longitudinal Study on Aging [CLSA], 2020; Gaudreau et al., 2007). Additional targeted sampling of low-education areas was conducted with telephone sampling and health registry mail-outs. Participants were recruited into strata defined by province, age group, and sex. A simple random sample was then taken from each stratum/subpopulation. For a summary of the study design specific to the Comprehensive cohort, see Appendix D, Figure D1.

The CLSA excluded persons living in the three territories and remote regions, Federal First Nations communities, full-time members of the Armed Forces, individuals living in institutions (i.e., long-term care), and temporary visa holders. In addition, participants were only eligible to participate in the CLSA if they were between the ages of 45–85. This age range was chosen as it captures mid-life experiences prospectively and includes those who are experiencing retirement or have reached old age. Further, participants were only included if they could complete interviews and testing in English or French and were free from cognitive impairment at baseline; however, the presence of other chronic conditions was not a criterion for exclusion. Individuals with cognitive impairment at baseline were excluded as this can compromise the validity and reliability of responses to interview questions. Cognitive impairment was determined by CLSA staff during first contact calls with participants. Participants unable to understand the purpose of the interview and provide reliable responses were considered cognitively impaired by staff — no screening questionnaires were used.

To participate in the Comprehensive cohort, participants had to agree to take part in an in-home interview and agree to the collection of physical, neuropsychological and anthropometric measures at one of 11 major data collection sites (DCS). These individuals also had the option to provide biospecimen samples, but refusal to do so was not a criterion for exclusion. Due to the commitment required by Comprehensive cohort participants, a DCS location had to be within 25–50 kilometres of the participants' homes. Thus, individuals in the Comprehensive cohort were recruited from the seven provinces (11 cities) where the DCS are located: British Columbia (Victoria, Vancouver, Surrey), Alberta (Calgary), Manitoba (Winnipeg), Ontario (Ottawa, Hamilton), Québec (Montréal, Sherbrooke), Nova Scotia (Halifax), and Newfoundland & Labrador (St. John's). Therefore, given the geographic limits of the DCS, the Comprehensive cohort did not recruit from Saskatchewan, Prince Edward Island, and New Brunswick.

3.2.4 CLSA Study Sample at Baseline

A final sample of 51,338 participants was recruited into the CLSA at baseline, of which 30,097 made up the baseline Comprehensive cohort. Overall, the CLSA data are largely generalizable to the nation; however, participants are generally more highly educated, report a higher level of functional social support, and have greater household income (Raina et al., 2019). Also, a high percentage of CLSA participants are Canadian-born.

The national response rate of the Comprehensive cohort was 10%. Notably, this baseline response rate is somewhat comparable with recent large cohort studies as noted by Raina et al. (2019). For a breakdown of the CLSA's Comprehensive cohort recruitment response rates by province, see Appendix D, Table D1. Over the last three decades, participation rates for epidemiological studies have been steeply declining (Galea & Tracy, 2007). Earlier cohort studies such as the Framingham Heart Study (est. 1948) and the National Health Interview Survey (est.

1960) saw response rates of around 70% and 95% respectively (for a review, see Galea & Tracy, 2007). More recent studies, such as the Canadian Study of Health and Aging (1991–2002), had a response rate of approximately 40% (The Canadian Study of Health and Aging, 2002). This trend of declining response rates may be due to factors including increased skepticism about research efforts conducted over the phone, an unfortunate consequence of increased telemarketing over time (Galea & Tracy, 2007). While the declining response rate is unfavourable for research, this decline is largely outside of the researcher's control.

To overcome the under- or over-representation of certain groups and provide the most accurate estimates of the Canadian population, sampling weights were constructed by the CLSA (2011). These weights were developed in 2011 and provide information regarding how many individuals within each province, and Canada, are represented by each CLSA participant. The function of sampling weights is to reduce the impact of particular characteristics, such as province, age, and sex, thus helping to ensure that the estimates obtained from data analyses are representative of the Canadian population. Therefore, each participant in the CLSA was assigned a sample weight based on their inclusion probability (CLSA, 2020). Overall, the use of these sampling weights helps to increase the representativeness of the statistics computed and thus helps to increase the overall generalizability of this study's results (Griffith, 2020). The data used for this study (dataset version 4.2) includes the new sampling weights, which are based on the National Household Survey and better reflect the target population around the DCS catchment areas (CLSA, 2020). For more information regarding how sampling weights were used in this study's analyses, see section 3.5.

3.3 Analytic Sample and Subsample

This study used the baseline Comprehensive cohort for data analyses (n=30,097). While the three-year follow-up data are available, only baseline data were examined. This was done for several key reasons. First, given that the association of interest has conceptual temporality (i.e., individuals learn languages earlier in life before cognitive testing at baseline), reverse causality between executive function performance and multilingualism is less of a concern than for some other risk factors. It is less likely that individuals choose to be multilingual because of better cognition or executive function: rather, individuals learn languages because of family, culture, immigration history, or their country of birth (Bialystok et al., 2012). Second, preliminary work with CLSA data suggests that the three-year interval between baseline and the first follow-up assessment may be insufficient to see cognitive change (Yoo, 2020). Further, this issue is exacerbated by the extent of missing cognitive data at follow-up. Specifically, as cognitive impairment is a common and consistent factor for attrition in longitudinal studies involving older adults, those CLSA participants with low cognitive performance at baseline are potentially more likely to have incomplete or no cognitive results at follow-up (Chatfield et al., 2005; Jacobsen et al., 2020); however, this has yet to be fully investigated in the CLSA data. Last, as the association of multilingualism with executive function has not been examined with CLSA data, this study offers a novel contribution to the field with a clear understanding of the events at baseline for future projects to build upon.

The analytical sample for the number of languages spoken was derived from the full baseline Comprehensive cohort. From this full sample, participants who did not complete their cognitive testing at a designated DCS were excluded to maintain consistency regarding the testing environment. Those with missing or incomplete data on the exposure, outcome and covariates of interest were then removed, thus only including complete cases for analyses. This analytic sample was used to answer the first research objective examining the number of languages spoken. From this analytical sample, the similarity of languages subsample was created by including monolingual speakers and bilingual speakers whose two spoken languages were both from the Indo-European language family. Bilinguals whose two spoken languages were not both from the Indo-European language family were excluded. Participants were also excluded from this subsample if they spoke three or more languages and if information needed to derive language similarity was incomplete. This subsample was used to answer the second research objective concerning the role of language similarity. For details and a rationale for choosing monolinguals and Indo-European bilinguals to examine language similarity, see section 3.4.1 below. Also, see Appendix E, Figure E1 for a diagram of the flowchart for the derivation of the number of languages analytical sample and the similarity of languages subsample.

3.4 Measures

3.4.1 Multilingualism

The exposure, multilingualism, was assessed at baseline through self-reported responses to questions concerning language. Three questions were asked: 1) “In what languages can you conduct a conversation?”, 2) “What language do you speak most often at home?”, and 3) “What is the language that you first learned at home in childhood and can still understand?”. The first question was used to derive the exposure measures for the number of languages spoken and the similarity of languages spoken. The number of languages spoken was classified into 1, 2, 3, 4 and 5+ languages. Similar approaches have been taken for the classification of languages into categories (e.g., Hack et al., 2019; Ihle et al., 2016; Kavé et al., 2008).

The measure of language similarity was formed based on the same question: “In what languages can you conduct a conversation?”. While there is no universally accepted measure of language similarity, it is widely acknowledged that languages within the same language family and subgroup (e.g., English and German from the Indo-European family, Germanic subgroup) are more similar than those from different groups (e.g., English and French, members of the Germanic and Romance subgroups respectively) (Dryer & Haspelmath, 2013; Katzner, 2002). As languages from the same family are classified based on common or similar linguistic features, such as typological similarity in vocabulary, phonology and grammar as well as language history, it is reasonable to assume that languages within the same family and subgroup are found to be more similar relative to those in different language families (Dorrel & Henderson, 2019; Dryer & Haspelmath, 2013). Similar approaches to classifying language similarity have been taken in previous studies examining language similarity with cognition. For example, participants were classified as speakers of similar languages based on language family (Oschwald et al., 2018) or language family subgroup (Olguin et al., 2019; Sörman et al., 2019). A recent study examining language distance used language family subgroups for the classification of bilinguals but also included a monolingual group for comparison (Ljungberg et al., 2020).

Considering how language similarity was defined in existing literature, the use of *language family subgroups* was adopted here to classify languages spoken as similar or dissimilar. Specifically, the role of language similarity was examined in *bilingual* participants whose two languages were both from the Indo-European language family. As the research on the role of language similarity and cognition is already limited in bilinguals (Olguin et al., 2019; Oschwald et al., 2018; Sörman et al., 2019), and to the best of the author’s knowledge, non-existent in speakers of more than two languages, the decision was made to restrict the sample to bilinguals and monolinguals as was done by Ljungberg et al. (2020). This allowed for the consideration of the number and similarity of languages spoken. Regarding the bilinguals in this subsample, Indo-European bilinguals were specifically chosen as languages within the Indo-European language family have been more frequently examined in the existing literature of cognition with language similarity (Oschwald et al., 2018; Sörman et al., 2019). Importantly, as participants in the CLSA are required to speak at least English or French (Raina et al., 2008) (which are both Indo-European languages), examining those who spoke Indo-European languages over other language families would arguably result in a larger group for analyses and be more generalizable to the Canadian context.

Therefore, in this study, similar bilinguals were defined as bilinguals whose two spoken languages were from the same Indo-European family subgroup (e.g., English and German, both within the Germanic subgroup) and dissimilar bilinguals were defined as bilinguals whose two spoken languages were from different Indo-European language family subgroups (e.g., English and French, Germanic and Romance subgroups respectively). See Appendix E, Figure E1 for a flowchart outlining the creation of this subsample and Appendix F, Table F1 for the classification of languages for CLSA participants into Indo-European language family and subgroups.

3.4.2 Executive Function

This study used the measures of executive function available in the Comprehensive cohort to derive a dichotomous measure of low/not low executive function at baseline. The CLSA's battery of executive function tests was chosen by the CLSA working group through a review of the literature and was based on the sensitivity and specificity of each test to detect changes in cognitive function and early decline (Tuokko et al., 2017). In addition, the tests were chosen based on their availability in English and French; no translation was required (Tuokko et al., 2020). The battery consists of the following tests: Animal Fluency Test (AFT), Controlled Oral Word Association Test (COWAT), Mental Alternation Test (MAT), Stroop Neuropsychological Screening Test – Victoria Version (Stroop-V), Event-based Prospective Memory Test (EPMT), and the Time-based Prospective Memory Test (TPMT). Of these six tests, this study did not consider the EMPT as a measure of executive function. Although the EPMT and TPMT both measure prospective memory, which is correlated with executive function (i.e., inhibition and working memory) (Mioni & Stablum, 2014), the TPMT, relative to the EPMT, places greater demands on the executive control system (O'Connell personal communication; Simard et al., 2019). As this study focuses on the executive function of multilinguals, the TMPT is thus a more appropriate measure relative to the EPMT. Therefore, TPMT was considered as one of the five executive function measures in this study, in addition to the AFT, COWAT, MAT and Stroop-V. The EPMT was not included. See Appendix G for a description of the five executive function tests used.

3.4.2.1 Creation of the Low Executive Function Measure

To derive the measure of executive function the five aforementioned tests were used. To maintain consistency in scoring, participants were excluded if they switched back and forth between languages or had bilingual responses on any of the five executive function tests. For tests that had audio recordings (AFT, COWAT, and MAT), responses that were impacted by poor audio quality were also excluded. Raw test scores were then converted into z-scores. This was done separately for tests completed in English and French. The z-scores for each individual test were then summed (AFT + COWAT + MAT + TPMT – Stroop-V) to create an overall composite score for executive function. On all five executive function tests, except the Stroop-V, a high score is indicative of better performance. As the Stroop-V is a time until completion task, the Stroop-V score was therefore subtracted when creating the overall executive function score.

To derive the measure of low executive function, the overall executive function score was dichotomized into low or not low executive function based on a cut-point, where ≥ 1.5 standard deviations (SD) below the mean indicated low executive function. This cut-point was determined based on previous literature on MCI (Petersen, 2016; Sachdev et al., 2014) and work conducted by our CLSA research group (Ha, 2019; Rutter, 2019). The 1.5 SD cut-off was calculated from a weighted, cognitively healthy subsample of CLSA participants. This subsample excluded participants who had a self-report or diagnosis of a cerebrovascular accident, transient ischemic attack, memory problems, AD, Parkinson's disease, multiple sclerosis, epilepsy and/or cancer of the eye, brain and other parts of the central nervous system (O'Connell et al., 2017). Moreover, it also excluded those who screened positive for a traumatic brain injury and had two or more head injuries or those who reported a concussion and had two or more head injuries (Bedard et al., 2018).

3.4.3 Covariates

To examine the association between multilingualism and executive function, the role of covariates as potential confounders and effect modifiers was explored. For each research question, the same covariates were used; these include age, sex and province due to the CLSA's complex sampling design (CLSA, 2020). Although the CLSA conducted targeted sampling in areas with lower education, this was largely completed for the Tracking cohort, with only extra mailouts and telephone calls completed for the Comprehensive cohort. Therefore, for this study, education was considered in relation to cognitive stimulation as opposed to a factor in the sampling design (CLSA, 2020; Griffith, 2020).

All covariates were baseline measures. The covariates were divided into four themed chunks: 1) sociodemographic (i.e., age, sex, province, urban/rural residence, annual household income, immigration status, first language learned at home, and language spoken most often at home); 2) general health (i.e., self-rated health, chronic conditions, and depressive symptoms); 3) health behaviours/lifestyle (i.e., smoking status, alcohol consumption, and overall social support availability); and 4) cognitively stimulating activities (i.e., education and frequency of participation in cognitive leisure activities, such as jigsaw puzzles). The choice of covariates was based on existing literature (see section 1.0) and previous work completed by the research team using CLSA data (e.g., Ha, 2019; Rutter, 2019; Yoo, 2020). See Appendix H, Figure H1 for a conceptual map of the association of multilingualism with executive function, and Table H1 for a description of the aforementioned covariates and how they were operationalized in this study.

3.5 Data Analysis

SAS Studio 3.6 Enterprise Edition (SAS Institute Inc., Cary, NC) was used for analyses. A two-sided p-value of < 0.05 was used as the threshold to indicate statistical significance.

3.5.1 Descriptive Analysis

To describe the analytic sample and subsample, descriptive analyses were conducted. Specifically, to summarize the properties of variables, univariate analyses (i.e., frequencies and percentages) were calculated for all covariates, multilingualism, and executive function. Bivariate analyses cross-tabulated the exposure and covariates with the outcome, low executive function. These descriptive analyses were run for both weighted and unweighted data. As recommended by the CLSA (2020), inflation weights were used for descriptive analyses. These weights are calculated by the CLSA based on an individual's inclusion probability as well as their DCS area. The CLSA's geographical strata variable (GEOSTRATA_COM) was also included in weighted analyses (CLSA, 2020). For the unweighted bivariate analysis, Pearson chi-square tests were used to test for significant associations between categorical variables and low executive function. For weighted bivariate analysis, Rao chi-square tests were used. A two-sided p-value of < 0.05 was used as the threshold to indicate statistical significance for bivariate analyses.

3.5.2 Multivariable Analysis

Weighted logistic regression models were used to address each research question. Models were created using PROC SURVEYLOGISTIC. Analytic weights (i.e., rescaled inflation weights, which sum to the sample size of the DCS location of each province rather than the total provincial population) were used according to CLSA (2020) recommendations. Weighted models also included the CLSA's geographical strata variable (GEOSTRATA_COM) (CLSA, 2020). Odds ratios (OR) were used to assess the overall strength of the association between multilingualism and low executive function, and 95% CI were used to assess the significance of this association. The analytic plan for research question one, where multilingualism was defined as the number of languages spoken, is presented in Appendix I (Table I1) and outlined below. This analytical plan also applied for the second research question, where multilingualism was further explored based on the similarity of spoken languages using the subsample.

To address both research objectives, the exposure variable was included in each model regardless of its significance level (Greenland, 1989). Logistic regression models were developed using multiple stages of model building. First, backwards elimination (BWE) was attempted to assess for interactions with the exposure (Kleinbaum et al., 2014). When attempting BWE to test for interactions, all first-order interaction terms were entered into the model, with the exposure and covariates forced in (Greenland, 1989; Tyas et al., 2000). All regression models were hierarchically well-formulated (i.e., all main effects of higher-order interaction terms were included in models with their interaction terms) (Kleinbaum & Klein, 2010). Significance testing at $\alpha=0.05$ was used for the elimination of interaction terms. Unfortunately, BWE to test for interactions was unsuccessful for objective one (i.e., models could not be computed) and returned many significant interactions for objective two. Therefore, stratification by frequency of participation in cognitive leisure activities was chosen based on *a priori* knowledge of the literature and model fit.

Second, unstratified models were built using chunkwise hierarchical model building. To account for the CLSA's (2020) complex study design, the base model (and all succeeding models, i.e., models A to D) contained age, sex and province, in addition to the exposure, as recommended (CLSA, 2020). This type of model building was chosen for covariates as it effectively incorporates knowledge about the set of variables in relation to the exposure (Kleinbaum et al., 2014; Polit, 2010). As all covariates were chosen *a priori*, reflecting either the CLSA's complex study design or existing literature, they were retained in each model regardless of statistical significance. Thus, for each subsequent block, all variables in the previous chunks, plus the new variables from the added block, were present. Including all covariates regardless of statistical significance takes into consideration the value epidemiological studies place on accuracy over precision (Kleinbaum & Klein, 2010). To ensure that forcing non-significant variables into the model did not negatively impact model fit, this was assessed throughout. See section 3.5.3 for details.

Stratification by cognitive leisure activities was chosen based on *a priori* knowledge of the literature and model fit. Stratification was performed using model D (the fully adjusted model, containing all covariates) for both objectives. Model D was chosen as it takes into account the impact of education and had the best model fit out of all the unstratified models for both objectives. Three strata for cognitive leisure activities—every day, several times a week, infrequent—were created from the original variable asking "How much time do you spend doing the following activities taking into account both work and leisure time? Playing board games, cards, crossword puzzles, jigsaw puzzles, or sudoku”. The responses of *several times a month*, *several times a year*, and *once a year or less* were combined to form the “infrequent” stratum. These categories for stratification were created based on approaches taken in the existing literature. Studies examining cognitive leisure activities as a categorical variable tend to either keep all levels as a continuous measure (e.g., Sattler et al., 2012) or collapse categories. Examples of collapsed categories include several days per week vs. rare (i.e., weekly or less) (Verghese et al., 2009); never, occasionally/few times a month, and multiple times per week/every day (Sörman et al., 2014). For this study, as the intent was to stratify, the author chose to reduce the number of categories for stratification. Further, as there is no consistent approach to combining these categories, the author chose “infrequent” based on previously used approaches using “occasionally,” and opted to leave “several times a week” and “every day” separate for added detail and knowledge translation. Similarity of odds ratios across categories of the cognitive leisure activities variable in the unstratified model D also helped to guide the decision to collapse categories.

3.5.3 Model Diagnostics

The potential for multicollinearity of exposures and covariates was assessed by Variance Inflation Factors (VIFs), where a value of greater than 10 suggested high collinearity between two variables and warranted further investigation (Kleinbaum et al., 2014). Further, model fit was assessed using the Mann-Whitney U statistic for the area under the receiver operating characteristic (AUC (ROC)) curve (Mason & Graham, 2002; Zhang et al., 2002). Observed versus predicted executive function plots were also examined to assess model fit. A plot demonstrating two distinct lines indicated good model fit.

3.5.4 Missing Data

This study used a complete-case approach and thus excluded those individuals with missing data on the exposure, outcome, or covariates of interest. Although imputation is a common method used to address missingness, it also presents challenges if the data are not missing completely at random (Garcia & Marder, 2017). Also, as the values used to impute the missing data are from the existing data, they can carry forward the biases already associated with the known data. Thus, a complete-case analysis was favoured for this study. However, as missingness can introduce bias into the study results (Kleinbaum et al., 2014), it is important to examine its potential impact. Therefore, bivariate analyses were used to examine the existence of a statistically significant difference between participants with and without missing data. Specifically, for categorical variables, a Pearson chi-square test for unweighted data (or Fisher's exact test where necessary based on expected cell count) and Rao Scott test for weighted data, were used to determine: 1) if multilingualism differed across individuals with and without executive function data, 2) if executive function differed across individuals with and without multilingualism data, and 3) if executive function differed among individuals with and without missing data on any covariate of interest. It should be noted that due to the large sample size of the CLSA, low p-values may be produced despite the potential for these significant results to not be clinically meaningful.

4.0 Results

Weighted univariate statistics (frequencies and percentages) describing the three samples (i.e., the full sample [n=30,097], the number of languages analytical sample [n=22,249], and the similarity of languages subsample [n=20,440]) are presented in section 4.1. Tables presenting the unweighted univariate statistics for all three samples can be found in Appendix J.

The first research objective, to "examine the association between the number of languages spoken and low executive function at baseline in a population-based sample of Canadians aged 45 to 85 years," is addressed in section 4.2. The analytical sample was used for all weighted and unweighted descriptive analyses and weighted multivariable logistic regression models (both unstratified and stratified) for this objective. The results of weighted descriptive analyses for objective one are presented in the text (section 4.2.1 to 4.2.2). Tables presenting the unweighted descriptive statistics for this objective can be found in Appendix J.

The second research objective, to "examine the association between the similarity of languages spoken and low executive function at baseline in a population-based sample of Canadians aged 45 to 85 years," is addressed in section 4.3. The subsample for similarity of languages spoken was used for all weighted and unweighted descriptive analyses and weighted multivariable logistic regression models (both unstratified and stratified) for this objective. The results of weighted descriptive analyses for objective two are presented in the text (section 4.3.1 to 4.3.2). Tables presenting the unweighted descriptive statistics can be found in Appendix J.

4.1 Univariate Analyses

Weighted univariate statistics for multilingualism and executive function in all three samples (the full sample, the analytical sample, and the subsample) are presented in Table 1. Parallel unweighted results can be found in Appendix J, Table J1. In the full sample, the majority of participants (61%) spoke only one language; this was also the case for the analytical sample (64%). In both of these samples, as the number of languages increased, the proportion of participants decreased. In the similarity of languages subsample, containing only monolinguals and Indo-European bilinguals, 71% of participants spoke only one language. Of the Indo-European bilinguals, 26% spoke two dissimilar languages and 4% spoke two similar languages. In the full sample, the prevalence of low executive function was 7%. This proportion was similar across both the analytical sample and subsample, with 6% of individuals having low executive function.

Weighted univariate statistics for the covariates in all three samples are presented in Table 2. Parallel unweighted results can be found in Appendix J, Table J2. The full sample was approximately 50% male and 50% female; this was also true for both the analytical sample and subsample. In the full sample, 30% of individuals were 65+ years of age; this percentage is similar in the analytical sample and subsample (27%). The remaining individuals in the full sample ranged between 45 to 64 years of age. For all samples, less than 10% of individuals were in the lowest (< $20,000) annual household income category. Geographically, British Columbia, Ontario, and Québec had the largest proportion of participants, and over 90% of individuals lived in urban centres. In the full sample, 81% were born in Canada; this percentage was similar for the analytical sample but increased to 87% in the subsample. In all three samples, over 95% of individuals reported speaking either English or French most often at home. In the analytical sample and full sample, almost 90% learned English or French as their first language; this proportion rose to 95% in the subsample.

In all samples, the majority (57–59%) of individuals were in “very good” or “excellent” health, although, in the full sample, most of the individuals reported having at least one chronic condition. The majority of individuals scored below the threshold for the presence of depressive symptoms. In all samples, “former” or “never” were the most prevalent responses to tobacco smoking status, and most individuals (74%) reported drinking regularly. Over 90% of individuals in all samples reported high social support availability. Roughly 62–63% of individuals across the three samples reported having a post-secondary degree/diploma and 16–17% reported having never graduated high school. Approximately 50% of individuals indicated that they engaged in cognitive leisure activities at least several times a week in all three samples.

Table 1 *Exposure and Outcome Univariate Statistics in the Weighted Full Sample, Number of Languages Analytical Sample and Similarity of Languages Subsample, Canadian Longitudinal Study on Aging*

	Weighted full sample n=3,812,085[1]		**Weighted number of languages analytic sample** n=2,768,453[2]		**Weighted similarity of languages subsample** n=2,511,612[3]	
Characteristic	**n**	**%**	**n**	**%**	**n**	**%**
Number of languages						
1	2,332,220	61.24	1,775,768	64.14	1,775,768	70.70
2	1,150,036	30.20	784,814	28.35	735,843	29.30
3	244,186	6.41	155,746	5.63	-	-
4	66,494	1.75	42,357	1.53	-	-
5+[4]	15,373	0.40	9,767	0.35	-	-
Similarity of language[5]						
Monolingual	2,332,220	68.66	-	-	1,775,768	70.70
Dissimilar bilingual	930,920	27.41	-	-	646,942	25.76
Similar bilingual	133,761	3.94	-	-	88,901	3.54
Executive function						
Not low	2,898,887	92.97	2,594,951	93.73	2,354,160	93.73
Low[6]	219,332	7.03	173,501	6.27	157,452	6.27

[1] Unweighted n=30,097
[2] Unweighted n=22,249
[3] Unweighted n=20,440
[4] 5 to 11 languages
[5] Monolinguals are speakers of one language; dissimilar bilinguals are bilinguals whose two spoken languages are from different Indo-European family subgroups; similar bilinguals are bilinguals whose two spoken languages are from the same Indo-European language family subgroup
[6] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants

Table 2 *Covariate Univariate Statistics in the Weighted Full Sample, Number of Languages Analytical Sample and Similarity of Languages Subsample, Canadian Longitudinal Study on Aging*

	Weighted full sample n=3,812,085[1]		**Weighted number of languages analytic sample** n=2,768,453[2]		**Weighted similarity of languages subsample** n=2,511,612[3]	
Characteristic	**n**	**%**	**n**	**%**	**n**	**%**
Age group						
45-54 years	1,487,595	39.02	1,137,074	41.07	1,016,010	40.45
55-64 years	1,182,355	31.02	881,686	31.85	807,551	32.15
65-74 years	697,840	18.31	479,349	17.31	438,657	17.47
75+ years	444,295	11.65	270,343	9.77	249,394	9.93
Sex						
Male	1,815,435	47.62	1,334,268	48.20	1,206,090	48.02
Female	1,996,650	52.38	1,434,185	51.80	1,305,522	51.98
Province						
Alberta	398,265	10.44	274,769	9.93	254,621	10.14
British Columbia	1,077,025	28.25	828,023	39.91	745,075	29.67
Manitoba	274,215	7.19	204,956	7.40	196,357	7.82
Newfoundland	78,260	2.05	62,825	2.27	61,930	2.47
Nova Scotia	144,120	3.78	112,315	4.06	108,650	4.33
Ontario	634,220	16.64	481,954	17.41	445,032	17.72
Québec	1,205,980	31.64	803,610	29.03	699,947	27.87
Residence						
Urban	3,612,614	94.77	2,612,305	94.36	2,362,701	94.07
Rural	199,471	5.23	156,147	5.64	148,911	5.93
Annual household income						
< $20,000	244,788	6.85	168,116	6.07	151,225	6.02
$20,000 – $49,999	806,463	22.58	585,640	21.15	525,573	20.93
$50,000 – $99,999	1,186,577	33.22	924,837	33.41	844,137	33.61
$100,000 – $149,999	715,825	20.04	583,896	21.09	532,440	21.20
≥$150,000	618,142	17.31	505,963	18.28	458,237	18.24
Country of birth						
Canada	3,082,248	80.88	2,291,642	82.78	2,189,507	87.18
Not Canada	728,489	19.12	476,811	17.22	322,104	12.82

	Weighted full sample n=3,812,085[1]		Weighted number of languages analytic sample n=2,768,453[2]		Weighted similarity of languages subsample n=2,511,612[3]	
Characteristic	**n**	**%**	**n**	**%**	**n**	**%**
Language spoken most often at home: English or French						
No	156,815	4.12	74,412	2.69	19,481	0.78
Yes	3,651,805	95.88	2,694,041	97.31	2,492,131	99.22
First language learned: English and/or French						
No	476,519	12.50	290,756	10.50	133,259	5.31
Yes	3,335,566	87.50	2,477,697	89.50	2,378,353	94.69
Self-rated health						
Excellent/very good	2,189,388	57.47	1,627,334	58.78	1,480,818	58.96
Good	1,232,327	32.35	882,289	31.87	792,807	31.57
Fair/poor	388,011	10.18	258,830	9.35	237,986	9.48
Presence of chronic conditions						
None	1,293,175	34.40	992,571	35.85	888,833	35.39
1+	2,466,181	65.60	1,775,882	64.15	1,622,779	64.61
Depressive symptoms[4]						
Absence	3,092,989	81.46	2,290,899	82.75	2,083,513	82.96
Presence	703,886	18.54	477,553	17.25	428,099	17.04
Tobacco smoking status						
Never	1,684,765	44.30	1,205,569	43.55	1,071,767	42.67
Former	1,680,598	44.19	1,255,400	45.35	1,152,922	45.90
Current	437,384	11.50	307,484	11.11	286,923	11.42
Alcohol use						
None in the past year	525,644	14.17	371,571	13.42	332,712	13.25
Occasional user	489,923	13.20	350,014	12.64	309,848	12.34
Regular user	2,694,803	73.63	2,046,868	73.94	1,869,052	74.42
Overall social support availability[5]						
High	3,487,800	92.92	2,595,417	93.75	2,356,896	93.84
Low	265,762	7.08	173,036	6.35	154,716	6.16
Education						

	Weighted full sample n=3,812,085[1]		Weighted number of languages analytic sample n=2,768,453[2]		Weighted similarity of languages subsample n=2,511,612[3]	
Characteristic	**n**	**%**	**n**	**%**	**n**	**%**
Less than high school	660,726	17.36	440,360	15.91	422,527	16.82
High school diploma	437,781	11.50	314,331	11.35	297,073	11.83
Some post-secondary	345,837	9.09	259,350	9.37	241,975	9.63
Post-secondary degree/diploma	2,362,207	62.06	1,754,413	63.37	1,550,037	61.71
Cognitive leisure activities						
Every day	1,214,005	32.04	889,712	32.14	823,340	32.78
Several times a week	739,255	19.51	552,231	19.95	505,509	20.13
Several times a month	555,828	14.67	419,061	15.14	386,687	15.40
Several times a year	445,535	11.76	320,948	11.59	286,209	11.40
Once a year or less	833,991	22.01	586,502	21.19	509,867	20.30

[1] Unweighted n=30,097
[2] Unweighted n=22,249
[3] Unweighted n=20,440
[4] Center for Epidemiological Studies Short Depression Scale (CES-D 10); a cut-point of ≥10 indicates the presence of depressive symptoms
[5] Modified from the Medical Outcomes Study – Social Support Survey; a score of less than 3 out of 5 indicates low social support availability

4.2 Objective One: Examine the Association Between the Number of Languages Spoken and Low Executive Function at Baseline in a Population-based Sample of Canadians Aged 45 to 85 Years

4.2.1 Descriptive Analyses for the Association Between Number of Languages Spoken and Low Executive Function

Weighted bivariate results for the association between the number of languages spoken and executive function are presented in Table 3. For parallel unweighted bivariate results for this association, see Appendix J, Table J3.

The exposure, the number of languages spoken, was not significantly associated with executive function in weighted analyses ($p=0.452$) (Table 3); however, this association was significant in unweighted analyses ($p<0.0001$) (Table J3). In the weighted sample, about 8% of individuals spoke three or more languages and 64% spoke only one language. Of those with low executive function, roughly 4% spoke three languages versus 6% of those without low executive function. Approximately 4–8% of individuals who spoke one to four languages had low executive function, whereas about 15% (1,425/9,767) of individuals who spoke 5+ languages had low executive function (data not shown: to derive these percentages using unweighted frequencies see Table J3).

Table 3 *Distribution of Number of Languages Spoken by Executive Function Status in the Weighted Number of Languages Analytical Sample, Canadian Longitudinal Study on Aging*

Multilingualism	Executive function[1]		
	Low (n=173,501)[2]	*Not low* (n=2,594,951)[3]	*Total* (n=2,768,453)[4]
	%	**%**	**%**
Number of languages			
1	64.77	64.10	64.14
2	28.53	28.34	28.35
3	3.95	5.74	5.63
4	1.93	1.50	1.53
5+[5]	0.82	0.32	0.35

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function
[2] Unweighted n=1,504
[3] Unweighted n=20,745
[4] Unweighted n=22,249
[5] 5 to 11 languages

4.2.2 Descriptive Analyses for the Association Between Covariates and Low Executive Function for Objective One

The weighted bivariate results describing the association between covariates and low executive function are presented in Table 4 (sociodemographics), Table 5 (general health), Table 6 (health behaviours/lifestyle), and Table 7 (cognitively stimulating activities). For unweighted bivariate results describing the association between covariates and low executive function, see Appendix J, Tables J4 to J7.

Age was positively significantly associated with executive function with those 75+ — accounting for 10% of the analytical sample — over-represented as 37% of those with low executive function (Table 4). Annual household income was significantly associated with executive function: only 4% of those with low executive function had an income of greater than $150,000 versus 19% of those without low executive function, almost a five-fold difference. Language spoken most often at home and first language learned were both significantly associated with a greater chance of low executive function: 7% of those with low executive function (vs. 2%

without) reported speaking a language other than English or French most often and 21% of those with low executive function (vs.10% without) reported having a first language other than English or French. Country of birth and province were also significantly associated with executive function, whereas sex and urban/rural residence were not.

Self-rated health was significantly associated with executive function, with those with “fair/poor” health — accounting for 9% of the analytical sample — over-represented as 19% of individuals with low executive function (Table 5). Reporting at least one chronic condition was significantly associated with low executive function; this was also true for those with depressive symptoms. The associations of alcohol use, tobacco smoking status and social support availability with executive function were also significant (Table 6).

Education was significantly associated with executive function, with those who had never graduated high school — accounting for 16% of the total analytical sample — constituting 45% of those with low executive function. Participation in cognitive leisure activities was also a significant factor: 31% of those with low executive function (vs. 21% without) reported participating in these activities once a year or less.

Table 4 *Distribution of Sociodemographic Covariates by Executive Function Status in the Weighted Number of Languages Analytical Sample, Canadian Longitudinal Study on Aging*

Sociodemographics	Executive function[1]		
	Low (n=173,501)[2]	*Not low* (n=2,594,951)[3]	*Total* (n=2,768,453)[4]
	%	%	%
Age group			
45-54 years	17.24***	42.67	41.07
55-64 years	18.79	32.72	31.85
65-74 years	27.28	16.65	17.31
75+ years	36.70	7.96	9.77
Sex			
Male	46.05	48.34	48.20
Female	53.95	51.66	51.80
Province			
Alberta	9.52*	9.95	9.93
British Columbia	26.25	30.15	29.91
Manitoba	9.89	7.24	7.40
Newfoundland	3.72	2.17	2.27
Nova Scotia	5.13	3.99	4.06
Ontario	16.90	17.44	17.41
Québec	28.59	29.06	29.03
Residence			
Urban	94.73	94.34	94.36
Rural	5.27	5.66	5.64
Annual household income			
< $20,000	13.45***	5.58	6.07
$20,000 – $49,999	49.18	19.28	21.15
$50,000 – $99,999	26.78	33.85	33.41
$100,000 – $149,999	6.50	22.07	21.09
≥$150,000	4.09	19.22	18.28
Country of birth			
Canada	75.49**	83.26	82.78
Not Canada	24.51	16.74	17.22
Language spoken most often at home: English or French			
No	7.42***	2.37	2.69
Yes	92.58	97.63	97.31
First language learned: English and/or French			
No	20.56***	9.83	10.50
Yes	79.44	90.17	89.50

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function
[2] Unweighted n=1,504
[3] Unweighted n=20,745
[4] Unweighted n=22,249
Rao Scott chi-square *p<0.05; **p<0.001; ***p<0.0001

Table 5 *Distribution of General Health Covariates by Executive Function Status in the Weighted Number of Languages Analytical Sample, Canadian Longitudinal Study on Aging*

General health	Executive function[1]		
	Low (n=173,501)[2]	*Not low* (n=2,594,951)[3]	*Total* (n=2,768,453)[4]
	%	**%**	**%**
Self-rated health			
Excellent/very good	40.66***	59.99	58.78
Good	40.57	31.29	31.87
Fair/poor	18.77	8.72	9.35
Presence of chronic conditions			
None	18.49***	37.01	35.85
1+	81.51	62.99	64.15
Depressive symptoms[5]			
Absence	73.92	83.34	82.75
Presence	26.08***	16.66	17.25

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function
[2] Unweighted n=1,504
[3] Unweighted n=20,745
[4] Unweighted n=22,249
[5] Center for Epidemiological Studies Short Depression Scale (CES-D 10); a cut-point of ≥10 indicates the presence of depressive symptoms
Rao Scott chi-square *p<0.05; **p<0.001; ***p<0.0001

Table 6 *Distribution of Health Behaviours/Lifestyle Covariates by Executive Function Status in the Weighted Number of Languages Analytical Sample, Canadian Longitudinal Study on Aging*

Health behaviours/lifestyle	Executive function[1]		
	Low (n=173,501)[2]	*Not low* (n=2,594,951)[3]	*Total* (n=2,768,453)[4]
	%	**%**	**%**
Tobacco smoking status			
Never	38.62	43.88	43.55
Former	49.56	45.06	45.35
Current	11.82	11.06	11.11
Alcohol use			
None in the past year	28.05***	12.44	13.42
Occasional user	15.94	12.42	12.64
Regular user	56.01	75.13	73.94
Overall social support availability[5]			
High	87.73***	94.15	93.75
Low	12.27	5.85	6.25

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function
[2] Unweighted n=1,504
[3] Unweighted n=20,745
[4] Unweighted n=22,249
[5] Modified from the Medical Outcomes Study – Social Support Survey; a score of less than 3 out of 5 indicates low social support availability
Rao Scott chi-square *p<0.05; **p<0.001; ***p<0.0001

Table 7 *Distribution of Cognitively Stimulating Activity Covariates by Executive Function Status in the Weighted Number of Languages Analytical Sample, Canadian Longitudinal Study on Aging*

Cognitively stimulating activities	Executive function[1]		
	Low (n=173,501)[2]	*Not low* (n=2,594,951)[3]	*Total* (n=2,768,453)[4]
	%	**%**	**%**
Education			
Less than high school	44.89***	13.97	15.91
High school diploma	12.43	11.28	11.35
Some post-secondary	7.41	9.50	9.37
Post-secondary degree/diploma	35.27	65.25	63.37
Cognitive leisure activities			
Every day	26.51***	32.51	32.14
Several times a week	15.00	20.28	19.95
Several times a month	18.96	14.88	15.14
Several times a year	8.90	11.77	11.59
Once a year or less	30.63	20.55	21.19

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function
[2] Unweighted n=1,504
[3] Unweighted n=20,745
[4] Unweighted n=22,249
Rao Scott chi-square *p<0.05; **p<0.001; ***p<0.0001

4.2.3 Unstratified Logistic Regression Analyses for the Association Between Number of Languages and Low Executive Function

For all models, VIF, AUC (ROC), and observed versus predicted plots were performed to assess model fit and multicollinearity. No concerns were found. For AUC (ROC) results, see Appendix K, Table K1. Results from the unstratified models (base model to model D) can be found in Table 8.

In the unstratified multivariable analysis, the number of languages spoken (reference group is monolinguals) was significantly associated with low executive function in all models (i.e., base model to model D). In the base model adjusted for age, sex, and province, speaking two or three languages (but not four or 5+) compared to speaking one language was significantly associated with a reduced odds of low executive function (2 languages: OR=0.76, 95% CI=0.65-0.89; 3 languages: OR=0.69, 95% CI=0.49-0.98). When additional sociodemographic factors were added (model A), the strength of the association of two and three languages with executive function increased and speaking four languages became significant. The strength of the association between the number of languages and low executive function was fairly consistent with the addition of each additional block of covariates (models B to D).

Overall, in the fully adjusted model D, the association between the number of languages spoken and low executive function was significant but reached a peak effect at four languages spoken. Specifically, with each additional language spoken, up to four languages, the strength of the association increased in a dose-response manner (2 languages: OR=0.68, 95% CI=0.57-0.81; 3 languages: OR=0.43, 95% CI=0.28-0.66; 4 languages: OR=0.34, 95% CI=0.18-0.64). Speaking 5+ languages was not significantly associated with low executive function in model D (OR=0.87, 95% CI=0.38-1.96), or in any model, and did not follow the dose-response that was seen for two, three, and four languages spoken.

4.2.4 Unstratified Logistic Regression Analyses for the Association Between Covariates and Low Executive Function for Objective One

The results for the base model and model A to model D for the association between covariates and low executive function can be found in Table 8.

4.2.4.1 Sociodemographics. Age was consistently positively associated with low executive function across all models. A dose-response association was seen, such that when compared to those 45 to 54 years, individuals aged 75+ had about an eight-fold greater odds of low executive function in the fully adjusted model. Sex was significantly associated with low executive function in models A to C, but this became nonsignificant after adjusting for education and cognitive leisure activities in model D. Geographically, compared to Ontario, living in British Columbia was consistently significantly protective against low executive function whereas living in Newfoundland and Labrador or Nova Scotia was significantly associated with a greater odds of low executive function. Behaving in a dose-response manner, annual household income was significantly associated with low executive function across all models. Compared to those who made $150,000+, those who earned less than $100,000 had significantly greater odds of low executive function. The association between language characteristics and low executive function was also significant in all models. Individuals who spoke another language other than English and/or French most often at home (vs. English or French) had consistently greater odds of low executive function (model D: OR=2.35, 95% CI=1.50-3.68). Reporting a first language other than English or French (vs. English and/or French) was also consistently associated with a greater odds of low executive function (model D: OR=2.25, 95% CI=1.59-3.17). Urban or rural residence and country of birth were not significant covariates in any model.

4.2.4.2 General health factors. Self-reported general health was significantly positively associated with low executive function in all models: in the fully adjusted model, those who reported their health as "good" or "fair/poor" compared to "excellent/very good" had a 41% and 88% increased odds of low executive function respectively. The presence of at least one chronic condition (vs. none) and the presence of depressive symptoms (vs. absence) were also significantly associated with low executive function.

4.2.4.3 Health behaviours/lifestyle factors. Overall social support availability was not significantly associated with low executive function in any model. When compared to non-drinkers, only those who reported drinking regularly, but not occasionally, had a significantly reduced odds of low executive function. The association between tobacco smoking status and low executive function was not significant after adjusting for cognitively stimulating activities.

4.2.4.4 Cognitively stimulating activities. Education was significantly associated with low executive function in a dose-response manner: compared to participants who had not completed high school, those who graduated high school, had some post-secondary education, or held a post-secondary degree/diploma had a 33%, 54%, and 55% reduced odds of low executive function, respectively. Participation in cognitive leisure activities (e.g., puzzles, sudoku) was also significantly associated with protection against low executive function. Compared to those who participated in these types of activities "once a year or less", those who participated "every day" had a 59% lower odds of low executive function. Individuals who participated many times a week, month or year also had significantly reduced odds of low executive function.

Table 8 *Unstratified Weighted Logistic Regression Models Assessing the Association Between Number of Languages Spoken and Low Executive Function, Number of Languages Analytical Sample, Canadian Longitudinal Study on Aging, n=22,249*

	Low executive function[1]				
	Base model OR (95% CI)	Model A OR (95% CI)	Model B OR (95% CI)	Model C OR (95% CI)	Model D OR (95% CI)
Number of languages (Ref.: Monolingual)					
2	**0.76 (0.65-0.89)**	**0.62 (0.52-0.73)**	**0.64 (0.54-0.76)**	**0.64 (0.54-0.76)**	**0.68 (0.57-0.81)**
3	**0.69 (0.49-0.98)**	**0.39 (0.26-0.59)**	**0.40 (0.26-0.62)**	**0.41 (0.27-0.62)**	**0.43 (0.28-0.66)**
4	0.70 (0.38-1.29)	**0.29 (0.16-0.54)**	**0.29 (0.16-0.55)**	**0.30 (0.16-0.57)**	**0.34 (0.18-0.64)**
5+	1.40 (0.67-2.89)	0.68 (0.30-1.53)	0.70 (0.31-1.58)	0.72 (0.31-1.65)	0.87 (0.38-1.96)
Age group (Ref.: 45–54 years)					
55–64 years	**1.71 (1.35-2.16)**	**1.43 (1.13-1.81)**	**1.42 (1.12-1.81)**	**1.44 (1.13-1.83)**	**1.49 (1.17-1.90)**
65–74 years	**4.76 (3.83-5.91)**	**3.25 (2.58-4.09)**	**3.41 (2.70-4.30)**	**3.55 (2.81-4.49)**	**3.72 (2.94-4.72)**
75+ years	**13.76 (11.14-17.01)**	**8.53 (6.79-10.71)**	**8.73 (6.93-11.01)**	**9.14 (7.21-11.58)**	**9.45 (7.42-12.03)**
Sex (Female vs. Male [Ref.])	1.05 (0.93-1.18)	**0.83 (0.73-0.95)**	**0.84 (0.74-0.96)**	**0.82 (0.72-0.94)**	0.91 (0.79-1.05)
Province (Ref.: Ontario)					
Alberta	1.09 (0.82-1.44)	1.09 (0.81-1.46)	1.10 (0.82-1.48)	1.09 (0.81-1.47)	1.18 (0.88-1.60)
British Columbia	**0.75 (0.61-0.91)**	**0.66 (0.54-0.81)**	**0.66 (0.54-0.81)**	**0.65 (0.53-0.80)**	**0.68 (0.55-0.84)**
Manitoba	**1.27 (1.03-1.57)**	1.02 (0.82-1.27)	1.02 (0.82-1.28)	1.01 (0.81-1.27)	1.10 (0.88-1.38)
Québec	1.19 (0.97-1.44)	0.88 (0.72-1.08)	0.85 (0.69-1.05)	0.88 (0.72-1.08)	0.83 (0.67-1.02)
Newfoundland	**1.58 (1.26-1.97)**	**1.46 (1.16-1.84)**	**1.49 (1.18-1.89)**	**1.49 (1.18-1.89)**	**1.67 (1.32-2.12)**
Nova Scotia	**1.41 (1.13-1.76)**	1.21 (0.97-1.52)	1.21 (0.96-1.52)	1.19 (0.95-1.49)	**1.29 (1.02-1.62)**
Residence (Rural vs. Urban [Ref.])		1.13 (0.88-1.46)	1.17 (0.91-1.51)	1.19 (0.92-1.53)	1.14 (0.88-1.48)
Annual household income (Ref.: ≥$150,000)					
< $20,000		**9.17 (6.52-12.90)**	**6.43 (4.57-9.03)**	**5.41 (3.83-7.65)**	**4.63 (3.25-6.58)**
$20,000 – $49,999		**5.05 (3.71-6.89)**	**4.09 (3.00-5.57)**	**3.67 (2.70-5.00)**	**3.42 (2.51-4.66)**

	Low executive function[1]				
	Base model OR (95% CI)	Model A OR (95% CI)	Model B OR (95% CI)	Model C OR (95% CI)	Model D OR (95% CI)
$50,000 – $99,999		**2.23 (1.64-3.03)**	**1.98 (1.46-2.69)**	**1.89 (1.39-2.56)**	**1.88 (1.39-2.56)**
$100,000 – $149,999		1.33 (0.94-1.88)	1.26 (0.89-1.79)	1.23 (0.87-1.75)	1.25 (0.88-1.76)
Country of birth (Not Canada vs. Canada [Ref.])		0.93 (0.78-1.11)	0.93 (0.78-1.11)	0.95 (0.79-1.13)	0.97 (0.80-1.16)
Language spoken most often at home: English or French (No vs. Yes [Ref.])		**2.71 (1.72-4.27)**	**2.74 (1.73-4.34)**	**2.62 (1.65-4.16)**	**2.35 (1.50-3.68)**
First language learned: English and/or French (No vs. Yes [Ref.])		**2.34 (1.80-3.06)**	**2.31 (1.77-3.02)**	**2.24 (1.72-2.93)**	**2.14 (1.63-2.81)**
Self-rated health (Ref.: Excellent/Very good)					
Good			**1.48 (1.29-1.71)**	**1.44 (1.25-1.66)**	**1.41 (1.22-1.63)**
Fair/Poor			**2.12 (1.75-2.56)**	**1.97 (1.63-2.39)**	**1.88 (1.55-2.29)**
Presence of chronic conditions (1+ vs. None [Ref.])			**1.24 (1.04-1.47)**	**1.23 (1.03-1.47)**	**1.24 (1.04-1.48)**
Depressive symptoms[2] (Presence vs. Absence [Ref.])			**1.40 (1.19-1.64)**	**1.36 (1.16-1.61)**	**1.30 (1.10-1.54)**
Overall social support availability[3] (Low vs. High [Ref.])				1.02 (0.81-1.29)	0.99 (0.78-1.25)
Tobacco smoking status (Ref.: Never)					
Former				1.01 (0.88-1.15)	0.98 (0.85-1.13)
Current				**1.29 (1.03-1.62)**	1.21 (0.96-1.53)
Alcohol use (Ref.: Non-user)					
Occasional user				0.84 (0.68-1.05)	0.85 (0.68-1.05)
Regular user				**0.64 (0.54-0.76)**	**0.67 (0.56-0.80)**
Education (Ref.: Less than high school)					
High school diploma					**0.67 (0.52-0.86)**
Some post-secondary					**0.46 (0.35-0.61)**

	Low executive function[1]				
	Base model OR (95% CI)	Model A OR (95% CI)	Model B OR (95% CI)	Model C OR (95% CI)	Model D OR (95% CI)
Post-secondary degree/diploma					**0.45 (0.36-0.55)**
Cognitive leisure activities (Ref.: Once a year or less)					
Every day					**0.41 (0.35-0.49)**
Several times a week					**0.50 (0.41-0.61)**
Several times a month					**0.65 (0.52-0.82)**
Several times a year					**0.59 (0.46-0.75)**

Abbreviations: OR = odds ratio, CI = confidence interval, Ref. = reference
The base model includes the exposure and covariates related to the CLSA design
Model A includes the exposure and all sociodemographic covariates
Model B includes the exposure, general health covariates + Model A covariates
Model C includes the exposure, health behaviours/lifestyle covariates + Model B covariates
Model D includes the exposure, cognitively stimulating activities + Model C covariates
[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants
[2] Center for Epidemiological Studies Short Depression Scale (CES-D 10); a cut-point of ≥10 indicates the presence of depressive symptoms
[3] Modified from the Medical Outcomes Study – Social Support Survey; a score of less than 3 out of 5 indicates low social support availability

4.2.5 Logistic Regression Analyses Stratified by Cognitive Leisure Activities: The Association Between Number of Languages Spoken and Low Executive Function

The fully adjusted model D was used for stratification by cognitive leisure activities as this model had the best fit of all unstratified models for objective one (see Appendix K, Table K1 for AUC [ROC] statistics). Three strata were used for frequency of participation in cognitive leisure activities (see section 3.5.2 for details). The following text presents only the results for the association between the exposure; the number of languages spoken; and the outcome, low executive function, for model D by each stratum (Table 9). The ORs and 95% CI for all other covariates in model D for each stratum can be found in Appendix L, Table L1.

For those individuals who participated in cognitive leisure activities "every day", knowing more than one language was not significantly associated with low executive function. Although nonsignificant, compared to only speaking one language, speaking two to four languages was associated with a reduced odds of low executive function but speaking 5+ languages was associated with a greater odds of low executive function. Participation in cognitive leisure activities “several times a week” resulted in non-significant findings. Interestingly, speakers of two languages were not different from monolinguals (OR=1.00, 95% CI=0.64-1.58).

Unlike the other two strata, for those individuals who participated in cognitive leisure activities “infrequently”, knowing multiple languages was significantly protective against low executive function. Speaking two to four languages, compared to only one language, was significantly associated with a reduced odds of low executive function in a dose-response manner: 43% lower odds for bilinguals (95% CI=0.45-0.72), 62% lower odds for trilinguals (95% CI=0.21-0.70), and 80% lower odds for speakers of four languages (95% CI=0.09-0.44). Similar to the unstratified results (section 4.2.3), protection against low executive function peaked at four languages spoken, as speaking 5+ languages was not significantly associated with low executive function.

Table 9 *Weighted Fully Adjusted Logistic Regression Model Assessing the Association Between Number of Languages Spoken and Low Executive Function Stratified by Cognitive Leisure Activities, Number of Languages Analytical Sample, Canadian Longitudinal Study on Aging, n=22,249*

Number of languages (Ref: Monolinguals)	*Low executive function*[1] **OR**[2]	**95% CI**
	Every day (n=7,915)	
2	0.76	0.55-1.05
3	0.49	0.24-1.00
4	0.81	0.31-2.10
5+	2.59	0.75-8.99
	Several times a week (n=4,151)	
2	1.00	0.64-1.58
3	0.52	0.21-1.26
4	0.51	0.06-4.21
5+	0.66	0.04-9.85
	Infrequently (n=10,183)	
2	**0.57**	**0.45-0.72**
3	**0.38**	**0.21-0.70**
4	**0.20**	**0.09-0.44**
5+	0.54	0.18-1.61

Abbreviations: OR = odds ratio, CI = confidence interval, Ref. = reference
[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants
[2] Fully adjusted model (model D) contains all covariate blocks (sociodemographics, general health, health behaviours/lifestyle, cognitively stimulating activities)

4.2.6 Summary of Results for Objective One

The results of objective one using unstratified models found that, after adjusting for all covariates (model D), the number of languages spoken was associated with a reduced odds of low executive function in a dose-response manner up until, and including, four languages spoken (Table 8). However, when model D was stratified by cognitive leisure activities, speaking multiple languages, up to and including four languages, was significantly associated with a lower odds of low executive function in individuals who participated in cognitive activities "infrequently", but not "every day" or "several times a month" (Table 9).

4.3 Objective Two: Examine the Association Between the Similarity of Languages Spoken and Low Executive Function at Baseline in a Population-based Sample of Canadians Aged 45 to 85 Years

4.3.1 Descriptive Analyses for the Association Between Similarity of Languages Spoken and Low Executive Function

Weighted bivariate results for the association between similarity of languages spoken and executive function are presented in Table 10. Parallel unweighted bivariate results for this association can be found in Appendix J, Table J8.

The similarity of languages spoken was significantly associated with low executive function in the weighted sample (p=0.016). Bilinguals, whose two spoken languages were Indo-European, comprised roughly 29% of those with low executive function. There was a higher prevalence of similar bilinguals in those with low executive function: 6% of those with low executive function spoke similar languages compared to 3% without low executive function. On the other hand, there was a lower prevalence of dissimilar bilinguals in those with low executive function: 22% of those with low executive function spoke dissimilar languages versus 26% without low executive function.

Table 10 *Distribution of Similarity of Languages Spoken by Executive Function Status in the Weighted Similarity of Languages Subsample, Canadian Longitudinal Study on Aging*

Multilingualism	Executive function[1]		
	Low (n=157,452)[2]	*Not low* (n=2,354,160)[3]	*Total* (n=2,511,612)[4]
	%	**%**	**%**
Similarity of Languages[5]			
Monolingual	71.38*	70.66	70.70
Dissimilar bilinguals	22.19	26.00	25.76
Similar bilinguals	6.43	3.35	3.54

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function
[2] Unweighted n=1,406
[3] Unweighted n=19,034
[4] Unweighted n=20,440
[5] Monolinguals are speakers of one language; dissimilar bilinguals are bilinguals whose two spoken languages are from different Indo-European family subgroups; similar bilinguals are bilinguals whose two spoken languages are from the same Indo-European language family subgroup
Rao Scott chi-square *p<0.05; **p<0.001; ***p<0.0001

4.3.2 Descriptive Analyses for the Association Between Covariates and Low Executive Function for Objective Two

The weighted bivariate results describing the association between covariates and low executive function are presented in Table 11 (sociodemographics), Table 12 (general health), Table 13 (health behaviours/lifestyle), and Table 14 (cognitively stimulating activities). For parallel unweighted bivariate results describing the association between covariates and low executive function, see Appendix J, Tables J9 to J12.

Age was positively significantly associated with executive function (Table 11). Accounting for 10% of the total population, those 75+ years of age constituted 38% of those with low executive function. Province and country of birth were significantly associated with executive function but sex and living in a rural or urban setting were not. Annual household income was significantly associated with executive function: only 4% of those with low executive function (vs. 19% without) had a household income of greater than $150,000. Speaking another language other than English or French most often at home or having a first language that is not English or French was more common in those with low executive function. That is, of those with low executive function, 14% spoke another language as their first/native language versus 5% of those without low executive function. For language spoken most often at home, 4% of those with low executive function (vs. 1% without) reported speaking another language other than English or French most often.

Self-rated general health was significantly associated with executive function with those reporting "fair/poor" health — accounting for about 9% of the total sample — comprised 20% of individuals with low executive function (Table 12). The presence of chronic conditions, depressive symptoms, alcohol use, and social support availability was significantly associated with low executive function, but tobacco smoking status was not (Table 13).

Education was significantly associated with executive function (Table 14). Those who reported having never graduated high school, accounting for 17% of the total sample, were over-represented as 47% of those with low executive function. Participation in cognitive leisure activities was also significantly associated with executive function: 30% of those with low executive function (vs. 20% without) reported participating in these activities "once a year or less".

Table 11 *Distribution of Sociodemographic Covariates by Executive Function Status in the Weighted Similarity of Languages Subsample, Canadian Longitudinal Study on Aging*

Sociodemographics	Executive function[1]		
	Low (n=157,452)[2]	*Not low* (n=2,354,160)[3]	*Total* (n=2,511,612)[4]
	%	%	%
Age group			
45-54 years	15.51***	42.12	40.45
55-64 years	19.06	33.03	32.15
65-74 years	27.09	16.82	17.47
75+ years	38.34	8.03	9.93
Sex			
Male	46.56	48.12	48.02
Female	53.44	51.88	51.98
Province			
Alberta	9.69*	10.17	10.14
British Columbia	25.93	29.92	29.67
Manitoba	10.65	7.63	7.82
Newfoundland	4.09	2.36	2.47
Nova Scotia	5.57	4.24	4.33
Ontario	17.32	17.75	17.72
Québec	26.75	27.94	27.87
Residence			
Urban	94.63	94.03	94.07
Rural	5.37	5.97	5.93
Annual household income			
< $20,000	13.10***	5.55	6.02
$20,000 – $49,999	49.71	19.00	20.93
$50,000 – $99,999	27.54	34.02	33.61
$100,000 – $149,999	5.77	22.23	21.20
≥$150,000	3.88	19.21	18.24
Country of birth			
Canada	80.42**	87.63	87.18
Not Canada	19.58	12.37	12.82
Language spoken most often at home: English or French			
No	3.57**	0.59	0.78
Yes	96.43	99.41	99.22
First language learned: English and/or French			
No	14.00***	4.72	5.31
Yes	86.00	95.28	94.69

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function
[2] Unweighted n=1,406
[3] Unweighted n=19,034
[4] Unweighted n=20,440
Rao Scott chi-square *p<0.05; **p<0.001; ***p<0.0001

Table 12 *Distribution of General Health Covariates by Executive Function Status in the Weighted Similarity of Languages Subsample, Canadian Longitudinal Study on Aging*

General health	Executive function[1]		
	Low (n=157,452)[2]	*Not low* (n=2,354,160)[3]	*Total* (n=2,511,612)[4]
	%	**%**	**%**
Self-rated health			
Excellent/very good	41.40***	60.13	58.96
Good	38.99	31.07	31.57
Fair/poor	19.61	8.80	9.48
Presence of chronic conditions			
None	18.72***	36.50	35.39
Any	81.28	63.50	64.61
Depressive symptoms[5]			
Absence	75.50	83.45	82.96
Presence	24.50**	16.55	17.04

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function
[2] Unweighted n=1,406
[3] Unweighted n=19,034
[4] Unweighted n=20,440
[5] Center for Epidemiological Studies Short Depression Scale (CES-D 10); a cut-point of ≥10 indicates the presence of depressive symptoms
Rao Scott chi-square *p<0.05; **p<0.001; ***p<0.0001

Table 13 *Distribution of Health Behaviours/Lifestyle Covariates by Executive Function Status in the Weighted Similarity of Languages Subsample, Canadian Longitudinal Study on Aging*

Health behaviours/lifestyle	Executive function[1]		
	Low (n=157,452)[2]	*Not low* (n=2,354,160)[3]	*Total* (n=2,511,612)[4]
	%	**%**	**%**
Tobacco smoking status			
Never	37.47	43.02	42.67
Former	50.10	45.62	45.90
Current	12.43	11.36	11.42
Alcohol use			
None in the past year	27.70***	12.28	13.25
Occasional user	16.28	12.07	12.34
Regular user	56.03	75.65	74.42
Overall social support availability[5]			
High	87.30***	94.28	93.84
Low	12.70	5.72	6.16

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function
[2] Unweighted n=1,406
[3] Unweighted n=19,034
[4] Unweighted n=20,440
[5] Modified from the Medical Outcomes Study – Social Support Survey; a score of less than 3 out of 5 indicates low social support availability
Rao Scott chi-square *p<0.05; **p<0.001; ***p<0.0001

Table 14 *Distribution of Cognitively Stimulating Activity Covariates by Executive Function Status in the Weighted Similarity of Languages Subsample, Canadian Longitudinal Study on Aging*

Cognitively stimulating activities	Executive function[1]		
	Low (n=157,452)[2]	*Not low* (n=2,354,160)[3]	*Total* (n=2,511,612)[4]
Education			
Less than high school	47.29***	14.79	16.82
High school diploma	11.53	11.85	11.83
Some post-secondary	7.59	9.77	9.63
Post-secondary degree/diploma	33.59	63.60	61.71
Cognitive leisure activities			
Every day	27.89***	33.11	32.78
Several times a week	15.04	20.47	20.13
Several times a month	19.82	15.10	15.40
Several times a year	7.55	11.65	11.40
Once a year or less	29.70	19.67	20.30

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function
[2] Unweighted n=1,406
[3] Unweighted n=19,034
[4] Unweighted n=20,440
Rao Scott chi-square *p<0.05; **p<0.001; ***p<0.0001

4.3.3 Unstratified Logistic Regression Analyses for the Association Between Similarity of Languages Spoken and Low Executive Function

For all models, VIF, AUC (ROC), and observed versus predicted plots were run to assess model fit and multicollinearity. No concerns were found. For AUC (ROC) results, see Appendix K, Table K2. Results from the unstratified base model to fully adjusted model D can be found in Table 15. Here, "dissimilar bilinguals" refers to Indo-European bilinguals who speak dissimilar languages (i.e., two languages from different Indo-European family subgroups) and "similar bilinguals" refers to Indo-European bilinguals who speak similar languages (i.e., languages from the same Indo-European language family subgroup). Monolinguals are speakers of one language.

In the unstratified multivariable analysis, the similarity of languages spoken by Indo-European bilinguals was significantly associated with low executive function in the base model and models A to D (Table 15). In the base model (adjusted for age, sex, and province), compared to being monolingual, speaking two dissimilar languages was significantly associated with a reduced odds of low executive function (OR=0.62, 95% CI=0.52-0.75), but speaking two similar languages was not significant (OR=1.20, 95% CI=0.89-1.63). However, the association between speaking two similar languages and low executive function became significantly protective with the addition of sociodemographic factors in model A, including additional characteristics of language (i.e., an individual's first language learned, and the language used most often at home). The association between language similarity and low executive function remained consistent in models B and C with a decrease in strength occurring after adjustment for cognitively stimulating activities in model D.

In model D, the significant association between the similarity of languages spoken and low executive function remained for similar and dissimilar bilinguals when compared to monolinguals. That is, compared to those speaking one language, Indo-European bilinguals who spoke two similar languages had a 38% lower odds of low executive function (95% CI=0.41-0.94); Indo-European bilinguals who spoke two dissimilar languages had a 33% lower odds of low executive function compared to monolinguals (95% CI=0.55-0.80).

Table 15 *Unstratified Weighted Logistic Regression Models Assessing the Association Between Similarity of Languages Spoken and Low Executive Function, Similarity of Languages Subsample, Canadian Longitudinal Study on Aging, n=20,440*

	Low executive function[1]				
	Base model OR (95% CI)	Model A OR (95% CI)	Model B OR (95% CI)	Model C OR (95% CI)	Model D OR (95% CI)
Similarity of Languages[2] (Ref.: Monolingual)					
Dissimilar bilingual	**0.62 (0.52-0.75)**	**0.61 (0.50-0.73)**	**0.63 (0.52-0.75)**	**0.63 (0.52-0.76)**	**0.67 (0.55-0.80)**
Similar bilingual	1.20 (0.89-1.63)	**0.55 (0.36-0.84)**	**0.57 (0.37-0.86)**	**0.57 (0.37-0.87)**	**0.62 (0.41-0.94)**
Age group (Ref.: 45–54 years)					
55–64 years	**1.77 (1.39-2.27)**	**1.45 (1.13-1.86)**	**1.45 (1.13-1.87)**	**1.47 (1.14-1.89)**	**1.54 (1.19-1.98)**
65–74 years	**4.91 (3.91-6.18)**	**3.29 (2.58-4.20)**	**3.46 (2.71-4.42)**	**3.61 (2.82-4.62)**	**3.80 (2.97-4.88)**
75+ years	**14.31 (11.43-17.91)**	**8.81 (6.92-11.22)**	**9.07 (7.10-11.57)**	**9.48 (7.40-12.15)**	**9.83 (7.63-12.68)**
Sex (Female vs. Male [Ref.])	1.04 (0.91-1.18)	**0.82 (0.72-0.94)**	**0.84 (0.73-0.96)**	**0.81 (0.71-0.94)**	0.90 (0.78-1.04)
Province (Ref.: Ontario)					
Alberta	1.07 (0.79-1.44)	1.10 (0.81-1.50)	1.11 (0.82-1.51)	1.10 (0.81-1.50)	1.20 (0.87-1.64)
British Columbia	**0.69 (0.56-0.85)**	**0.63 (0.51-0.78)**	**0.63 (0.51-0.78)**	**0.63 (0.50-0.78)**	**0.65 (0.52-0.81)**
Manitoba	**1.26 (1.01-1.57)**	1.05 (0.83-1.31)	1.04 (0.83-1.31)	1.03 (0.82-1.30)	1.12 (0.88-1.41)
Québec	**1.26 (1.03-1.56)**	0.88 (0.72-1.09)	0.86 (0.70-1.06)	0.89 (0.72-1.10)	0.83 (0.67-1.03)
Newfoundland	**1.62 (1.29-2.03)**	**1.48 (1.17-1.88)**	**1.51 (1.19-1.92)**	**1.52 (1.20-1.93)**	**1.70 (1.33-2.16)**
Nova Scotia	**1.42 (1.13-1.78)**	1.22 (0.97-1.54)	1.21 (0.96-1.53)	1.20 (0.95-1.51)	**1.29 (1.02-1.64)**
Residence (Rural vs. Urban [Ref.])		1.15 (0.89-1.49)	1.19 (0.92-1.54)	1.20 (0.93-1.56)	1.16 (0.89-1.51)
Annual household income (Ref.: ≥$150,000)					
< $20,000		**9.67 (6.77-13.80)**	**6.82 (4.79-9.72)**	**5.76 (4.03-8.25)**	**4.88 (3.39-7.04)**
$20,000 – $49,999		**5.15 (3.73-7.12)**	**4.19 (3.04-5.77)**	**3.77 (2.73-5.20)**	**3.53 (2.56-4.87)**
$50,000 – $99,999		**2.29 (1.67-3.16)**	**2.04 (1.48-2.81)**	**1.95 (1.42-2.68)**	**1.95 (1.42-2.68)**

	Low executive function[1]				
	Base model OR (95% CI)	Model A OR (95% CI)	Model B OR (95% CI)	Model C OR (95% CI)	Model D OR (95% CI)
$100,000 – $149,999		1.38 (0.96-1.98)	1.31 (0.91-1.88)	1.28 (0.89-1.84)	1.29 (0.90-1.86)
Country of birth (Not Canada vs. Canada [Ref.])		0.92 (0.76-1.11)	0.92 (0.76-1.12)	0.94 (0.77-1.13)	0.96 (0.79-1.17)
Language spoken most often at home: English or French (No vs. Yes [Ref.])		**3.22 (1.65-6.31)**	**3.21 (1.64-6.26)**	**3.17 (1.63-6.17)**	**2.90 (1.53-5.49)**
First language learned: English and/or French (No vs. Yes [Ref.])		**2.43 (1.72-3.45)**	**2.42 (1.71-3.42)**	**2.35 (1.66-3.32)**	**2.25 (1.59-3.17)**
Self-rated health (Ref.: Excellent/Very good)					
Good			**1.48 (1.28-1.71)**	**1.44 (1.24-1.66)**	**1.41 (1.22-1.64)**
Fair/Poor			**2.13 (1.75-2.59)**	**2.00 (1.63-2.42)**	**1.91 (1.56-2.33)**
Presence of chronic conditions (1+ vs. None [Ref.])			**1.21 (1.01-1.45)**	**1.21 (1.01-1.44)**	**1.21 (1.01-1.45)**
Depressive symptoms[3] (Presence vs. Absence [Ref.])			**1.36 (1.15-1.60)**	**1.32 (1.12-1.57)**	**1.26 (1.06-1.49)**
Overall social support availability[4] (Low vs. High [Ref.])				1.06 (0.83-1.35)	1.03 (0.80-1.31)
Tobacco smoking status (Ref.: Never)					
Former				0.98 (0.85-1.13)	0.95 (0.83-1.10)
Current				1.25 (0.99-1.58)	1.17 (0.92-1.49)
Alcohol use (Ref.: Non-user)					
Occasional user				0.84 (0.67-1.05)	0.84 (0.67-1.06)
Regular user				**0.65 (0.54-0.78)**	**0.67 (0.56-0.81)**
Education (Ref.: Less than high school)					
High school diploma					**0.61 (0.47-0.79)**
Some post-secondary					**0.45 (0.34-0.60)**
Post-secondary degree/diploma					**0.44 (0.36-0.54)**
Cognitive leisure activities					

	Low executive function[1]				
	Base model OR (95% CI)	Model A OR (95% CI)	Model B OR (95% CI)	Model C OR (95% CI)	Model D OR (95% CI)
(Ref.: Once a year or less)					
Every day					**0.42 (0.36-0.50)**
Several times a week					**0.52 (0.42-0.64)**
Several times a month					**0.69 (0.54-0.86)**
Several times a year					**0.61 (0.47-0.79)**

Abbreviations: OR = odds ratio, CI = confidence interval, Ref. = reference
The base model includes the exposure and covariates related to the CLSA design
Model A includes the exposure and all sociodemographic covariates
Model B includes the exposure, general health covariates + Model A covariates
Model C includes the exposure, health behaviours/lifestyle covariates + Model B covariates
Model D includes the exposure, cognitively stimulating activities + Model C covariates
[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants
[2] Monolinguals are speakers of one language; dissimilar bilinguals are bilinguals whose two spoken languages are from different Indo-European family subgroups; similar bilinguals are bilinguals whose two spoken languages are from the same Indo-European language family subgroup
[3] Center for Epidemiological Studies Short Depression Scale (CES-D 10); a cut-point of ≥10 indicates the presence of depressive symptoms
[4] Modified from the Medical Outcomes Study – Social Support Survey; a score of less than 3 out of 5 indicates low social support availability

To specifically examine the role of language similarity with executive function, similar bilinguals and dissimilar bilinguals needed to be compared to each other; therefore, Table 16 presents the association between language similarity and executive function, as was done above, but using dissimilar bilinguals as the reference group.

Compared to speaking two dissimilar languages, speaking two similar languages was significantly associated with low executive function in the base model (adjusted for age, sex, and province) (OR=1.93, 95% CI=1.37-2.74); however, when sociodemographic factors, such as other characteristics of language were controlled for, this association became non-significant. In model D, there was no significant difference in the odds of low executive function when comparing similar bilinguals to dissimilar bilinguals. Monolinguals compared to dissimilar bilinguals had a greater odds of low executive function across all models — this is the reciprocal of what is seen in Table 15 when dissimilar bilinguals were compared to monolinguals.

Table 16 *Unstratified Weighted Logistic Regression Models Assessing the Association Between Similarity of Languages Spoken with Low Executive Function — Dissimilar Bilinguals as the Reference Group*

	Low executive function[1]				
	Base model OR (95% CI)	**Model A** OR (95% CI)	**Model B** OR (95% CI)	**Model C** OR (95% CI)	**Model D** OR (95% CI)
Similarity of languages[2] (Ref.: Dissimilar bilingual)					
Monolingual	**1.61 (1.34-1.93)**	**1.65 (1.37-1.99)**	**1.60 (1.33-1.92)**	**1.59 (1.32-1.91)**	**1.50 (1.24-1.82)**
Similar bilingual	**1.93 (1.37-2.74)**	0.90 (0.58-1.40)	0.90 (0.59-1.39)	0.90 (0.59-1.38)	0.93 (0.61-1.41)

Abbreviations: OR = odds ratio, CI = confidence interval, Ref. = reference
The base model includes the exposure and covariates related to the CLSA design
Model A includes the exposure and all sociodemographic covariates
Model B includes the exposure, general health covariates + Model A covariates
Model C includes the exposure, health behaviours/lifestyle covariates + Model B covariates
Model D includes the exposure, cognitively stimulating activities + Model C covariates
[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants
[2] Monolinguals are speakers of one language; dissimilar bilinguals are bilinguals whose two spoken languages are from different Indo-European family subgroups; similar bilinguals are bilinguals whose two spoken languages are from the same Indo-European language family subgroup

To summarize the results of section 4.3.3 (Tables 15 and 16), there is a significant protective effect of being an Indo-European bilingual (either a similar or dissimilar bilingual) compared to being a monolingual (Table 15, model D) — a protective effect of speaking more than one language. When Indo-European bilinguals are compared to each other, the type of languages spoken (i.e., similar bilingualism vs. dissimilar bilingualism) had no significant effect on the odds of having low executive function.

4.3.4 Unstratified Logistic Regression Analyses for the Association Between Covariates and Low Executive Function for Objective Two

The results for the base model and model A to model D for the association between covariates and low executive function can be found in Table 15 above.

4.3.4.1 Sociodemographics. Age was consistently positively associated with low executive function across all models. A dose-response was seen, such that when compared to people 45 to 54 years of age, persons aged 75+ had an almost ten-fold greater odds of low executive function. Annual household income was significantly positively associated with low executive function across all models in a dose-response manner. The association between other language characteristics and low executive function was also significant in all models. That is, those who spoke another language other than English and/or French most often at home (vs. English or French) had a three-fold greater odds of low executive function. Reporting a first/native language other than English or French (vs. English and/or French) was also associated with a greater odds of low executive function (model D: OR=2.25, 95% CI=1.59-3.17). There were significant provincial differences across models. After adjusting for all covariates, sex, residence, and country of birth were not significantly associated with low executive function.

4.3.4.2 General health factors. *S*elf-rated general health was significantly associated with low executive function in all models. Compared to those who reported having "excellent/very good" health, those who reported "fair/poor" health had a 91% greater odds of low executive function; those with "good" health had a 41% greater odds of low executive function. The presence of at least one chronic condition (vs. none) and the presence of depressive symptoms (vs. absence) were also significantly associated with low executive function.

4.3.4.3 Health behaviours/lifestyle factors. Compared to being a non-drinker, drinking alcohol regularly, but not occasionally, was associated with a reduced odds of low executive function in the fully adjusted model. Tobacco smoking status and overall social support availability were not significantly associated with low executive function.

4.3.4.4 Cognitively stimulating activities. Education was significantly negatively associated with low executive function in a dose-response manner. Compared to those who reported having completed less than a high school education, those who reported having graduated high school, having some post-secondary education, or having a post-secondary degree/diploma had a 39%, 55% and 56% reduced odds of low executive function respectively. Participation in cognitive leisure activities was also significantly associated with executive function: compared to individuals who participated “once a year or less”, those who engaged in these activities “every day” or “several times a week” had 58% and 48% reduced odds of having low executive function respectively.

4.3.5 Logistic Regression Analyses Stratified by Cognitive Leisure Activities: The Association between Similarity of Languages Spoken and Low Executive Function

The fully adjusted model D was used for stratification by cognitive leisure activities as this model had the best fit of all unstratified models for objective two (see Appendix K, Table K2 for AUC (ROC) statistics). Three strata were used for frequency of participation in cognitive leisure activities (see section 3.5.2 for details). The following text presents only the results for the association between the exposure, similarity of languages spoken, and the outcome, low executive function, using model D for each stratum (Table 17). The ORs and 95% CI for all other covariates in model D for each stratum can be found in Appendix L, Table L2.

For those individuals who participated in cognitive leisure activities “every day”, being an Indo-European bilingual, either dissimilar or similar, compared to being monolingual, was not significantly associated with low executive function. These non-significant results were also found in those individuals who participated in cognitive leisure activities “several times a week”.

Unlike the other two activity strata, those who participated in cognitive leisure activities “infrequently” experienced a significant effect of language similarity. Compared to monolinguals, being an Indo-European bilingual, either dissimilar or similar, was associated with a reduced odds of low executive function: 54% lower odds (95% CI=0.41-0.70) for dissimilar bilinguals and 49% lower odds (95% CI=0.29-0.83) for similar bilinguals.

Table 17 *Weighted Fully Adjusted Logistic Regression Model Assessing the Association Between Similarity of Languages Spoken and Low Executive Function Stratified by Cognitive Leisure Activities, Similarity of Languages Subsample, Canadian Longitudinal Study on Aging, n=20,440*

Similarity of Languages[2] (Ref: Monolingual)	*Low executive function*[1]	
	OR[3]	**95% CI**
	Every day (n=7,360)	
Dissimilar bilinguals	0.75	0.54-1.05
Similar bilinguals	0.72	0.35-1.47
	Several times a week (n=3,827)	
Dissimilar bilinguals	1.04	0.66-1.64
Similar bilinguals	0.91	0.20-4.06
	Infrequently (n=9,253)	
Dissimilar bilinguals	**0.54**	**0.41-0.70**
Similar bilinguals	**0.49**	**0.29-0.83**

Abbreviations: OR = odds ratio, CI = confidence interval, Ref. = reference
[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants
[2] Monolinguals are speakers of one language; dissimilar bilinguals are bilinguals whose two spoken languages are from different Indo-European family subgroups; similar bilinguals are bilinguals whose two spoken languages are from the same Indo-European language family subgroup
[3] Fully adjusted model (model D) contains all covariate blocks (sociodemographics, general health, health behaviours/lifestyle, cognitively stimulating activities)

As was done for the unstratified results, to examine the role of language similarity specifically with respect to executive function, similar bilinguals were compared to dissimilar bilinguals (i.e., dissimilar bilinguals were used as the reference category) (Table 18).

Among those individuals who participated in cognitive leisure activities "every day" or "several times a week" there was no significant difference in the odds of low executive function between similar bilinguals and dissimilar bilinguals. This was also the case for those who participated infrequently; however, in this "infrequent" stratum, monolingualism (vs. dissimilar bilingualism) was significantly associated with low executive function (OR=1.86, 95% CI=1.43-2.41) (i.e., the reciprocal of what was found in Table 17 as the reference group was switched).

Table 18 *Weighted Fully Adjusted Logistic Regression Model Assessing the Association Between Similarity of Languages Spoken and Low Executive Function Stratified by Cognitive Leisure Activities — Dissimilar Bilinguals as the Reference Group*

Similarity of Languages[2] (Ref: Dissimilar bilinguals)	*Low executive function*[1]	
	OR[3]	**95% CI**
	Every day (n=7,360)	
Monolinguals	1.33	0.95-1.86
Similar bilinguals	0.96	0.48-1.92
	Several times a week (n=3,827)	
Monolinguals	0.96	0.61-1.51
Similar bilinguals	0.87	0.20-3.89
	Infrequently (n=9,253)	
Monolinguals	**1.86**	**1.43-2.41**
Similar bilinguals	0.92	0.53-1.59

Abbreviations: OR = odds ratio, CI = confidence interval, Ref. = reference
[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants
[2] Monolinguals are speakers of one language; dissimilar bilinguals are bilinguals whose two spoken languages are from different Indo-European family subgroups; similar bilinguals are bilinguals whose two spoken languages are from the same Indo-European language family subgroup
[3] Fully adjusted model (model D) contains all covariate blocks (sociodemographics, general health, health behaviours/lifestyle, cognitively stimulating activities)

4.3.6 Summary of Results for Objective Two

The results of objective two using unstratified models found that, after adjusting for all covariates (i.e., model D), there was a significant difference in the odds of low executive function when Indo-European bilinguals (either similar or dissimilar) were compared to monolinguals; however, there was no significant difference when comparing similar bilinguals to dissimilar bilinguals. When model D was stratified by cognitive leisure activities, language similarity was only significantly protective against low executive function in those who engaged in these activities “infrequently”. Like the unstratified results, significant differences in the odds of low executive function occurred only in the infrequent activity stratum and specifically only when comparing Indo-European bilinguals (either similar or dissimilar) to monolinguals; similar bilinguals did not differ from dissimilar bilinguals in their odds of low executive function.

4.4 Missing Data Analyses

Missing data analyses were performed on unweighted and weighted data (see Appendix M, Tables M1 to M3). Weighted results are discussed in the following text. The results of analyses examining if: 1) multilingualism differed across individuals with and without executive function data, and 2) if executive function differed across individuals with and without multilingualism data are presented first, followed by 3) the results for the association between those with executive function data versus those with missing data on any covariate of interest.

Among those with data on the number of languages, multilingualism was associated with missingness of executive function data ($p<0.0001$). However, missingness of multilingualism data (i.e., the number of languages spoken) was not associated with executive function among those with complete executive function data ($p=0.785$). Since there was a very small sample (unweighted $n=4$) with missing data on language similarity, bivariate analyses with missing language similarity data were not performed.

Overall, missingness on any covariate was significantly associated with executive function ($p<0.0001$). When examined by themed covariate block, missingness in the sociodemographics, health behaviours/lifestyle, and cognitively stimulating activities blocks were significantly associated with executive function ($p<0.0001$). The association between missing data in the general health block and executive function was not significant ($p=0.190$). The implications of these results will be discussed in section 5.4. See Appendix E, Figure E1 for details on the number of individuals with missing data in each covariate block.

5.0 Discussion

5.1 Summary of Study Findings

This study investigated the association between multilingualism — the number and type of languages spoken — with low executive function, a domain of cognition that can be indicative of further cognitive decline and dementia (Clark et al., 2012; Guarino et al., 2019). The impact of a variety of sociodemographic factors, general health factors, health behaviours/lifestyle, and cognitively stimulating activities on this association was also considered.

Almost two-thirds of participants were monolingual. Bilinguals had the second-highest prevalence after monolinguals since as the number of languages spoken increased, the proportion of participants in each group decreased. In the language similarity subsample, the majority of Indo-European bilinguals spoke two dissimilar languages. This is likely due to Canada's two languages (English and French) being classified as dissimilar languages in this study: English is a Germanic language and French is a Romance language. Regarding the outcome, the prevalence of low executive function was less than 10% in both the analytical sample and subsample. The CLSA's recruitment criteria, which excluded individuals with overt cognitive impairment, is likely largely responsible for this relatively cognitively healthy sample of participants.

In weighted bivariate analyses, the number of languages spoken was not significantly associated with low executive function; however, this association was significant in unweighted analyses. There was a higher prevalence of trilinguals without vs. with low executive function. However, speakers of 5+ languages were over-represented in the low executive function group. The prevalence of speakers of 5+ languages was higher in those with low executive function than without.

The similarity of languages spoken was significantly associated with executive function in weighted analyses. The prevalence of low executive function was higher in monolinguals than in Indo-European bilinguals. Considering the Indo-European bilinguals, there were more dissimilar bilinguals without low executive function than with low executive function. However, similar bilinguals were over-represented in those with low executive function.

Overall, using weighted multivariate logistic modelling, this study found that the number of languages but not the similarity of languages spoken was associated with executive function. Specifically, speaking multiple languages, up to and including four languages, was protective against having low executive function after adjusting for sociodemographic, general health, health behaviours/lifestyle, and cognitively stimulating covariates. There was no effect of language similarity as similar Indo-European bilinguals did not significantly differ from dissimilar Indo-European bilinguals in their odds of low executive function. In the fully adjusted model for each sample, similar trends were seen for key covariates: older age groups had a significantly greater odds of having low executive function compared to middle-aged groups, and speaking another language other than English or French at home or having a native language other than English or French (vs. English or French) significantly increased the odds of having of low executive function. Country of birth was not associated with executive function. Reporting high levels of cognitively stimulating activities was protective against low executive function.

When stratified by cognitive leisure activities, the same conclusions regarding multilingualism and executive function held — the number of languages, but not the similarity of languages spoken, was key. Importantly, this finding was only significant in those who participated in cognitive leisure activities infrequently, suggesting a ceiling effect of cognitively stimulating activities as a protective factor against cognitive impairment. For those who participated in cognitive activities several times a week or every day, the effect of multilingualism on low executive function was reduced by the frequent participation in other cognitive activities. Thus, a maximum level of protection may have already been achieved through the frequent participation in other cognitive activities, rendering the impact of multilingualism on executive function non-significant.

5.2 Discussion of the Unstratified Study Results

5.2.1 Objective One: The Number of Languages Spoken

The unstratified results for objective one, the number of languages spoken, will be discussed in line with the literature examining: 1) the association between the number of languages spoken and cognition, and 2) the association between speaking at least two languages, "bilingualism," with executive function. First, the similarities and inconsistencies between this literature and the current study will be examined. Second, an exploration of why the current results may differ from these studies will be discussed. Lastly, the unexpected results concerning speakers of 5+ languages will be addressed.

After adjusting for covariates, including education and cognitive leisure activities, the number of languages spoken was protective against low executive function in a dose-response manner, with peak protection occurring at four spoken languages. This finding is consistent with the general theoretical mechanism of the multilingual advantage (Bialystok et al., 2012; Green, 1998).

Literature explicitly examining the association of the *number of languages* spoken, rather than the less detailed, or somewhat muddled, "speakers of *at least* two languages", with cognition (e.g., dementia, AD, executive function) have found results similar to the current study. That is, speaking multiple languages is protective against cognitive impairment or is associated with better cognition (Chertkow et al., 2010; Hack et al., 2019; Ihle et al., 2016; Kavé et al., 2008). In their immigrant population, Chertkow et al. (2010) found that multilingualism, categorized as 1 to 4+ languages, was protective against dementia in a dose-response manner; this is also similar to Kavé et al. (2008), who found a main effect of the number of languages, but that speaking 4+ languages had the strongest effect on cognitive performance. Studies comparing bilinguals to multilinguals have also found a protective effect of a greater number of languages spoken on cognitive impairment (Bak et al., 2014; Perquin et al., 2013) and executive function subcomponents of the MMSE (Liu et al., 2017). Yet, the results of this current study do not align with some of the literature that explicitly examines the number of languages spoken. For example, some studies examining multilingualism with cognition have not found a dose-response association (Alladi et al., 2013; Hack et al., 2019) or have found a protective effect of multilingualism peaking at two (Alladi et al., 2013) or three languages (Perquin et al., 2013), not four.

The current study fits with existing studies examining the association between bilingualism (or *at least two* languages) and executive function. Although this literature is mixed, this study aligns with the results that support the existence of a bilingual advantage (for a recent review, see Ware et al., 2020). Further, considering that the vast majority of this literature involves smaller sample sizes, most often under 1,000 participants, the current study provides a relatively robust set of results that helps to further support the existence of a multilingual advantage. Notably, however, current results can be contrasted with a recent study that also used a large sample size (n=11,041) and did not find a significant association between 2+ languages and executive function (Nichols et al., 2020).

There are several possible explanations for the discrepancy between these above-mentioned results and what was found in this study. In particular, differences in: 1) adjusting for language characteristics (i.e., other aspects of the multilingual experience), 2) definitions or criteria used to define multilingualism, 3) controlling for other cognitively stimulating activities, 4) the level of acculturation, and 5) the testing experience for speakers of *many* languages versus speakers of a few languages, may explain the inconsistencies between previous studies and the current results. The large sample size of the CLSA allowed for the adjustment of many potential confounding factors that have not often been included in previous studies. Importantly, as covariates in multivariable modelling, this study was able to adjust for a few key aspects of the multilingual experience (e.g., first language learned) and other cognitively stimulating experiences. These factors may explain the difference in the peak protection for the number of languages spoken, that is, why this study found a peak effect at four languages spoken while others have found peak effects at two (Alladi et al., 2013) or three languages (Perquin et al., 2013). Differences in these factors between studies may also explain why other studies, unlike the current study, were unable to replicate a dose-response effect (Alladi et al., 2013; Hack et al., 2019; Nichols et al., 2020). Differences in definitions of multilingualism may also contribute to mixed findings in the field as a whole (Calvo et al., 2016) and acculturation and differences in those who speak many languages may specifically account for the inconsistencies found regarding speakers of 5+ languages (Celik et al., 2020; Xu et al., 2017).

First, a lack of adjustment for other aspects of language such as testing language and language-learning histories may explain the discrepancies between this study and previous results. For example, Alladi et al. (2013) acknowledged their lack of control for other characteristics of language when they could not replicate a dose-response effect. Moreover, the null findings by Nichols et al. (2020), in their study of 11,041 participants, could also be a result of the absence of control for testing language or other language characteristics (as is suggested by Mendis et al., 2021). However, Hack et al. (2019), who found an effect of only 4+ languages on the risk of dementia, did consider aspects of linguistic ability, grammatical complexity and idea density (but also controlled for risk factors for AD such as *APOE* status). When idea density, in particular, was adjusted for, Hack et al. (2019) noted that the effect of multilingualism was weakened and suggested that their finding of a protective effect of only 4+ languages spoken may be reflective of the complex association between spoken language and linguistic ability (and other cognitively stimulating experiences, discussed below) rather than a failure to find an effect of a lower number of languages spoken, or a dose-response, on dementia risk.

Importantly, in the current study, when covariates of language (i.e., first language learned and language spoken most often at home) were controlled for, the peak protection and the strength of the association between multilingualism and executive function changed. Although it is acknowledged that these language variables are limited in that they cannot be considered true measures of language frequency or age of acquisition, they do, however, account for some of the potential impacts of testing in a non-native language or less frequently used language (Arce Renteria, 2021). Importantly, testing language has also been shown to impact performance on cognitive tests (Celik et al., 2020). Considering the impact of these language characteristics on the association between the number of languages spoken and cognition in the current study (and others such as Hack et al., 2019), the lack of adjustment for these factors and other variables related to the multilingual experience may be, in part, why the literature is so mixed regarding a peak effect of the number of languages spoken, or even the existence of a multilingual advantage (Arce Renteria, 2021; Baum & Titone, 2014). Overall, the influence of these covariates on the association between the number of languages spoken and cognition in this study underscores the importance of adjusting for other aspects of the multilingual experience, and how a lack of consideration for these factors may be contributing to the inconsistent results in the field (Baum & Titone, 2014; Celik et al., 2020).

Second, in addition to differences in language characteristics and the multilingual experience, differences in the definitions of multilingualism and subjective measures of proficiency may also contribute to the mixed results. Briefly, while the current definition of multilingualism is not as rigorous as some of the objective measures of proficiency used in other studies (e.g., the Language and Social Background Questionnaire [Berkes et al., 2021; Bialystok, Craik, et al., 2014], or the Boston Naming Test [de Bruin et al., 2015]), it is comparable to the subjective definitions used by the aforementioned studies explicitly examining the number of languages (e.g., Alladi et al., 2013; Hack et al., 2019; Kavé et al., 2008; Perquin et al., 2013). Despite the similar subjective definitions of multilingualism, inconsistencies remain between the results of this study and previous studies examining the association between the number of languages spoken and cognition (e.g., differences in a peak effect of language). These differences may be due to the inherent variability associated with self-reported measures themselves (Calvo et al., 2016). Moreover, it has been suggested that objective measures of the multilingual experience are needed as simply asking if persons are multilingual is not sufficient to capture a consistent definition of multilingualism (Gollan et al., 2012). Ultimately, methodological consistency is needed with a focus on obtaining more detailed measures of the multilingual experience. It is recognized that inconsistent definitions of multilingualism (and bilingualism) from using self-reported measures is a limitation in the field as a whole (Calvo et al., 2016).

In addition to the differences in adjustment for language characteristics and definitions of multilingualism, potential confounding by other cognitively stimulating experiences may also explain the discrepancy between the results of previous studies and what was found in the current study. For example, Hack et al.'s (2019) finding of an effect of only 4+ languages spoken on the risk of dementia may be, in part, because their study population (the Nun Study) differs from the general population. The Nun Study participants arguably have a unique set of cognitively stimulating experiences and language use (e.g., through continued service in the church community, including teaching into a later age where their linguistic abilities would be used). Moreover, Hack et al. (2019) suggest that it may be those religious sisters who spoke 4+ languages who may have actively utilized their multilingual abilities and thus have a reduced risk of dementia, versus speakers of fewer languages. In comparison, Perquin et al. (2013) who found a peak effect at three languages spoken, accounted for different but detailed measures of cognitive stimulation, such as productive activities and non-formal educational courses, in addition to formal education. In the current study, a peak effect at four languages occurred, even after considering formal education and frequency of participation in cognitive leisure activities. Overall, it could be that the benefits of multilingualism on cognition are inconsistent because individuals vary in their number and type of cognitively challenging and stimulating experiences, which all promote superior executive function or cognitive performance (Valian, 2015). If studies are adjusting for cognitive activities differently in modelling, it could be this inconsistent consideration of these factors that may explain the variable results for a peak effect of the number of languages spoken. Moreover, residual confounding by cognitive activities that are not accounted for may still be present as it is not possible to account for all forms of cognitive stimulation, including those activities that have not yet been investigated (Valian, 2015).

Fourth, different levels of acculturation, in particular, may explain why this study found that speaking 5+ languages was not significantly protective against low executive function. Additionally, it may also explain why individuals who spoke 5+ languages were found to have a higher prevalence of low executive function compared to speakers of one, two, three, or four languages. As discussed, the results of this study strongly support that testing in a non-native language (or frequently used language) increases the odds of being classified as having low executive function. Although the influence of testing language is considered in this study, what is not, and what may be closely linked to the language of test administration (Celik et al., 2020) and poor executive function performance (Xu et al., 2017), is culture and ethnicity or acculturation. Although country of birth was not a significant covariate in the current results, Xu et al. (2017) argue that the association between immigration status and cognitive function is poorly understood, and that country of birth may be better represented by measures of acculturation. As well, cultural differences among certain subgroups, such as immigrants or refugees, have been linked to differences in cognitive performance, with higher levels of acculturation found to be associated with better cognitive testing performance (for reviews see, e.g., Celik et al., 2020; Xu et al., 2017). As such, the use of linguistically or culturally appropriate tools for cognitive assessment may be an important confounder as different levels of acculturation can influence the interpretation of cognitive assessment tests (Ng et al., 2018). It may be that speakers of 5+ languages experience lower levels of acculturation which may explain their poor performance. In addition, speakers of many languages, as opposed to a few, may more likely be refugees or belong to a minority group and as a result, may experience poorer psychological and physical health outcomes (Tong et al., 2020). Ultimately, this is a notable gap in our knowledge and should be explored further in future studies.

Lastly, besides acculturation, or differences in ethnicity or refugee status, it may be that multilinguals who know many languages, such as those who speak 5+, differ from those who speak two, three or four languages (Keeley, 2019; Kurniawati, 2013). As there is a paucity of literature on how speaking and knowing a *much greater* number of languages affects the intricacies of executive function processing, it is difficult to discern why speakers of 5+ languages in the current study were not significantly protected against low executive function (or were more likely to have low executive function). One suggestion could be that speakers of many languages, especially when less proficient in some known languages, may experience greater performance anxiety (e.g., related to code-switching or even pronunciation) which, in turn, has the potential to disrupt their executive functions and impact attention (Keeley, 2019). Although this explanation for poor performance could be applied to trilinguals or speakers of four languages, levels of anxiety could be greater in those who are speakers of many languages where concerns about involuntary code-switching and cross-interference could be greater (Keeley, 2019). Importantly, even if some of this anxiety was adjusted for when considering testing language in the current study, its effect on performance may still be present.

Alternatively, it is important to consider that the speakers of 5+ languages in this study are a small subsample of the analytical sample and, therefore, may not be representative of all speakers of many languages. Furthermore, those who completed executive function tests bilingually (i.e., switching languages when responding) were excluded from this study. If these excluded individuals were more likely to be speakers of many languages (i.e., 5+), then the exclusion of these participants may bias the current results of 5+ speakers towards poorer performance, as multilinguals have been shown to perform better on cognitive tests when they can respond in multiple languages (Celik et al., 2020). The decision to exclude individuals who switched languages during testing was made to ensure consistent and accurate scoring of participants. Future studies should consider how bilingual or multilingual responses could be scored to potentially reduce this bias if it is indeed present.

5.2.2 Objective Two: The Similarity of Languages Spoken

The unstratified results for objective two, the similarity of spoken languages, will be discussed in line with the literature examining the role of language distance or similarity with cognition followed by an exploration of why the current results may differ from these existing studies.

After adjustment for all covariates, current results showed that similar bilinguals did not significantly differ from dissimilar bilinguals in their odds of having low executive function. Significant protection was only found when comparing Indo-European bilinguals (i.e., either similar or dissimilar) to monolinguals. These results suggest that language similarity does not play a role, rather it is the number of languages spoken that is key. Based on existing theories of how language similarity may impact executive function or cognition generally (see Antoniou & Wright, 2017), the null results of this objective may be unexpected.

However, studies comparing similar bilinguals to dissimilar bilinguals have also found no differences in executive function and general cognition (Ljungberg et al., 2020; Sörman et al., 2019). Other studies that have examined language similarity while also considering a monolingual group have found that speakers of similar languages had better cognitive performance (Houtzager et al., 2017) or protection against dementia (Zheng et al., 2018) compared to monolinguals; however, these studies did not have a dissimilar language group, and thus were unable to directly compare similar bilinguals to dissimilar bilinguals. Consequently, they were unable to examine the role of language similarity, and rather, their results were confounded by the effect of the number of languages on cognition. Unlike these studies, Ljungberg et al. (2020) compared similar bilinguals, dissimilar bilinguals, and monolinguals, and found that dissimilar bilinguals did not differ from monolinguals on executive function performance, but that similar bilinguals had better executive function than monolinguals. Their results are inconsistent with those of the current study, which found that both similar or dissimilar bilinguals had a reduced odds of low executive function relative to monolinguals.

The dearth of studies examining language similarity and cognition make it difficult to reason why the results of the current study do, or do not, align with the literature. Still, aside from the issue of studies that confounded type and number of languages, a possible explanation for the discrepancy between the aforementioned results and the results of the current study may be the different definitions of similar or dissimilar bilinguals used. For example, Ljungberg et al. (2020) defined dissimilar bilinguals as speakers of two languages from different language families, whereas the current study defined dissimilar bilinguals as speakers of two languages from different language family *subgroups*, a comparatively closer language distance. Importantly, where the results of the current study align with Ljungberg et al. (2020) (i.e., finding that similar bilinguals had better cognitive performance than monolinguals), the definitions of similar bilingualism are the same: both spoken languages are from the same language family subgroup. However, their results still suggest a role of language type on cognition (as well as the number of languages spoken). Studies that have only compared dissimilar bilinguals to similar bilinguals and used the definition of language family (e.g., Sörman et al., 2019), report null results regarding the role of language type. Notably, for example, Sörman et al.'s (2019) definition of similar and dissimilar bilingualism is different from the current study (i.e., comparisons are made at the language family level rather than the family *subgroup* level), and thus so too are the language distances. These inconsistencies in the definition of language similarity, and hence language distances, may be contributing to the varied results in this limited area of research and the abundance of mixed findings in the bilingualism and cognition literature as a whole (Antoniou & Wright, 2017).

5.3 Discussion of the Results Stratified by Cognitive Leisure Activities

In the following section, the results of both objectives stratified by cognitive leisure activities will be examined together and discussed in the context of other literature on cognitive stimulation and the ceiling effect. After a summary of the stratified results, a discussion of these results in the context of multilingualism literature (that also considers the effect of cognitive stimulation) and literature that examines cognitive leisure activities generally (i.e., not necessarily with multilingualism) will be explored. This section will conclude with a discussion of the unexpected results concerning speakers of 5+ languages.

When stratified by frequency of participation in cognitive leisure activities, and after adjusting for all covariates, the same overall finding as that of the unstratified results was found: the number of languages was significantly associated with a reduced odds of low executive function in a dose-response manner, up to and including four languages spoken (objective one), but that language type was not significant (objective two). However, most importantly, this message was only true for those individuals who participated in cognitive leisure activities infrequently rather than every day or several times a week. In fact, in these latter strata, multilingualism was not significantly associated with executive function.

These findings align with the theory of mutual compensation, or a ceiling effect of cognitive reserve (Valian, 2015). That is, the cognitively stimulating factors (multilingualism and cognitive leisure activities) are working together (i.e., mutually compensating) to achieve the maximum level or "ceiling" of resilience against low executive function. Further, as a protective effect of multilingualism was only found in those who participated in cognitive leisure activities infrequently, this suggests that those who may be lacking stimulation from cognitive leisure activities build their reserve capacity through the use of multiple languages; however, for those who benefit from more frequent participation in cognitive leisure activities (i.e., weekly or daily), the protective effect of multilingualism is modified, specifically reduced, by the protective effect provided by the frequent engagement in other cognitive leisure activities.

To the best of the author's knowledge, this is the first study to examine the impact of multilingualism on executive function by the frequency of participation in cognitive leisure activities. Studies that have examined multilingualism, or bilingualism, with other cognitively stimulating activities, have either: 1) adjusted for other cognitive factors in their models without considering effect modification, or 2) stratified by educational level. Thus, the current results will be discussed in relation to these two areas of literature.

First, studies examining multilingualism and cognition that have controlled for other cognitively stimulating factors have found multilingualism to be significantly protective or associated with better cognitive performance after adjusting for these factors (e.g., Ihle et al., 2016; Kavé et al., 2008; Perquin et al., 2013; for a review, see, e.g., Stern & Munn, 2010). However, similar to the results found in this study, the effect of multilingualism on cognition was not independent of the effects of other cognitive activities; in short, multilingualism is not working in isolation. For example, the effect of multilingualism on cognition was not found to be independent of education (Kavé et al., 2008) or education and other cognitively stimulating experiences (Ihle et al., 2016; Perquin et al., 2013). Comparably, general cognitive leisure literature (i.e., literature that does not explicitly consider language) has also found a synergistic effect of cognitive leisure activities and education. That is, cognitive leisure activities and education have been found to work together to produce higher cognitive performance and/or protection against AD and dementia (Park et al., 2019; Sattler et al., 2012; Scarmeas et al., 2001; X. Zhu et al., 2017); neither are independent of the effects of the other. These studies, with the current results, suggest that different *combinations* of cognitively stimulating events help to build reserve against cognitive impairment. Importantly, these findings support the theory of mutual compensation towards achieving protection against cognitive impairment. Together, these results show that multilingualism is not independently protective against cognitive impairment; rather, multiple cognitive activities work together to create a protective effect. This theory can also be related to the inconsistencies for a peak effect seen for objective one.

Second, comparable to the current effect modification by cognitive leisure activities are the results of a study that examined multilingualism and cognition stratified by educational level. Liu et al. (2017) found that once stratified by education, the association of multilingualism with cognition was only significant in those with low education (i.e., only multilinguals with low levels of education had better MMSE scores than bilinguals). Other studies examining cognitively stimulating activities more generally, without multilingualism, report that the effect of cognitive leisure activities on cognition is also differentially influenced by the level of education. For example, cognitive or mental activities have been associated with better cognitive function only in individuals with lower levels of education (Litwin et al., 2017) and were not significant in more highly educated individuals (Park et al., 2019). Overall, these findings are comparable to the results of the current study where a significant effect of multilingualism on executive function was only found in those with infrequent participation in cognitive leisure activities. In other words, it was only when the level of another form of cognitive stimulation was low that the effect of multilingualism on cognitive function was significant. These results, and the results of similar studies, suggest the presence of a ceiling effect, with multilingualism as a protective factor that is only beneficial in those experiencing low levels of cognitive stimulation through other challenging activities. In those with higher levels of cognitive stimulation, the effect of language on cognition is not beneficial; the maximum level (i.e., the ceiling) of a protective effect against cognitive impairment has been achieved through other means.

Lastly, similar to the unstratified results, there are some irregularities regarding speakers of 5+ languages in these stratified results. Specifically, the peak protection against low executive function remained at four languages, and the dose-response effect was not present for speakers of 5+ languages. As discussed (see section 5.2.1), differing levels of acculturation, differences between speakers of many languages, and exclusion of individuals with bilingual responses may be contributing to these unexpected results. More studies are needed to examine the role of culture and acculturation differences by participation in cognitive leisure activities. Alternatively, it is again important to consider that the speakers of 5+ languages are a small subsample and may not be representative of all speakers of many languages.

5.4 Summary and Discussion of the Missing Data Results

The results of the missing data analyses suggest that not completing at least one executive function test (i.e., missing executive function data) was associated with the number of languages spoken. Missing multilingualism data was not significantly associated with executive function. Overall, these results suggest that those with missing executive function test data may be different from those who have complete test data. Although it is not possible to determine if these data are missing at random, it is highly plausible they are not random as those with missing cognitive data are more likely to have cognitive impairment or lower cognitive status (Helliwell et al., 2001; Jacobsen et al., 2020). Therefore, multiple imputation was not used to address missingness as this method would introduce further bias by carrying forward the biases that already exist in the current sample. For example, if the existing CLSA data were to be used for imputation, these data would likely bias the results by further underrepresenting those with low executive function status, as those with low executive function are likely already underrepresented in the current sample (Helliwell et al., 2001).

It is important to recognize the potential impact of these missing executive function data and covariate data on the results of the current study. First, in this study, the effect of language on cognition may be overestimated if those with missing data were more likely to have low executive function and were also more likely to be multilinguals. Given that those with missing executive function data are more likely to have low performance (Helliwell et al., 2001; Jacobsen et al., 2020), and that multilinguals (speakers of two to 5+ languages), but not monolinguals, were more likely to have missing executive function data, than not missing, the protective effect of the number of languages spoken on executive function may be overestimated (i.e., multilinguals with low executive function may be underrepresented in the analytical sample).

Second, the impact of missing covariate data also may impact the results. Individuals with missing data on sociodemographic, health behaviours/lifestyle and cognitively stimulating activities were more likely to have low executive function. The missing data for these covariates would likely underestimate the association between these factors and executive function, which, in turn, could exaggerate the effect of multilingualism on cognition. For example, if education (a cognitively stimulating activity) is underrepresented and thus under-adjusted, the association between multilingualism and executive function would likely be overestimated. Education can be underrepresented if the proportion of those with low education and low executive function who are in the study is lower than expected based on the general population due to non-response or refusal to participate, or if those with low education and low executive function are more likely to be missing. However, given the large sample size, it is also possible that the statistical significance of this missing data does not have clinical importance. Ultimately, caution should be applied before generalizing the results of this study to populations that differ from the analytical sample.

5.5 Strengths

The current study has many strengths including: 1) the population-based study design, 2) the consideration of a variety of covariates, 3) the derived measure of overall executive function, 4) the detailed measure of 1 to 5+ languages spoken (rather than *at least* two languages), and 5) the novel measure of language similarity. These strengths will be discussed in the following section.

A key strength of this study is the population-based study design of the CLSA. As a considerable amount of the literature examining multilingualism and cognition is clinic-based, the CLSA provided the opportunity to examine this association in a population-based sample of Canadians. The CLSA obtained this national sample through their sampling strata (i.e., age, sex and province), and targeted sampling in areas with higher rates of low education. This approach helped to ensure that Canadians from all provinces were represented in the total final sample (Raina et al., 2008). Further, the sampling weights provided by the CLSA helped to increase the representativeness of statistics computed, and thus the generalizability of findings. Specifically, the sampling weights helped to reduce the impact of characteristics that are overrepresented in the CLSA (i.e., education and annual household income) (CLSA, 2020; Griffith, 2020).

In addition to helping increase the representativeness of the CLSA, the sampling design also allowed for the recruitment of a large number of participants. This large sample size provided by the CLSA allowed for the inclusion of a large number of covariates in multivariable modelling. Also, the CLSA's extensive questionnaires allowed for the investigation of a variety of covariates that are either lacking in existing literature or have not been often explored (e.g., cognitive leisure activities).

An additional strength of this study was the CLSA's multiple executive function tests, which allowed for a comprehensive measure of executive function, one that is arguably more exhaustive than a single test. For example, it has been suggested that measures of executive function, such as those used in the CLSA, provide a more precise picture of cognitive functioning than do global or broad measures of cognition, such as the MMSE (Bialystok, Craik, et al., 2014). Further, the dichotomous measure of low/not low executive function used in this study provides clinical value over a continuous measure of executive function, as the use of a cut-point from a cognitively healthy subsample provides some sense of clinical meaningfulness. That is, those individuals with low executive function may be at a higher risk for cognitive impairment and subsequent cognitive decline or dementia relative to their peers. Although this derived cut-point is not a standard cut-off for poor executive function, it provides the ability to identify individuals in this population who may be at risk of cognitive impairment. The investigation of factors that may protect against low executive function is key to helping older adults remain independent. Since executive function is responsible for integrating information across cognitive domains and coordinating behaviours, deficits in executive function may impact an individual's ability to appropriately respond and regulate behaviour (Diamond, 2013; West, 1996) and may increase fall risk (Fraser & Bherer, 2013). Being aware of impairment in this domain of cognition can help older adults plan for current needs as well as future decline and may encourage them to build their protection against cognitive impairment by engaging in cognitively stimulating activities. Moreover, the investigation of factors that may protect against low executive function can help to inform clinicians and researchers in constructing potential dementia prevention strategies.

Finally, interventions for dementia that are focused on cognitively stimulating experiences may benefit from the more detailed measures of multilingualism used in this study. That is, compared to a field that has often focused on the effects of bilingualism, or speakers of at least two languages, the measure of the number of languages spoken as 1 to 5+ offers much-needed granularity, for both the field of study and clinical interventions. Further, the similarity of languages measure used in this study provides a novel addition to a field where a dearth of studies exists.

5.6 Limitations

Although the current study has many strengths, it did face some challenges, such as the generalizability of study results (especially given the exclusion of those with overt cognitive impairment at recruitment), the response rate of the CLSA, the use of cross-sectional data, and the use of self-reported measures of multilingualism.

First, despite the great effort made by the CLSA to recruit a large sample that is generalizable to the Canadian population, the final sample was not a perfect reflection of all Canadians. Arguably due to self-selection bias, participants in the CLSA were more highly educated, had a higher annual income, and were disproportionally Canadian-born compared to the general Canadian population (Raina et al., 2019). Further, because of the recruitment strategies used for the Comprehensive cohort specifically, this sample does not include data from three provinces (SK, PEI and NB), and excludes populations such as those in First Nations communities and long-term care. Moreover, the ability to generalize to individuals with dementia or other diagnosed forms of age-related cognitive impairment in this study is limited as the CLSA excluded Canadians with overt cognitive impairment at recruitment. Because the CLSA is a relatively healthy sample, the current study was unable to determine how multilingualism is associated with more advanced cognitive impairment, and thus the ability to generalize to clinical practice and the general population may be limited. However, the measure of low executive function used may provide a sense of who may be at risk of future cognitive impairment relative to their healthy peers.

Second, the overall response rate of the CLSA, at 10% (with subpopulation response rates of 6% to 25%), although relatively low compared to previous epidemiological studies in past decades, is somewhat within the range of overall response rates from more recent studies such as the 45 and Up Study (response rate 18%) (Banks, 2008), the German Aging Survey (response rate in 2014, 27%) (German Centre of Gerontology, n.d.) and the Healthy Aging Longitudinal Study in Taiwan (response rate ~30%) (Hsu et al., 2017). However, the CLSA rate is still low compared to the overall response rate of other Canadian population-based studies with clinical assessment such as the Canadian Study of Health and Aging (response rate 72%) (McDowell et al., 1994) and the Canadian Multicentre Osteoporosis Study (response rate ~46%) (Tenenhouse et al., 2000). Importantly, it is well recognized that response rates for population-based studies have been on the decline (Galea & Tracy, 2007; Hartge, 2006). Nevertheless, response rates alone should not be used as a metric of study quality as even studies with low response rates (e.g., < 20%) can produce accurate results similar to studies with higher response rates (e.g., 60–70%) (Holbrook et al., 2007; Morton et al., 2012). Still, the CLSA’s low response rate contributes to non-response bias, such that there may be differences in those individuals who chose to participate versus those who did not. For example, it is suggested that those who are more highly educated are more likely to participate; this overrepresentation of the highly educated is true in the CLSA (Raina et al., 2019). Further, selection bias can also be found in those who chose to participate but were excluded from analyses due to missing data on one or multiple variables of interest. Despite these aforementioned examples of selection bias, the CLSA's sample is largely heterogeneous and is national in scope, which in turn may help to increase the representativeness of the sample.

Third, the use of cross-sectional data in this study is also a limitation. Cross-sectional data prevent the ability to determine cognitive change over time and thus the ability to determine if multilingualism is protective against cognitive decline. While concerns of reverse causality exist with cross-sectional data, they are, however, somewhat less of a concern in this study since the association of baseline executive function with multilingualism has some conceptual temporality (Bialystok et al., 2012) (see section 3.3).

Lastly, measures of the number and similarity of languages spoken were based on self-report of the CLSA's (2018) question asking in which language(s) an individual could conduct a conversation. It has been suggested that using objective measures such as the Multilingual Naming Test (MINT) would provide more accurate measures of language proficiency (Gollan et al., 2012). Unfortunately, there are no available objective data in the CLSA on the level of proficiency; however, previous studies have found that subjective reports of language and some objective standardized measures of language use have a strong positive correlation (e.g., Marian et al., 2007). In addition, other characteristics of multilingualism (i.e., fluency, age of acquisition, and frequency of use) could not be controlled for in this study. Although the covariates "first language learned" and "language spoken most often at home" cannot be considered true measures of age of acquisition or frequency of use, they may account for some of the potential impact of testing in a non-native or less frequently used language, which has also been shown to impact performance on cognitive tests (Arce Renteria, 2021).

Given these limitations and the potential confounding that exists in a large population-based sample such as the CLSA, the results of this study should be interpreted accordingly. However, they further the field of multilingualism and cognition, suggesting that multilingualism could be beneficial for some individuals (i.e., those who are most accurately reflected in the analytical sample), and that number rather than type of language may be key. These findings are an encouraging step for future projects to build upon.

5.7 Implications and Future Directions

The results of the current study add to the existing literature that supports the association of multilingualism with executive function (or cognition) and provide novel information concerning the impact of the similarity of languages spoken. This study's findings suggest that in this sample of Canadians, speaking more than one language is protective against low executive function in a dose-response manner, but that a limit for protection is reached at four languages. Importantly, it was the number of languages spoken that was protective for these individuals — the type of language learned (i.e., similar or dissimilar) did not offer additional protection. Moreover, the association was modified by the frequency of engagement in cognitively stimulating leisure activities, as only those in the sample who participated in cognitive leisure activities infrequently benefited from speaking multiple languages. These results by differential engagement in cognitive leisure activities suggest the presence of a ceiling effect for those who engage in cognitive leisure activities frequently. Overall, these results may encourage those who are interested in learning a new language, *any new language,* to do so, especially if they are not interested or infrequently participate in other cognitive activities.

The current study addresses gaps in the existing literature by adding to the evidence supporting an association between multilingualism and executive function in middle to older-aged community-living adults. The results provide knowledge regarding the association of the specific number of languages spoken with executive function in a field that has often ambiguously explored the effects of speaking *at least two* languages. Moreover, this study contributes novel findings regarding language similarity to a field where a dearth of literature exists examining this association. The availability of multiple covariates in this study allowed for the exploration of potential confounders and interactions that may have influenced the association.

Future studies could build on the current, preliminary, baseline results by examining the association between multilingualism and executive function using longitudinal data. The CLSA has the first follow-up data available, which could be used to determine if multilingualism protects against cognitive decline over time. Second, future studies should strive to include other characteristics of language. Age of acquisition, language dominance, and frequency and proficiency of second language use are key aspects of the multilingual experience that should be deconstructed (Arce Renteria, 2021) as they can differentially impact cognitive function (Celik et al., 2020; Green & Abutalebi, 2013). Further, although appropriate, the measure used for the similarity of spoken languages is a qualitative approach based on language family groups and subgroups. Language similarity in future studies could be measured through quantitative methods such as the Swadesh list, which was developed to quantitatively classify language distance (i.e., the interrelatedness of languages) (Swadesh, 1952), and could consider other language families in addition to the Indo-European family. Further, if the impact of language type is to be examined in speakers of more than two languages, ways of classifying language similarity, or linguistic distances, across multiple sets of languages need to be addressed (Ljungberg et al., 2020).

The results of this study, as well as existing studies, support that testing in an individual's first language learned (or well-known language) is key, as testing in a non-native language increases the odds of poor executive function performance, especially for language-based tasks (for a review see, e.g., Celik et al., 2020) for some individuals. Future studies should work to ensure that participants are tested in their preferred language particularly when verbal-based tasks are involved. Language of test administration could also be considered in connection to culture and ethnicity, or acculturation (i.e., the use of linguistically or culturally appropriate tools for cognitive assessment) (Celik et al., 2020). Future studies should consider the role of refugee or immigrant status as confounding variables or effect modifiers to account for differences in culture, and testing language, on cognitive performance. These limitations regarding testing language and culture/acculturation demonstrate the difficulty of disentangling the interaction between linguistic and participant differences on cognitive performance.

Lastly, in terms of other potential confounders or effect modifiers not mentioned above, future studies could examine male and female subgroups, as little is known about the impact of sex differences on the association between multilingualism, cognition and cognitive reserve (Subramaniapillai et al., 2021). Future research could also explore the role of mutual compensation further by examining the impact of language on cognition in different subgroups of cognitive stimulation, such as by education and occupation status. This work would help to further support that protection against cognitive impairment could be achieved through different combinations of cognitively stimulating activities.

5.8 Conclusions

As the population continues to age, knowledge about interventions and strategies to protect against cognitive impairment and build cognitive reserve is key to helping older adults remain independent. Further, an individual's awareness of impairment in the executive function domain of cognition now may encourage them to engage in cognitively stimulating activities. In investigating the association of the number and similarity of languages spoken with executive function, and the difference in this association by participation in cognitive leisure activities, this study contributes to the understanding of how engagement in cognitive stimulation, specifically multilingualism, is protective against cognitive impairment while adjusting for a large variety of sociodemographic, general health, health behaviours/lifestyle and cognitively stimulating factors.

Overall, the results of this study support that cognitive stimulation through multilingualism is protective against cognitive impairment (low executive function), but that this association differs based on the frequency of engagement in other cognitive leisure activities. Moreover, it is the number of languages that matters; therefore, an individual can choose *any* language to learn as language similarity is not key. Future studies could consider the role of other language characteristics when defining multilingualism.

Ultimately, given the limitations of this study, these results are most generalizable to those Canadians who are represented in the analytical sample. While the findings are an encouraging addition to our understanding of the association between language and cognition, learning multiple languages may only be protective for some Canadians, that is, those who are most comparable to the sample used in this study. Nevertheless, the results of this study can be considered an encouraging step towards reducing some uncertainty regarding the role of the number and type of languages spoken with cognition. The results may also help inform language-based dementia prevention strategies (i.e., language learning may be a meaningful area to explore for prevention). The results may also encourage individuals who are already learning a new language to continue these efforts or to encourage those interested to start learning. They may also reassure those Canadians who know multiple languages that they may already have some protection. Individuals may also be motivated to ensure their children learn an additional language at young ages, such that the impact of multilingualism is working throughout the life course to build cognitive reserve and resilience against poor cognitive function in later years. In closing, it is better to “use it” than to “lose it”, and multilingualism can provide a means to do just that.

6.0 References

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7.0 Appendices

Appendix A: Literature Search Strategy — Search Terms and Subject Headings

Table A-1 *Literature Search Strategy for PubMed*

Concept	Cognitive function	Multilingualism	Age
Keywords	Executive function* Executive control Cognitive dysfunction Cognitive impairment Cognitive decline Cognitive function Cognitive control Attention Problem solving Cognitive performance Cognition Cognitive reserve Neuropsychological test* Neuropsychologic test* Dementia Alzheimer* Mild cognitive impairment	Multilingual* Multi-lingual* Bilingual* Bi-lingual* Language proficiency Dual language Bilingual advantage Language control L2 proficiency	Aged Elderly Senior* Older adult* Middle aged Older Older bilinguals Later age Aging
Medical Subject Heading (MeSH)	Cognition[mesh:NoExp] Cognitive dysfunction[mesh] Executive function[mesh] Neuropsychological tests[mesh] Dementia[mesh] Alzheimer disease[mesh]	Multilingualism[mesh]	Aged[mesh:NoExp] Aged, 80 and over[mesh] Middle Aged[mesh]

Overall search string for PubMed: **#1** AND **#2** AND **#3** (restricted to English):

#1 cognition[mesh:NoExp] OR cognitive dysfunction[mesh] OR executive function[mesh] OR neuropsychological tests[mesh] OR dementia[mesh] OR Alzheimer disease[mesh] OR executive function* OR “executive control” OR “cognitive dysfunction” OR “cognitive impairment” OR “cognitive decline” OR “cognitive function” OR “cognitive control” OR “attention” OR “problem solving”

OR “cognitive performance” OR “cognition” OR “cognitive reserve” OR neuropsychological test* OR neuropsychologic test* OR “dementia” OR Alzheimer* OR “mild cognitive impairment”
#2 multilingualism[mesh] OR multilingual* OR multi-lingual* OR bilingual* OR bi-lingual* OR “language proficiency” OR “dual language” OR “bilingual advantage” OR “language control” OR “L2 proficiency”
#3 aged[mesh:NoExp] OR Aged, 80 and over[mesh] OR middle aged[mesh] OR “aged” OR “elderly” OR senior* OR older adult* OR “middle aged” OR “older” OR “older bilinguals” OR “later age” OR “aging”

Search performed April 24, 2020 retrieved 715 articles
Search performed April 1, 2021 retrieved 73 articles

Table A-2 *Literature Search Strategy for PsycINFO*

Concept	Cognitive function	Multilingualism	Age
Keywords	Executive function* Executive control Cognitive dysfunction Cognitive impairment Cognitive decline Cognitive function Cognitive control Attention Problem solving Cognitive performance Cognition Cognitive reserve Neuropsychological test* Neuropsychologic test* Dementia Alzheimer* Mild cognitive impairment	Multilingual* Multi-lingual* Bilingual* Bi-lingual* Language proficiency Dual language Bilingual advantage Language control L2 proficiency	Aged Elderly Senior* Older adult* Middle aged Older Older bilinguals Later age Aging

Overall search string for PsycINFO: **#1** AND **#2** AND **#3** (restricted to English); run separately for "Keywords", "Title" and "Abstract":

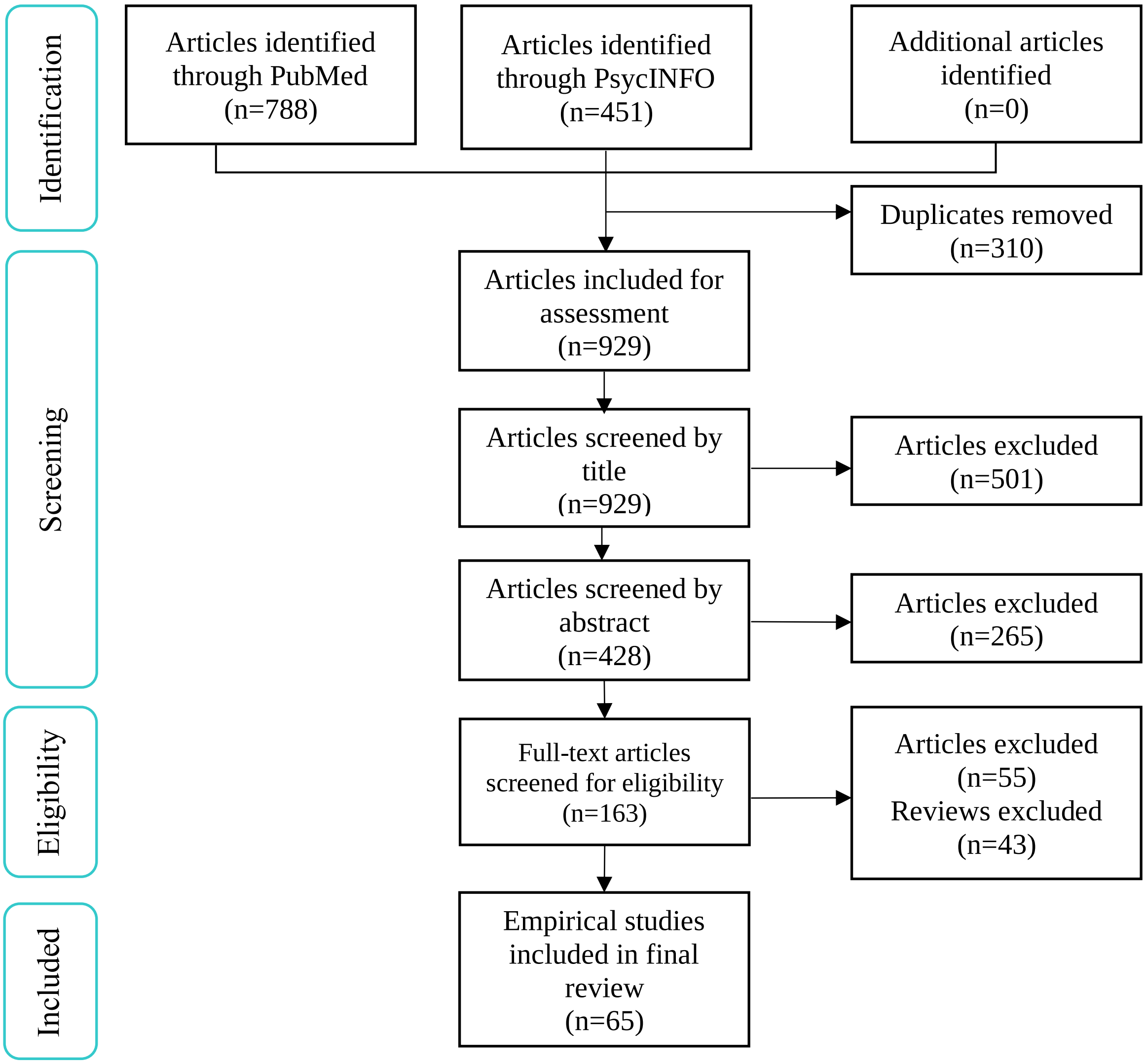
#1 executive function* OR "executive control" OR "cognitive dysfunction" OR "cognitive impairment" OR "cognitive decline" OR "cognitive function" OR "cognitive control" OR "attention" OR "problem solving" OR "cognitive performance" OR "cognition" OR "cognitive reserve" OR neuropsychological test* OR neuropsychologic test* OR "dementia" OR Alzheimer* OR "mild cognitive impairment"
#2 multilingual* OR multi-lingual* OR bilingual* OR bi-lingual* OR "language proficiency" OR "dual language" OR "bilingual advantage" OR "language control" OR "L2 proficiency"
#3 "aged" OR "elderly" OR senior* OR older adult* OR "middle aged" OR "older" OR "older bilinguals" OR "later age" OR "aging"

Search performed April 24, 2020 returned a total of 413 articles
Search performed April 1, 2021 retrieved 38 articles

Appendix B: Detailed Description of Literature Search Strategy and Search Results

Articles in the literature review were screened and excluded based on the following criteria: the sample age; if the exposure was not multilingualism; if the outcome was not global cognitive function, executive function, overall dementia, MCI or AD; the study design; and the article type. Specifically, with respect to the sample age, articles were excluded if the age was limited to participants under 45 years. Articles were excluded if multilingualism, as the exposure, was not defined as the number of languages spoken, or the similarity of languages spoken; therefore, articles that considered multilingualism as the degree of proficiency or as a continuous variable based on proficiency level were excluded. Regarding the outcome, in addition to the above-mentioned criteria for exclusion based on cognition, studies that considered the cognitive language processing of bilinguals were also excluded. Studies of bilinguals that contained relevant behavioural data from executive function or global cognitive tasks were included even if this was not the study's primary focus (i.e., articles focusing on brain imaging and electrophysiological measurement). Regarding study design, articles were excluded if there was no control group, (i.e., case studies). Finally, records were excluded based on article type, i.e., if they were not peer-reviewed empirical studies (including dissertations, editorials, commentaries, etc.). As well, the large number of review articles, 43, were excluded at the final eligibility stage, but kept for reference. The total number of peer-reviewed empirical articles included in the final review was 65. For a summary of this literature, see Appendix C.

Figure B-1 *Modified PRISMA Flowchart of the Systematic Literature Review: Search Strategy Results*



Articles were excluded if the:

- Sample was limited to participants under the age of 45 years.
- Exposure was not number of languages spoken or similarly of languages spoken.
- Outcome was not global cognitive function, executive function, overall dementia, mild cognitive impairment, or Alzheimer's disease.
- Study design had no comparison group (i.e., case-study).
- Record type was not a peer-reviewed empirical study.

Appendix C: Summary of Literature Included in Review

Table C-1 *Summary of Literature*

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
Rosselli et al., 2000; **Verbal fluency and repetition skills in health older Spanish-English bilinguals**	82 older adults (28 men and 54 women); mean age 61.76 years. 45 English monolinguals, 18 Spanish monolinguals and 19 Spanish-English bilinguals. Language groups did not differ in age, education and MMSE.	Bilingualism (Spanish-English); Subjective – Questionnaire; received more that 5 years of education in English and work for at least 10 years in both languages. Used both on a daily basis. AoA was obtained (before age 12, after age 12). Monolingualism (English, Spanish). *Covariates:* MMSE, proficiency, age, education.	Verbal fluency; describe a picture using semantic and phonemic restrictions. Repetition; sentence-repetition test.	t-test; ANOVA	Bilinguals performed significantly worse than monolinguals in the semantic fluency test (fewer words/category). Bilinguals' performance on phonemic fluency did not differ significantly from monolinguals. Performance was similar for bilinguals in either English or Spanish. AoA of L2 was not a significant predictor for verbal fluency task performance.
Bialystok et al., 2004; **Bilingualism, aging and cognitive control: Evidence from the Simon task**	Three studies: 1-2) Middle-aged adults (30-54 years), older adults (60-85 years) 3) Participants aged 30-55 years. Participants were similar in gender,	Bilingualism; Subjective – Questionnaire; spoke both languages approximately 50% of the time (i.e., balanced); AoA was 6 years. 1) Tamil-English bilinguals. 2) Tamil-English or English-Cantonese.	Inhibition processing; Simon task performance on congruent and incongruent trials (reaction time and accuracy, Simon effect).	n-way ANOVA	In all three studies bilinguals had a smaller Simon effect than their monolinguals age-matched peers. Older adults had poorer performance vs. middle-aged. Bilingualism attenuates the age-related decline in executive function; though interaction between

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
	SES, and all had a bachelor's degree. They performed similarly on background cognitive measures of working memory and intelligence. Cross-sectional study design.	3) French-English. Monolingualism (English); not functionally fluent in another language (except exposure in school). *Covariates:* age (matched), gender, education, SES, measures of vocabulary.	Working memory; colour trials version of the Simon task.		age*language*simoneffect was not significant in Study 1, results from the three studies together suggest that the age-related increase in the Simon effect was less in bilinguals vs. monolinguals. Bilinguals performed better on congruent trials and Simon tasks involving working memory compared to monolinguals. This suggests global executive function benefits, not just inhibition. Gap between monolinguals and bilinguals diminished with practice in Study 3. This suggests the bilingual advantage is in controlled processing.
Bialystok et al., 2006; **Executive control in a modified antisaccade task: Effects of aging and bilingualism**	Two studies. Monolingual and bilingual younger and older adults comparable in terms of social, cultural, age and education characteristics.	Bilingualism (variety of language pairs); Subjective – Language questionnaire; both languages have been actively used on a daily basis since childhood. 6 years AoA for young	Executive control; modified antisaccade task to measure specific domains of executive function (response suppression, inhibitory control,	ANOVA	Study 1's antisaccade task found no significant effects of aging or bilingualism on performance. Study 2, using a behavioural response method, found that older participants and monolinguals had the longest

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
	Cross-sectional study design.	adults and 12 years for older adults. Monolingualism; had some exposure to another language but not proficient. *Covariates:* age, education.	task-switching); mode of response in Study 1 was eye movements (more automatic control), Study 2 was keypresses (less automatic, more controlled).		reaction times. Bilinguals had better performance than monolinguals (less costs in response suppression, inhibitory control and task-switching), resolving conflict faster. This advantage over monolinguals increased in the older group. Importantly, there was no decline in accuracy for faster reaction time in older bilinguals indicating a protective factor of bilingualism on age-related executive function decline.
Craik et al., 2006; **Planning and task management in older adults: Cooking breakfast**	60 healthy participants: 30 young adults (18-30 years) and 30 older adults (60-80 years). There were 15 bilinguals and 15 monolinguals in each age group. Older adults and monolinguals had better vocabulary and education.	Age; younger vs. older adults. Bilingualism (English and L2); Subjective – spoke 2 language every day from an early age (6 for young adults and 10 for older adults) and have present use of both languages with excellent comprehension in both. *Covariates:* education.	Planning and task management (prospective and working memory); cooking breakfast task and background table-setting task (computerized).	ANOVA	Younger adults vs. older adults performed similarly on the simple condition, but in the complex version (with greater working memory demands) young adults performed better than older adults. In both age groups the monolinguals and bilinguals performed similarly; however, in planning and preservation measures, bilinguals performed slightly better than monolinguals suggesting more efficient use of time and task-

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
	Cross-sectional study design.				switching. This difference was greater for older bilinguals.
Bialystok et al., 2007; **Bilingualism as protection against the onset of symptoms of dementia**	Baycrest Memory Clinic sample of 184 patients (91 monolingual and 93 bilingual) who were complaining of cognitive complaints. Majority of bilinguals were immigrants, but monolinguals were not. Monolinguals had higher education. Retrospective cohort study design.	Bilingualism (speakers of 25 different L1); Subjective – defined as speaking at least two languages for the majority of their life (at least from early adulthood), and regular use of these languages. Judges classified participants into monolingual or bilingual. Language fluency was also recorded. *Covariates*: gender, education, occupation, initial MMSE score.	Age of onset of cognitive impairment; Subjective - determined by family/caregiver report.	ANCOVA	Bilinguals had a delay in onset of dementia symptoms by 4.1 years compared to monolinguals. This was independent of immigration status, education, gender and occupation. Both groups had non-significant differences in baseline cognition. Bilingualism shifts onset of dementia symptoms but does not change rate of decline.
Bialystok et al., 2008; **Cognitive control and lexical access in younger and older bilinguals**	96 participants: 48 young adults, 48 older adults. 24 monolingual or bilingual in each age group. Sample included immigrants who arrived in Canada before age 6 or 12.	Bilingualism (English and another language [dominant not specified]); Subjective – Likert scale (1–4) proficient questionnaire; reported speaking English and L2 daily. *Covariates:* age (matched), education.	Lexical retrieval; Peabody Picture Vocabulary Test, BNT, letter and category fluency. Working memory; forward and backward Corsi block span and the self-ordered pointing test.	ANOVA	Monolinguals outperformed bilinguals in lexical access tasks. There was no interaction between age and language suggesting equal effects of aging in this task for both language groups. Overall, on working memory tasks, older adults recalled fewer items than younger adults. There was no

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
	Older participants had more years of education than younger participants. Cross-sectional study design.		Executive control; Simon, Stroop colour naming (interference suppression), and Sustained Attention Response Task [SART] (response inhibition).		significant effect of language group in this task. Bilinguals outperformed monolinguals on executive function tasks. Older bilinguals had the smallest Simon effect and older monolinguals the largest, suggesting a bilingualism attenuates age-related decline in executive function. On the Stroop, there was a main effect of age and language but no interaction; older bilinguals had smaller costs relative to older monolinguals. SART performance was similar for monolinguals and bilinguals. There was no effect of age.
Kavé et al., 2008; **Multilingualism and cognitive state in the oldest old**	Cross-sectional and Longitudinal Aging Study. 814 oldest old (mean = 83) Israeli Jewish population (wave 1). 12 year-follow-up. Prospective cohort study design;	Multilingualism (35 different language combinations, at least Hebrew and one other); Subjective – self-report. Classified as bilinguals, trilinguals, or multilinguals. Mother tongue and best language were recorded.	Cognitive state; Katzman cognitive screening test and MMSE (latter use to validate Katzman results). Low Katzman and high MMSE	ANOVA, ANCOVA Hierarchal regression analysis	Multilinguals had the best cognitive state throughout all three waves (12 years) on Katzman and MMSE. There was a significant main effect of language group on cognitive status (for MMSE and Katzman) after adjustment for all covariates.

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
	Population-based sample.	No strict criteria used. Additional details (frequency, AoA etc) not obtained. *Covariates:* age, gender, place of birth, education, age at immigration.	indicate better performance.		Multilingualism added to the prediction of cognitive state (MMSE and Katzman) beyond the contribution of covariates Multilingualism was the strongest predictor of cognitive status in those with no formal education suggesting a distinction between language and education. Those whose better language was not their mother tongue had better cognitive scores than those who spoke their mother language best.
Chertkow et al., 2010; **Multilingualism (but not always bilingualism) delays the onset of Alzheimer's disease: Evidence from a bilingual community**	632 participants with memory complaints who were diagnosed with AD. Recruited from a memory clinic in Montréal. Cross-sectional study design.	Bilingualism/Multilingualism; Subjective – defined as having spent the majority of their lives, at least from early adulthood, regularly using at least two languages. Obtained from language history and interviews. Classified in three levels (1, 2, 3+). Groups were similarly educated.	Age of symptom onset; Subjective – family interviews (available in subset of 143 subjects). Age of AD diagnosis; determined my formal evaluation by neurologist or geriatrician.	chi-square and z-tests used for descriptive analyses Regression analyses (simple and multiple linear)	There was no significant difference between monolinguals and bilinguals on age of symptom onset of diagnosis. A small significant protective effect in those speaking 3+ languages on delay of symptom onset and diagnosis. Speaking 2+ languages in native-French speakers, delay in onset trended towards significance, but in native-

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
		Monolingualism; only English or French speakers. Non-native (immigrants); Assumption – non-native participants whose first language was neither English or French and were educated outside of Canada. *Covariates:* immigration status/native status, SES (occupation as a proxy), education, sex.			English speakers this association was not found. In the immigrant group, a significant delay of onset was found in a dose response manner with number of languages spoken (bilinguals had a 5-year delay, trilingual had a 6.4-year delay, 4+ languages had a 9.5-year delay).
Craik et al., 2010; **Delaying the onset of Alzheimer's disease: Bilingualism as a form of cognitive reserve**	211 participants diagnosed with probable AD. Recruited from a memory clinic at Baycrest. 102 bilinguals, 109 monolinguals. Monolinguals had higher level of education. Bilinguals were older and had lower occupational status.	Bilingualism (speakers of 21 L1s); Subjective – defined as those who spent the majority of life, from early adulthood, regularity using at least two languages; structured questionnaire completed by patients or caregivers. Fluency was also recorded. *Covariates:* occupation, education, place of birth, immigration status.	Age of onset of cognitive impairment (AD symptoms); Subjective – recorded by patients or caregivers.	2-way ANOVA	Bilinguals were diagnosed 4.3 years later and had symptoms occur 5.1 years later than monolinguals. There was no effect of immigration status in sub-analyses. Both groups had equal levels of impairment at time of diagnosis. Monolinguals had higher occupational and education status.

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
	Retrospective cohort study design.				
Kousaie et al., 2012; **Ageing and bilingualism: Absence of a "bilingual advantage" in Stroop interference in a non-immigrant sample**	38 younger (18–35 years) monolinguals and 35 bilinguals. 25 older (60–81 years) monolinguals and 20 bilinguals. Majority of bilinguals were sequential. Non-immigrants born in Canada, living in Montréal. All participants had normal cognition (MoCA) and bilinguals had high proficiency (animacy task). Cross-sectional study design.	Bilingualism (English-French); Subjective – native English speakers with self-reported high proficiency in French (use on a daily basis) or were simultaneous learners of both English and French. Objective – measure of proficiency with the animacy judgment task. *Covariates:* age (matched), education.	Executive function (interference suppression/inhibitory function); Stroop task – Stroop effect, reaction time, accuracy (small effect indicated better control).	ANOVA, between subjects MANOVA	There were no differences in age and language groups in accuracy. Young adults were faster (reaction time) than older adults. Overall, across all conditions, young bilinguals faster than young monolinguals, indicating no specific advantage regarding inhibition. There was no difference between older monolinguals and bilinguals. Interaction between age and language was non-significant indicating no advantage for bilinguals relative to monolinguals differing by age group.
Alladi et al., 2013; **Bilingualism delays age at onset of dementia, independent of education**	Sample of 648 patients' case records from a memory clinic in India. Homogenous sample where bilingualism is acquired	Bilingualism; Subjective – defined as those with an ability to communicate with self and society in two or more languages. Language history was obtained from family.	Age of onset of first dementia symptoms (including subtypes); Subjective – the age when first clinical symptom	t-test, ANOVA, General linear modeling	(non-immigrant sample) Bilinguals were 4.5 years older at time of symptom onset compared to monolinguals. This was found for AD, frontotemporal dementia and vascular dementia. Association remained after adjustment for

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and immigration status	simultaneously and is contact-based (social/culture) not education-based. Non-immigrant sample. Retrospective cohort study design.	Categorized by number spoken (1–4+). *Covariates:* literacy, education, dwelling, occupation (SES), family history, health risk factors.	of dementia was seen. Family report.		covariates listed, and among illiterate subjects. Number of languages spoken, above two, had no additional protective effect.
Gold et al., 2013; **Lifelong bilingualism maintains neural efficiency for cognitive control in aging**	Two studies. 1) 30 community dwelling participants (15 older adult monolinguals,15 older adult bilinguals). 2) 80 community dwelling participants (20 young adult monolinguals, 20 younger adult bilinguals, 20 older adult monolinguals and 20 older adult bilinguals). Cross-sectional study design.	Bilinguals (lifelong); Subjective – defined as those speaking another language in addition to English on a daily basis since age 10 or younger. Questionnaire also included AoA, proficiency. *Covariates:* SES, intelligence, working memory (digit span performance), GMV.	Cognition (global task-switching); Colour-shape task-switching paradigm. Measured reaction time and accuracy. Functional networks/activation of brain regions of interest; fMRI.	ANOVA	1) Older bilinguals performed better on task-switching (faster switching reaction times) than older monolinguals. 2) Older adults had poorer performance, and increased neural activation compared to young adults suggesting age-related decline in efficiency. Among older adults, with similar GMV, bilinguals performed better than monolinguals on task-switching, while requiring less activity in several frontal brain regions (ACC, PFC) required for effortful processing. This was similar to young adult bilinguals.

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Luo et al., 2013; **Bilingualism interacts with a domain in a working memory task: evidence from aging**	157 healthy participants; young (18–35 years) and older adults (60–80 years), either monolingual or bilingual. Younger bilinguals had a younger AoA, used English less frequently, and had lower fluency in both languages. Cross-sectional study design.	Bilingualism (English L1 with a variety of L2); Subjective – Questionnaire; use of both languages fluently on a daily basis. Monolingualism; only spoke English. *Covariates:* vocabulary, intelligence, age, education.	Working memory; Verbal (word span and alpha span tasks – alpha is more complex), Spatial (Corsi blocks test).	chi-square, t-test, ANOVA, ANCOVA	Bilinguals and young adults had lower vocabulary. Older adults performed worse than young adults on both working memory tasks and this was not influenced by task difficulty. Bilinguals (older and younger) performed better on spatial task, monolinguals on verbal tasks (language*domain was significant). After controlling for vocabulary, bilinguals still performed worse in verbal tasks suggesting a deficit in processing not due to vocabulary. Interaction between aging and bilingualism were non-significant suggesting that bilingualism does not attenuate age-related decline in working memory.
Perquin et al., 2013; **Lifelong exposure to multilinguali sm: New**	232 volunteers without dementia (44 CIND, and 188 CIND-free) were recruited from the	Multilingualism; Subjective – the number of fluent languages spoken all life, the maximum practiced at the	Cognition; Cognitive impairment no dementia (CIND) or “free of CIND”.	Bilinguals vs. multilingua l; ordinal 2–5+ languages	Lifelong multilinguals were three times less likely to have CIND than bilinguals independent of age and education.

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evidence to support cognitive reserve hypothesis	Luxembourg population.	same time, AoA, duration of use (in years) Participants spoke 2–7 languages (bilinguals as reference). *Covariates:* education, leisure, physical activity, socio-cultural activities (graded on 5-point Likert scale).		Bivariate analysis (t-test, chi-square, Mann-Whitney), mixed model logistic regression	Trilingualism (three languages) appears to be the threshold/peak, as there was no added benefit to speaking four or more languages vs. three on odds of CIND. Bilinguals who learned a third language, and faster/earlier, were *seven times* more likely to be protected from CIND. Those who learned simultaneously were even more likely to be protected. Multilingualism may not be predominant over other “cognitively simulating factors”. Those with CIND-free were more likely to have more leisure activity and higher education.
Bak et al., 2014; **Does bilingualism influence cognitive aging?**	853 participants from the Lothian Birth Cohort (homogenous sample of European, English native speakers, non-immigrants).	Bilingualism; Subjective – Questionnaire asking how many languages, AoA and frequency of use (active/passive) in different settings. Defined as those who reported	Cognition; general intelligence, memory, processing speed, verbal reasoning, vocabulary, verbal fluency (letter).	Multiple regression analysis (power analysis revealed sufficient	Bilingualism protects against age-related cognitive decline (reading, verbal fluency, and general intelligence) independent of childhood intelligence, SES, gender and social class.

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
	Wave 1: 1936, Wave 2: 2008–2010. Prospective cohort study design; Population-based sample.	being able to communicate in an L2. *Covariates:* age at testing, sex, social class, childhood intelligence.	Each test was an outcome.	sample size)	Knowing three (or more) languages showed a stronger protective effect than bilingualism. Little difference between active and passive bilingualism was found. Late-acquisition was also protective.
Bialystok, Craik et al., 2014; **Effects of bilingualism on the age of onset and progression MCI and AD: Evidence from executive function tests**	74 MCI patients and 75 AD patients (about 50% bilingual in each group). Participants were recruited from a memory clinic at Baycrest.	Bilingualism (many different L2s, L1 was English); Subjective – Language and Social Background Questionnaire by caregivers or patients. Defined as those who spent the majority of their lives, from at least early adulthood, speaking two or more languages fluently (ideally daily, but at least weekly). *Covariates:* Sex, MMSE at baseline, immigration status, education, diet, frequency of alcohol consumption, smoking, physical and social activity.	Age of MCI/AD onset; Subjective – Questionnaire completed by caregivers or patients. Executive function; three D-KEFS tests (TMT, Colour-Word Interference test.	ANOVA; logistic regression; mixed effects modelling	Bilingualism significantly delayed the onset of MCI symptoms (4.7 years) and AD symptoms (7.3 years) independent of lifestyle factors and diet, immigration status, education, SES, MMSE (i.e., bilinguals were older at onset). At time one, executive function test performance was not significantly different between language groups, suggesting that bilinguals did not wait longer to seek treatment, and that it protected against age-related executive function decline. Bilinguals with AD showed smaller Stroop effect, and had higher probability of completing the complex subsets tests.

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					Executive function test performance declined at similar rates over time for both language groups.
Bialystok, Poarch et al., 2014; **Effect of bilingualism and aging on executive function and working memory**	Two studies. Healthy older and younger adults. Bilinguals and monolinguals. Study 1) 130 participants. Study 2) 108 participants. Older adults and monolinguals had better vocabulary. Cross-sectional study design.	Bilingualism (English and many L2s); Subjective – Questionnaire; AoA was 10 or younger. All bilinguals reported high fluency, regular use of both languages. *Covariates:* vocabulary, intelligence.	Executive function (interference); Stroop and verbal and nonverbal (figure) versions of working memory test; both require controlled attention, inhibition.	ANOVA	In Stroop task colour naming (verbal component) bilinguals named slower. However, in interference component older participants were slower, but a significant age*language showed that among older adults, bilinguals outperformed monolinguals (faster reaction time). Among young adults, monolinguals and bilinguals did not differ in performance. In all working memory conditions, young adults were faster and more accurate. A bilingual advantage was found during the figure task but not the verbal/letter version for both age groups. The advantage here was larger for older adult bilinguals.
Kousaie et al., 2014; **Executive function and**	97 older and 121 younger monolinguals and bilinguals (French,	Bilingualism (English-French); high self-reported proficiency in both languages before age	Executive control*; (Interference suppression)	t-test; ANOVA	A slight bilingual advantage in the Stroop task as monolingual francophones produced fewer incongruent naming than

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bilingualism in older and younger adults	English). Homogenous (non-immigrant) sample recruited from Ottawa or Québec City. Majority of older bilinguals were French native speakers; majority of young bilinguals were English native speakers. Highly proficient in L2. Cross-sectional study design.	13 (AoA); proficiency was self-reported and determined with the animacy judgement task. Monolingualism (either French or English); minimal exposure to L2. *Covariates:* (matched) age, education, MoCA, right-handed.	Stroop, Simon, (Response inhibition) Sustained Attention Response task [SART], (cognitive flexibility) Wisconsin Card Sorting task [WCST], (working memory) digit span. Language disadvantage*; BNT, category and letter fluency. *analyzed separately.		bilinguals (and monolingual anglophones who performed similar to bilinguals). There were no language group effects on the Simon task. Monolingual francophones had longer reaction times for SART than monolingual anglophones and bilinguals who did not differ. Monolinguals and bilinguals performed similarly on the digit span. Monolingual francophones performed better than monolingual anglophones and bilinguals (who performed similarly) on the WCST. Regarding language tasks, on all three tasks, monolingual anglophones showed and advantage relative to bilinguals and monolingual francophones. Overall, results do not support clear bilingual advantage on executive function and suggest a potential effect of culture and language environment.

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Yeung et al., 2014; **Is bilingualism associated with a lower risk of dementia in community-living older adults? Cross-sectional and prospective analyses**	1468 participants for cross-sectional analysis; 990 cognitively healthy participants for prospective analysis. Participants are from the Manitoba Study of Health and Aging.	Bilingualism; Subjective – asked what languages they speak. Categorized into monolingual English, English bilingual (L1 is English) and ESL (L2 is English). English monolingual vs. (English bilingual, ESL) comparisons. *Covariates:* age, sex, education, subjective memory loss, 3MS.	Dementia; Objective – clinical examination and 3MS score.	Bivariate analysis using chi-square (categorical variables) and Student t-test (continuous variables) Logistic regression Sensitivity analysis (linear regression)	1) Cross-sectional analysis shows no significant association between bilingualism and dementia after adjustments (at baseline). Interaction between subjective memory loss and number of languages found. 2) Prospective analysis shows that bilingualism did not predict the development of dementia over 5 years in cognitively healthy participants at time one. No significant association between bilingualism and dementia. Bilingualism was not associated with higher cognitive test scores (3MS) or change in test scores over time. Results may be influenced by English testing language.
Zahodne et al., 2014; **Bilingualism does not alter cognitive decline or dementia**	1067 Hispanic immigrants; sample is recruited from a single population. Primary language for all was Spanish. Learned English as	Bilingualism (Spanish-English); Subjective and objective – four categories “not at all”, “not well” “well”, and “very well” proficiency. Confirmed with reading test (note:	Cognitive decline four domains (episodic memory, language, executive function and processing speed); Objective	chi-square used for bivariate analysis 1) Multi-level	Greater level of bilingualism was associated with better performance on baseline executive function and episodic memory scores (adjusted for covariates listed); however, cognition declined at

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risk among Spanish-speaking immigrants	adults after moving to the United States. Longitudinal prospective cohort study design (23-year follow-up).	subjective and objective measures were not significant different). "Not at all" were considered monolinguals. Frequency or AoA were not measured. *Covariates:* gender, education, time in the United States, age at enrollment, country of origin, recruitment wave.	– neuropsychological tests (executive function – verbal and nonverbal abstraction, letter fluency, colour trails test). Incident dementia (conversion to dementia); Objective – diagnosed by specialist, expert consensus.	modelling (growth models) 2) Cox regression	the same rate for monolinguals and bilinguals (i.e., superior cognitive function did not translate to protection over time). Bilingualism was not independently associated with incident dementia after adjustment for covariates. Bilinguals were better educated and younger age at immigration.
Abutalebi et al., 2015; **Bilingualism provides a neural reserve for aging populations**	19 healthy bilinguals from Hong Kong and 19 healthy Italian monolinguals. Groups were matched on age, MMSE score, education and SES. Cross-sectional study design.	Bilingualism (Cantonese-English, Cantonese-Mandarin); Objective – tested in L1 on a BNT (measure of proficiency), translation task. Subjective – self-report questionnaire of language exposure and AoA. *Covariates:* baseline MMSE, SES, age, education (matched).	Cognition (executive function); Flanker test – reaction times on congruent and incongruent trials (measure of attentional control and inhibition). Neuroimaging; brain regions associated with aging GMW.	Ex-Gaussian distribution due to general positive skew of reaction times in attention tasks; t-test, 2-way ANOVA,	Aging bilinguals performed better (faster reaction time) than aging monolinguals on both congruent and incongruent trials; indicates better inhibition and automatic processing in bilinguals. Bilingualism was associated with increased grey matter in the ACC.; overall aging effects on performance was only associated with monolinguals to decreased grey matter in the DLPFC.

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				correlation analysis	
Ansaldo et al., 2015; **Interference control in elderly bilinguals: Appearances can be misleading**	20 Older adults. French monolinguals and late (age 5) English-French bilinguals. Groups were equivalent regarding age and education. Born and raised in Montréal (non-immigrants). Groups were highly educated. Cross-sectional population-based study design.	Bilingualism; Subjective – Questionnaire identify proficiency, percentage of L2 use (was at least 30%). Objective – AoA was obtained. Monolingualism; Subjective – neither exposed to L2 or used it (below 4 on Likert scale). *Covariates:* age, education, (all non-immigrants).	Executive function (interference control); Simon task (reaction time and accuracy on congruent and incongruent trials) during fMRI.	t-test, ANOVA	Bilinguals performed significantly better than monolinguals on the incongruent Stroop trials (a language-based task). Simon (non-language) task performance was similar for both groups. Monolinguals relied on a cognitive control network (PFC) to complete the task, bilinguals relied on visuospatial network and thus lack of PASA; suggests proactive control and efficient recruitment of networks not vulnerable to aging.
de Bruin et al., 2015; **Examining the effects of active versus inactive bilingualism on executive control in a carefully matched**	76 participants from Hebrides, Scotland, non-immigrants – homogenous population with similar SES, education and backgrounds (thus, participants only differed in number of languages).	Bilinguals (Gaelic, English); Subjective – acquired both languages during childhood (5 years AoA). Active bilinguals reported more use in both languages and switched between them more often than inactive users. Proficiency was measured with questionnaire and	Executive function; Simon arrow task (with keypress) with high and low switching from congruent to incongruent conditions; task-switching paradigm,	ANOVA	Reaction times on the Simon task were not statistically different for monolinguals, active bilinguals and inactive bilinguals. Simon costs (difference between congruent and incongruent tasks) were the same across language groups also. Importantly, there was no significant effect of

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non-immigrant sample	60 years and over, 24 monolinguals and 28 active bilinguals and 24 inactive bilingual. Cross-sectional study design.	with BNT (objective); active bilinguals had higher naming accuracy in Gaelic. Monolinguals (English); never spoke an L2. *Covariates:* (matched) all non-immigrants, education, IQ, SES (from occupation and education), lifestyle, gender.	switching and mixing between colour and shape tasks.		language in either the simple or complex Simon conditions. Active bilinguals did show smaller switching costs relative monolinguals in unadjusted analysis; inactive bilinguals did not differ significantly from either group. After adjustment the differences became non-significant.
Friesen et al., 2015; **Proficiency and control in verbal fluency performance across the lifespan for monolinguals and bilinguals**	7-year old children, 10-year old children, young adults, older adults. Each age group was recruited from previous studies' samples. Cross-sectional study design.	Bilingualism (English and L2); Subjective – spoke English and another language fluently on a daily basis. AoA was obtained. Monolingualism (English); spoke only English and have minimal knowledge of L2. Older adults in this sample were matched on vocabulary (measure of proficiency) and screened with MMSE.	Verbal fluency; phonemic/letter and semantic/categorical. (Executive function considered in the slope/performance over the course of the trial).	ANOVA	For older adults there was no effect of bilingualism in the category fluency task. Older bilinguals had better performance than monolinguals in the letter fluency task (flatter slopes). Category fluency was primarily impacted by age and vocabulary knowledge, while letter fluency is influenced by vocabulary knowledge and executive control/bilingualism.

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Kowoll et al., 2015; **Neuropsychological Profiles and Verbal Abilities in Lifelong Bilinguals with Mild Cognitive Impairment and Alzheimer's Disease**	69 MCI or AD (22 MCI, 47 AD) and 17 healthy controls. 41 were lifelong bilinguals and 45 monolinguals. Recruited from a memory clinic or nursing homes. Bilinguals were more likely to be immigrants than monolinguals. Cross-sectional study design; Clinic-based sample.	Bilingualism (14 different L1s, 11 different L2s); Subjective – those who spent the majority of their lives, at least from early adulthood, regularly using at least two languages. Monolinguals; some had knowledge of L2 but did not fit definition. Language dominance; Objective – BNT, language history questionnaire. *Covariates:* education, gender, test language (immigration was not controlled for).	Neuropsychological profile (Global cognition); CERAD-NP, Clock drawing, TMT, Wechsler memory scale 34% of participants completed these tests in their non-dominant language (sub-analysis suggested this had no effect).	Scores on neuropsychological profile were transformed into z-scores ANOVA	There was no significant difference between bilinguals with MCI and AD and monolinguals on neuropsychological test performance. Main effect of diagnostic group was significant. Healthy bilinguals showed better performance on TMT (executive function) compared to monolinguals, but this did not reach significance. Dominant language is compromised early-on in disease progression (seen in MCI) and nondominant deficits occur later (seen in AD).
Lawton et al., 2015; **Age of dementia diagnosis in community dwelling bilingual and monolingual Hispanic Americans**	Participants were from the SALSA. Self-identified as Hispanic Americans (either immigrants or United States-born). 81 bilingual/monolingual dementia cases were used.	Bilingualism; Subjective – Questionnaire; combined "not at all" and "not very often" as monolingual and "very often" and "almost always" as bilingual. *Covariates:* immigrant status, education.	Age of clinically diagnosed AD or Vascular dementia; Objective – diagnosed by a team of neurologists and neuropsychologists.	chi-square for bivariate analysis 2-way ANOVA	The mean age of dementia diagnosis for bilinguals was not significantly different than monolinguals for either native born or immigrant groups. But mean age of diagnosis was *descriptively* higher in monolinguals.

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	Bilinguals were better educated. Prospective cohort study; population-based sample.				
Woumans et al., 2015; **Bilingualism delays clinical manifestation of Alzheimer's disease**	69 monolinguals and 65 bilinguals with probable AD. Recruited from hospital referrals. Homogenous non-immigrant sample, living L1 dominant environment.	Bilingualism (speakers of Dutch-French with high proficiency); Subjective – questions concerning proficiency and frequency of use. Composite score was created based on Likert scale answers; Bilinguals were classified based on proficiency and frequency as "good" and spoke L2 weekly. Monolinguals therefore had some proficiency and use of an L1. *Covariates:* age, baseline MMSE, education, gender, education, occupation (proxy for SES), L1 language type.	Age of diagnosis of probable AD and age of symptom onset; Objective – diagnosis made by neurologist and neuropsychologist.	Linear regression	Bilingualism significantly delayed the onset of symptom manifestation by 4.6 years, independent of occupation, education, baseline MMSE, L2 AoA. Bilingualism significantly delayed the age of AD by 4.8 years, independent of gender, education, baseline MMSE and L1. Addition of L2 AoA only slightly decreased delay to 4.6 years. More demanding occupation was related to earlier symptom manifestation (non-significant).
Antón et al., 2016; **Does bilingualism**	Two studies. 1) 48 elderly lifelong bilinguals (mean =	1) Bilingualism (Basque-Spanish); Subjective – use both languages every day	Executive function (inhibition/monitoring); verbal and	t-test, ANOVA, ANCOVA	1) Performance on both the verbal and numerical versions of the Stroop revealed no

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shape inhibitory control in the elderly?	69.06 years); 24 healthy bilinguals and 24 monolinguals (matched), *non-immigrants* recruited in the same city (culture); bilinguals are highly proficient. Sample is generally low educated, normal MMSE. 2) 70 Basque-Spanish bilinguals (no monolinguals), same characteristics as sample from Study 1. Different education profile. Cross-sectional study design.	and rate themselves as highly proficient in comprehension and production. Objective – reviewed by a native speaker of both languages. Monolingualism (Spanish). 2) Degree of bilingualism; proficiency of bilinguals in L2 Basque on Likert scale, also confirmed by interviewer. AoA 12 years. *Covariates:* (matched in Study 1) SES, ethnicity, intelligence.	numerical versions of the Stroop task (reaction time = monitoring, Stroop effect = inhibition).		significant differences between bilinguals and monolinguals on overall inhibition (Stroop effect) and monitoring skills (reaction times). Results were the same for low educated sub-analysis. 2) Degree of Basque proficiency, with adjustment for IQ, education, showed no significant effect of knowledge or L2 on both versions of the Stroop.
Clare, Whitaker, Craik et al., 2016; **Bilingualism, executive control and age at diagnosis**	86 older Welsh/English bilingual and English monolinguals who meet criteria for AD diagnosis. All participants share a common	Bilingualism (Welsh-English); defined as speaking both Welsh and English for all or most of one's life and being fluent in both (but not any other). Objective tests for proficiency.	AD; Age at diagnosis– Objective diagnosis made by ICD-10 criteria, MMSE score. Executive function task performance;	chi-square, ANOVA and ANCOVA; regression analyses	Bilingualism delayed the onset of AD by 3 years independent of education; however, this was non-significant and bilinguals as a group were older and more cognitively impaired at time of diagnosis.

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
among people with early stage Alzheimer's disease in Wales	culture and social background (i.e., non-immigrants). Sample size of 42 in each language group required based on power analysis. (only 37 bilinguals in AoA of AD and only 24 had full test scores available). Cross-sectional study design; population-based sample.	Monolinguals (English); defined as those who were fluent in English, but no other language. *Covariates:* age, gender, education, SES.	Metal flexibility and speed (D-KEFS, verbal fluency [categorical and letter], TMT), two working memory tests, two set-shifting and switching tests, Inhibition and response conflict tests (Simon, Go-No Go, Stroop).		There was no significant difference between monolinguals and bilinguals on executive function tests that could be attributed to language (after adjustment). Monolinguals performed better on English language tests and vocabulary than bilinguals, bilinguals on inhibition and conflict monitoring. Underpowered (small sample size).
Clare, Whitaker, Martyr et al., 2016; **Executive control in older Welsh monolinguals and bilinguals**	99 healthy older adults (60 years or older) recruited from the socially and culturally homogenous community of North Wales, UK. Wales is a bilingual country, primarily rural. 49 monolinguals and 50 bilinguals.	Bilingualism (Welsh-English); defined as speaking both English and Welsh for most of their life and are fluent in both but not any additional languages. Objective – assessed with Language Questionnaire. Proficiency with BNT. AoA was birth or primary school age degree of bilingualism.	Executive function (four domains); non-linguistic tasks grouped into the four domains of 1) mental generativity/speed. 2) working memory. 3) set-shifting/switching. 4)	chi-square, Mann-Whitney, ANOVA, MANOVA	Bilinguals and monolinguals did not differ significantly in their performance of any executive function tasks. Notably, data trended towards favouring monolingual performance in 10/17 indices. Monolinguals did outperform bilinguals on background language/naming tasks. Degree of bilingualism was non-significant also.

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
	Cross-sectional study design.	Monolingualism (English); spoke only English for most of their life. [49% indicated they had some experience with another language]. *Covariates:* age, gender, SES, education, reading, lifestyle, MMSE.	inhibition/conflict monitoring. *Stroop (due to its linguistic component) was completed in Welsh or English by bilinguals. No significant differences in test performance.		
Cox et al., 2016; **Bilingualism, social cognition and executive functions: A tale of chickens and eggs**	90 Lothian Birth Cohort participants. Male, native English speakers who spent majority of their lives in Scotland. Completed intelligence at age 11 and executive function tests at age 74. Participants were cognitively normal, not depressed, not taking glucocorticoid medications. Most bilinguals used English in their daily	Bilingualism (English-many different L2); Subjective – Questionnaire; asked if they learned another language other than English, how many, AoA, frequency of use, could converse in English. *Covariates:* Early-life intelligence, own social class, paternal social class, AoA (before and after age 11).	Executive function/social abilities tests; Simon task [Simon effect], Tower test (reasoning/planning), Self-ordered pointing task (working memory and monitoring), Faux Pas test (theory of mind), moral dilemmas (social), reversal learning (behavioural flexibility).	Simple and multiple linear regression	Before adjustment, bilinguals showed an advantage on the Simon task ($p = 0.025$) and trended towards significance on Faux Pas ($p = 0.06$) only. Adjustment for childhood intelligence and social class resulted in bilingual Faux Pas advantage becoming non-significant compared to monolinguals; advantage was attenuated by childhood IQ ($p < 0.001$). However, the bilingual advantage on the Simon task remained borderline significant ($p = 0.049$).

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	life and learned L2 after age 11. Prospective cohort study (11–74 years).		Test was performed in participants' native language (English).		AoA did not significantly alter results in a sensitivity analysis.
Ihle et al., 2016; **The relation of the number of languages spoken to performance in different cognitive abilities in old age**	2812 healthy older adults from the LIVES project in Switzerland. Mean age 77.9 years. Final sample in analysis was slightly younger, better educated and healthier. Cross-sectional analysis; Population-based study sample.	Multilingualism; Subjective – indicate the number of different languages spoken (frequency, proficiency and AoA not obtained). *Covariates:* education (low, mid, high), physical demand of occupation, cognitive level of occupation, engagement in leisure activities at age 45 (physical, social and mental categories used), gainful activity in older age.	Cognitive ability; psychometric testing (verbal ability [Vocabulary scale], processing speed [TMT-A], cognitive flexibility [TMT-B]). Scores were not influenced by language of administration.	1) Bivariate analysis 2,4) Regression analysis 3) with interaction term	Bivariate analysis: number of languages was associated with better cognitive performance. Regression analysis: number of languages was associated with better cognition (verbal and processing speed) over and above leisure/physical demand of occupation/gainful activity, but not education/cognitive occupation. Interaction/moderation effects were nonsignificant. Speaking three or more languages showed better cognitive performance (verbal and processing), this was not independent of education.
Padilla et al., 2016; **Bilingualism in older Mexican American**	289 monolinguals and 339 bilinguals (65+ years of age) from the SALSA. Culturally homogenous, all-	Bilingualism (Spanish-English); Subjective – do you speak English "not very often", "often", "almost always"	Cognition; 3MS (global cognitive function – verbal memory/fluency, executive function, visuospatial,	t-test, chi-square, ANOVA; ANCOVA (for longitudina	After adjusting for covariates, bilinguals performed better than monolinguals on baseline 3MS (driven by better executive function, visuospatial, language/paraxis,

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
immigrants is associated with higher scores on cognitive screening	immigrant sample (born in Mexico) with only one language pair Spanish-English. Generally low SES and education. Population-based study; Cross-sectional and longitudinal (6–year follow-up) analyses.	Monolingualism (Spanish); Subjective – do you speak English "not at all". *Covariates:* depression, age, education, gender, household income. (could not account for region in Mexico participants came from).	language/paraxis) and Spanish-English Verbal Learning Test [SEVLT] (verbal memory).	l adjusted for baseline differences in demographics and depression)	but not verbal memory). There was no significant difference in SEVLT performance between groups after adjustment. No differences in rate of longitudinal decline in 3MS before and after adjustment. Frequency of language use and test-language did not influence results.
Anderson et al., 2017; **Neuropsychological assessments of cognitive aging in monolingual and bilingual older adults**	184 participants; those diagnosed with AD or MCI were recruited from a memory clinic, healthy participants were recruited from the community. Cross-sectional study design.	Bilingualism (Heterogenous L2s); Subjective – language-based questionnaires. Proficiency was also obtained. Healthy aging, MCI or AD; Objective – classification by neuropsychologist. *Covariates:* age, education.	Neuropsychological test scores; MMSE and three tests from the D-KEFS (TMT, verbal fluency, colour-word inference test). All testing was completed in English.	t-test, ANCOVA	There was no difference between healthy bilinguals and monolinguals in MMSE, age and education, but monolinguals performed better on Stroop and verbal fluency; suggests that not accounting for verbal tests may bias results for bilinguals in cognitive diagnosis. Performance across cognitive status (Healthy, MCI, AD) was linear for monolinguals and quadratic for bilinguals.
Berroir et al., 2017; **Interference**	10 French-English bilinguals and 10	Bilingualism (French-English); Subjective – Language Experience and	Cognition (executive function); Simon	t-test used for group comparison	Bilinguals did not differ from monolinguals on Simon task performance (in either

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control at the response level Functional brain networks reveal higher efficiency in the bilingual brain	French monolinguals born in Montréal. Non-immigrant. Participants were equivalent in age, years of education and were right-handed. Leisure was similar and participants scored similarly on behavioural neuropsychological assessments. Excluded based on variety of health characteristics. Cross-sectional study design.	Proficiency questionnaire. Objective – Proficiency was assessed using the Bilingual Aphasia Test. Monolinguals stated they were not significantly exposed or used an L2. L2 proficiency, exposure and frequency of use were obtained. *Covariates:* age, education, handedness, cognition, health status, leisure activities.	task – visuospatial interference control (incongruent and congruent trials). Simon effect – difference in reaction time for congruent and incongruent trials. Whole-brain functional connectivity analysis; fMRI.	s/demographic characteristics ANOVA Correlational analysis	condition). The Simon effect was the same. Monolingual and bilinguals showed significantly different brain network activation during Simon task. Bilinguals had greater connectivity in the inferior temporal sulcus (used in visuospatial processing). Monolinguals used regions involved in visual, motor, interference control and executive function. Bilinguals resolve visuospatial tasks/interference more efficiently than monolinguals; fewer regions.
Houtzager et al., 2017; **A bilingual advantage in task switching? Age-related differences between German monolinguals**	50 early bilinguals and 50 monolinguals divided between middle aged (36–56 years) and older adults (65–85 years). Non-immigrant sample. Cross-sectional study design.	Bilingualism (Dutch-Firisian); AoA was before 6 years and used both languages on a daily basis. Monolinguals (German, English). *Covariates:* (matched) SES (occupation and education), rural or urban	Cued task-switching task; switching and mixing costs, reaction times.	ANOVA, Linear mixed effect modelling	Bilinguals had lower switching costs vs. monolinguals; this was more evident in older participants suggesting bilingual older adults were less affected by age-related decline than monolinguals. Bilinguals and monolinguals did not differ in mixing costs. Age-related increase in reaction time were found but

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and Dutch-Frisian bilinguals		dwelling, gender, occupation, music, video games, working memory.			bilingualism did not modulate age-related increase in reaction time. Findings were independent of covariates.
Kousaie et al., 2017; **A behavioural and electrophysiological investigation of the effect of bilingualism on aging and cognitive control**	43 cognitively healthy older adults (21 monolingual English, 22 high proficient early English-French bilinguals) from Montréal, Québec. Small sample sizes for language group comparisons for each task. Cross-sectional study design.	Bilingualism (English-French); Subjective – defined as use on a daily basis; Objective – animacy judgement task for proficiency. Monolinguals had minimal exposure to an L2. *Covariates:* age, education, MoCA (matched).	Behavioural measure of executive function (conflict monitoring, response inhibition and interference suppression); colour Stroop, spatial Simon, Flanker. Each had congruent and incongruent trials. Brain response; ERP (N2 and P3) – measured with EEG.	ANOVA	Bilinguals showed better performance on Stroop task (faster reaction time and greater accuracy), on incongruent trials compared to monolinguals demonstrating larger interference control. Electrophysiological results support superior bilingual performance on this task. No behavioural differences were present on Simon and Flanker, suggesting little convergent validity between tasks; advantages were seen in ERP measures of bilinguals suggesting an executive/cognitive processing advantage.
Liu et al., 2017; **Speaking one more language in early life has**	73 Taiwanese, Mandarin, Japanese multilinguals and 441 Taiwanese, Mandarin bilinguals. Aged 70 and above	Multilingualism (Japanese-Taiwanese-Mandarin); defined as those with the ability to fluently communicate in all three languages.	Dementia; positive MMSE or AD8 and confirmed by neurologist and neuropsychologist (DSM-4 criteria)	Student's t-test Regression analysis	There was no significant difference in dementia prevalence between bilinguals and multilinguals. Multilinguals were older but

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only minor effects on cognitive in Taiwanese with low education level: the Taishan Project	from the Taishan Project. Generally low-proficient. Cross-sectional study design; Population-based.	Bilingualism (Taiwanese-Mandarin); could not speak Japanese and received no Japanese education. Subjective – completed by family or participants. *Covariates:* education. Did not control for factors such as occupation and SES.	General cognitive function; MMSE and/or AD8 score.	Stratification by education (greater than and equal to six vs. less than) was completed.	this was not significantly different. Multilinguals compared to bilinguals had better MMSE scores indicating better global cognition. After stratification by education, this difference in MMSE was only significant between language groups who were low educated. MMSE sub-analysis showed significance for multilinguals on visuospatial and attention, (suggesting executive function advantages).
Mukadam et al., 2017; **The relationship of bilingualism compared to monolingualism to the risk of cognitive decline or dementia: A systematic review and meta-analysis**	13 out of 1154 studies were included, 4 of the 13 in the meta-analysis. Participants of studies included had no pre-existing neurological disorders. Prospective and retrospective studies were included.	Included studies where bilingualism/multilingualism was compared to monolingualism. Studies comparing multilinguals to bilinguals (i.e., no monolinguals group) were not included.	Cognitive outcome was either measured on a cognitive test, as incident dementia or MCI.	Meta-analysis used a random effects model – pooled odds ratio meta-analysis of prospective studies (n = 4),	Results of prospective studies' meta-analysis show that bilingualism has a protective effect on dementia, compared to monolingualism, but that this is non-significant (OR = 0.96, CI = 0.74–1.23). Qualitative analysis: Retrospective studies found that bilinguals were reported to develop symptoms of decline later than monolinguals.

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				retrospective studies were qualitatively assessed.	
Ramakrishnan et al., 2017; **Comparative effects of education and bilingualism on the onset of mild cognitive impairment**	115 patients with mild cognitive impairment recruited from a memory clinic in India. 93 bilinguals (*majority spoke three languages*) and 22 monolinguals. Retrospective cohort study design.	Bilingualism; Subjective – defined as participants with the ability to meet communicative demands in societal/normal functioning, and interaction with others, in two or more languages. Education; 1–10 years (primary and secondary school), 11–15 years (undergraduate) and 15+ (postgraduate). *Covariates:* gender, education, occupation, rural vs. urban dwelling, cardiovascular risk factors.	Age of onset of cognitive complaints/MCI diagnosis; Objective – neuropsychological battery of testing, imaging and clinical evaluation.	Demographic variables analyzed using chi-square and t-test Univariate general linear modeling (adjusted for covariates) – age at onset was compared between monolinguals and bilinguals and across education levels	1) There was no significant association of level of education with age on MCI onset. 2) Bilinguals compared to monolinguals were significantly older at age of onset by 7.4 years. Bilinguals performed significantly better in global cognitive assessment, verbal fluency and visuospatial. As bilinguals were higher educated, a sub-analysis with similarly educated language groups showed age of onset was 7.7 years later in bilinguals. Association was independent of covariates.

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Sörman et al., 2017; **Longitudinal effects of bilingualism on dual-tasking**	24 monolinguals and 24 bilinguals from the Betula study. Mean age is 49.2 and years of education 13.6. Prospective longitudinal study (10-year follow-up); Population-based sample.	Bilingualism (Swedish-English); Subjective – Questionnaire; Likert scale (1–6) for ability to read, write and speak (proficiency). Score of four or more across all abilities. Sequential bilinguals. AoA 9 years. Monolingualism (Swedish); did not speak L2. *Covariates:* (matched with propensity score) age, sex, education, fluid intelligence, time (in decades).	Executive processing (task-switching); Dual-task – free recall (12-word span) with card sorting during encoding; free recall with card sorting during retrieval, free recall with card sorting during both.	t-test, linear mixed models	At baseline bilinguals had lower dual-task costs compared to monolinguals during the free recall with card sorting during encoding (the task that requires the highest demand on executive function) and retrieval but no other tasks. Dual-task costs for bilinguals increased over the 10-year period, showing the baseline differences between language groups are not maintained over time. May be due to retirement age.
Del Maschio et al., 2018; **Neuroplasticity across the lifespan and aging effects in bilinguals and monolinguals**	Healthy bilinguals (22 young and 22 older adults) from Hong Kong. Healthy monolinguals (22 young and 22 older adults) from Milan. Matched on SES, education, age (younger vs. older).	Bilingualism; Objective – BNT and translation task used to verify bilingual status and proficiency. AoA was obtained. *Covariates:* SES, education (matched), total intracranial volume.	Behavioural measure of cognitive efficiency/cognitive reserve; Flanker test (attention control and conflict monitoring). Structural indicator of neural/brain	t-test (for bivariate comparisons between groups bilingual and monolingual groups) Linear regression and linear	Bilingual older adults performed better on the Flanker test than monolingual older adults. This was not seen in young adults. Older adults had less GMV than young adults. Bilinguals, younger and older, had more GMV than their age matched monolinguals in regions associated with executive control.

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	Cross-sectional study design.		reserve; MRI scan for GMV of regions known to subserve executive control (PFC, ACC).	mixed-effects modelling	Greater GMV offered a behavioural benefit on the Flanker test for bilingual older adults (but not young adults), suggesting bilingualism foster cognitive reserve in aging groups despite atrophy.
Lehtonen et al., 2018; **Is bilingualism associated with enhanced executive functioning in adults? A meta-analytic review**	152 cross-sectional studies were synthesized; compared healthy monolingual and bilingual, younger (aged 18–59), older (aged 60 and older). Mean age of studies included was 18.	Bilingualism (studies had to compare monolinguals to bilinguals). *Other moderating factors considered:* matching of groups, country where study was conducted, testing language, immigration, verbal vs. nonverbal tasks, AoA, proficiency, language pairs, tasks used.	Executive function; include studies with inhibitory control, monitoring, shifting, working memory, attention and verbal fluency. (within it considers verbal vs. nonverbal task differences and L1 vs. L2 test administration).	Meta-analysis	A small (less than 1% of explained variance) bilingual advantage was found in inhibition, switching and working memory, and a disadvantage in verbal fluency; however, after adjustment for publication bias, there was no significant advantage in any executive function domain. Only disadvantages for verbal fluency remained. Difference between verbal and nonverbal task performance is due to test language not being a bilingual's L1. None of the moderating variables considered in the analyses were associated with bilingual advantage on any domain (including older age

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					vs. young adults, proficiency, early vs. late AoA, language pair) after adjusting for bias.
Mukadam et al., 2018; **The relationship of bilingualism to cognitive decline: The Australian Longitudinal Study on Ageing**	2087 participants from the Australian Longitudinal Study on Ageing cohort. Aged 65 or more at baseline. Prospective cohort study; population-based sample. Bilinguals were less educated, immigrants. Monolinguals were non-immigrants.	Bilingualism (English and L2); Subjective – those who spoke another language than English at home. Assumed English was L2. Monolingualism (English). *Covariates:* time, baseline MMSE, education (National Adult Reading Test [NART] – formal education), vascular risk factors, alcohol consumption, exercise, depression, social activities, marital status, occupation.	Global cognition; MMSE Executive function (these are primarily language tests); BNT, verbal fluency [categorical and phonemic], describing similarities and differences between items. Tests were provided in English only. No wave 1 data for verbal fluency (Appendix)	t-test, chi-square, mixed models, linear regression	Bilinguals had lower MMSE than monolinguals, however, after adjustment for NART there was no significant difference in MMSE. NART was only significantly protective/associated with MMSE. Cognitive decline over time did not differ between language groups. Bilingual baseline executive function did not differ from monolinguals after NART adjustment. Only NART predicted executive function performance. Overall, results of cognition and executive function are accounted for by quantity and quality of education. Low MMSE and executive function in bilingualism over time was significantly associated with missing data.

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Mungas et al., 2018; **Education, bilingualism and cognitive trajectories: Sacramento Area Latino Aging Study**	1499 Hispanics (60 years and older) from the SALSA study. Subsample of 493 chosen for analysis. Follow-up occurred every 12–15 months. Those born in United States had higher education and were more likely to be bilingual and English monolingual. Sample education was low (mean = 7.5 years), with Mexico having the lowest educated. Prospective cohort study; Hispanic population-based study.	Education; years of formal education and country of education (place of birth). Bilingualism (Spanish-English); Subjective – self-reported fluency, spoke both languages “very often” or “almost always”. Monolingual (English or Spanish); spoke only one “very often” or “almost always” and L2 “not at all” or “not very often” Suggesting monolinguals have exposure to L2. Proficiency was also obtained by self-report. *Covariates:* age, test language, sex, education.	Cognition; 3MS (global cognitive function). Verbal/episodic memory; Spanish and English Verbal Learning Test. *each tested in their preferred language.	Mixed effects longitudina l modelling	Education was associated with baseline cognition and memory but did not influence cognitive decline over time (9 years). Differences regarding place of education were non-significant. Monolingual Spanish speakers had lower baseline cognition, but bilinguals did not differ from monolingual English speakers. Differences were not independent of education level. Results were consistent when proficiency measures were used. Monolingual/bilingual status was not related to cognitive decline/trajectory.
Zheng et al., 2018; **The protective effect of**	129 Alzheimer’s disease patients recruited from a memory clinic.	Bilingualism; Subjective – defined as those who spent the majority of their lives, at least from early-	Age of AD symptom onset; Subjective – Caregiver or	one-way ANOVA and chi-square	Bilinguals had older age at onset and older age at first clinic visit. Bilinguals and Mandarin monolinguals had

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Cantonese/Mandarin bilingualism on the onset of Alzheimer disease	48 Cantonese monolinguals, 20 Mandarin monolinguals, 61 bilinguals. Retrospective cohort study design.	adulthood, speaking two languages fluently. Monolinguals spoke only one language fluently. *Covariates:* sex, constant leisure activity, constant physical activity, education, occupation, relocation in China, cardiovascular health, rural or urban dwelling, baseline MMSE, disease duration.	patient interview question.	were used to determine between group difference in continuous and categorical data respectively Multiple linear regression (bilinguals vs. Cantonese monolinguals; bilinguals vs. Mandarin bilinguals)	higher education and occupation vs. Cantonese monolingual (former is thus better controlled). Bilinguals had delayed AD symptoms by 5.5. years compared to Cantonese monolinguals; delay was 3.9 years compared to Mandarin monolinguals; In both models, leisure also independently associated with onset. Associations were intendent of other covariates.
Hack et al., 2019; **Multilingualism and dementia**	325 participants from the Nun study (a population-based sample) who were	Multilingualism; Subjective – participants reported the number of languages with which they had proficiency (1–5).	Dementia onset; Objective – cognitive and functional assessments by	Bivariate analyses: Pearson chi-square, independen	There was no significant association between dementia and multilingualism overall. Adjusted odds ratios (for age, APOE) showed that speaking

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risk: Longitudinal analysis of the nun study	cognitively healthy at baseline. Prospective cohort study design; population-based sample.	Combined into four categories: 1, 2, 3, 4+. *Covariates:* age, education, occupation, immigration, APOE status, written linguistic ability, time/transition periods.	trained gerontologist. Assessed based on memory impairment +1 other domain. Dementia diagnosis required evidence of decline in activities of daily living capability.	t sample t-test; Discrete-time survival analysis was used to determine hazard probability of dementia	4+ languages (but not 2 or 3) compared to monolinguals was associated with 7-fold decrease in the odds of dementia. The protective effect of 4+ languages was weakened with the addition of idea density (in model with age and APOE). Suggests that idea density is the strongest predictor (rather than multilingualism); however, multilingualism was not associated with idea density.
López-Zunini et al., 2019; **Task-switching and bilingualism in older and younger adults: A behavioural and electrophysiological investigation**	43 young adults (23 monolinguals, 20 bilinguals) and 36 older adults (18 monolinguals, 18 bilinguals) with high proficiency in French-English. Recruited from Ottawa, Ontario. Groups did not differ in age or education level or baseline cognition.	Bilingualism (English-French); Subjective – rated proficiency on a Likert scale. *Covariates:* age, education, baseline cognition.	Behavioural measure of executive function (task-switching); cued number-letter task switching paradigm (single and mixed) Brain response; ERP (N2 and P3b). – measured with EEG.	ANOVA	Bilinguals compared to monolinguals (in both age groups) had smaller switching and mixing costs compared to age-matched peers. Interactions between age and language were not significant. Bilinguals compared to monolinguals had overall large target-locked N2 amplitudes (suggestive over superior conflict monitoring). Older bilinguals also had smaller P3b amplitudes. ERP difference suggest differences in

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	Cross-sectional study design.				processing strategy as bilinguals age.
Marsh et al., 2019; **Executive processes underpin the bilingual advantage on phonemic fluency: Evidence from analyses of switching and clustering**	197 participants from the (aged 35–65 years) Betula longitudinal study. 139 monolinguals and 58 bilinguals. Bilinguals are assumed to have at least the same vocabulary size as monolinguals. Prospective longitudinal study (15 years); population-based sample.	Bilingualism (Swedish-English); Subjective – Questionnaire; Likert scale (1–6) for ability to read, write and speak (proficiency). Score of four or more across all abilities. Monolingualism (Swedish); did not speak L2. *Covariates:* education, age; post hoc MMSE, and visuospatial ability.	Executive function (unsure which specific domains); Phonemic fluency (clustering and switching not number of words).	Correlation, Structural Equation Modeling; Latent Growth Modeling	Bilinguals compared to monolinguals had better clustering and switching at baseline and throughout three further time points. Longitudinal advantage in phonemic performance for bilinguals vs. monolinguals held when education, MMSE score and visuospatial ability were controlled for. Suggests stability in phonemic fluency advantage difference over time.
Nielsen et al., 2019; **Cognitive advantages in adult Turkish bilingual immigrants – a question of the chicken or the egg**	71 healthy middle-aged and older adults, Turkish immigrant population who migrated to Denmark as teenagers. No L2 proficiency before migration.	Bilingualism (Turkish-Danish); Questionnaire and rater assessment 3-point scale for Danish proficiency. Classified into three categories based on degree of bilingualism (Turkish monolinguals, "fairly good to well" bilinguals, "very well" bilinguals).	Cognitive function (five domains); executive function [overall and inhibition/task-switching](Colour Trails Test, Five Digit Test), episodic memory (Recall of Picture tests), language (naming,	chi-square; ANOVA; ANCOVA	Unadjusted analysis: Greater degree of bilingualism was associated with better executive function performance, visuospatial function, and processing speed domains in these Turkish immigrants. Further, "very well" bilinguals outperformed monolinguals. Degree of bilingualism was not associated with memory,

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	Cross-sectional study design.	*Covariates:* years of education, ethnicity, gender, proportion of life lived in Denmark.	repetition, comprehension, semantic fluency/animal fluency), visuospatial function (copying tasks, Clock Reading test), processing speed (Colour Trials test, Five Digit test).		language, task-switching, inhibition. After adjustment for covariates, greater degree of bilingualism (vs. none) was associated with executive function domain and task-switching (14% variance explained). Performance by monolinguals on executive function tests was poor compared to "fairly good to well" bilinguals.
Papageorgiou et al., 2019; **Evidence against a cognitive advantage in the older bilingual population**	74 healthy older monolingual and bilingual participants (matched on covariates). 37 English monolinguals and 31 bilinguals. Cross-sectional study design; Population-based.	Bilingualism; Subjective – highly proficient in both languages and reported the language use in daily life for 50+ years. Monolinguals; native English speakers. AoA was obtained. *Covariates:* (matched on) age, gender, SES (measured by education and occupation).	Cognition; battery of six assessments (assessing executive function and visuo-spatial working memory) – vocabulary, nonverbal reasoning, executive function (Simon), planning/problem solving (Tower of London), working memory.	t-test, ANOVA, linear regression, and Bayesian methods (null/alternative hypothesis)	There were no significant differences between monolinguals and bilinguals on any tasks. The only advantage found was for monolinguals on the Tower of London (monolinguals had faster response times). Early AoA was a predictor of best incongruent Simon performance.
Sörman et al., 2019; **Different**	193 healthy 50–75-year-old participants who learned L2 after	Bilingualism (treated as a continuous variable, two indicators); *Estimated*	Executive functioning (inhibitory control,	Hierarchical multiple regression	Bilingualism (estimated or L2 proficiency) did not significantly predict

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features of bilingualism in relation to executive functioning	age of 6 (late-bilinguals). Only 6% of the sample were pure monolinguals. Approximately 50% of bilinguals were immigrants to Sweden. Cross-sectional study design.	*bilingualism* – participants rated their level of bilingualism on scale 1–10. *Proficiency in L2*; rated ability to speak, read and listen in L2 from 1–10. Language distance; within the same language family (Swedish – English) and different language family (Swedish – Finnish). *Covariates:* age, fluid intelligence (G*f*).	task-switching); six executive tasks: Inhibition – Flanker, Stroop (verbal version), Simon. Switching – number-letter task, Colour-Shape task, Local Global task.	analyses; Bayesian factors	performance on any of the tasks (when G*f* and age are controlled). Analysis regarding language distance (which thus considered culture/background) also showed similar results. Post-hoc analyses of AoA found no association. Bayesian factors support strong evidence for the null hypothesis in most models that include bilingualism as predictors suggesting that bilingualism is not related to performance in any executive function task.
Berkes et al., 2020; **Conversion of mild cognitive impairment to Alzheimer's disease in monolingual and bilingual patients**	158 older adult participants who were monolingual or bilingual. Recruited from a memory clinic. Diagnosed with MCI Retrospective cohort study design; Clinic-based sample.	Bilingualism. *Covariates:* education, cognitive level, immigration status, sex.	Conversion to AD; time to convert, age of MCI diagnosis, age of AD diagnosis.		Bilinguals with diagnosed MCI (in some analyses) later than monolinguals (2.3 years). After adjustment for covariates, bilinguals with MCI converted to AD faster than monolinguals (1 year faster). Results suggest a faster cognitive decline/conversion to

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					AD for bilinguals relative to monolinguals.
Brini et al., 2020; **Bilingualism is associated with a delayed onset of dementia but not a lower risk of developing it: A systematic review and meta-analyses**	21 studies were included in quantitative synthesis. Studies were longitudinal prospective or cross-sectional in design. Meta-analyses.	Studies compared monolingual and bilingual participants. Studies were included even if different measures for bilingualism were used.	Age of symptom onset; age at diagnosis of MCI, AD, or dementia; risk of developing dementia. Disease severity (degree of impairment measured by MMSE).	Meta-analyses (used summary data not individual data)	Bilingualism did not delay diagnosis of MCI. Bilinguals compared to monolinguals experienced AD symptoms 4.7 years later, were diagnosed with dementia 3.3 years later (on average). Bilinguals were older at age of diagnosis. No significant risk reduction in developing dementia was found for bilinguals relative to monolinguals. No significant difference in disease severity but bilinguals were older than monolinguals. Immigration status and education likely not to play a role in findings.
de Leon et al., 2020; **Effects of bilingualism on age at onset in two clinical Alzheimer's**	Clinic-based sample; 286 participants with amnestic Alzheimer's dementia or lvPPA. Participants were excluded if it was unclear if they were monolingual or	Bilinguals: Speakers of two or more languages (subjective based on medical chart - ability to communicate with native speakers; regular use of a second language; heterogeneity of languages).	Age at symptom onset: the age that the participant or family member first observed a clinical symptom indicative of dementia.	t-test; Fisher exact test; ANCOVAs	Overall bilinguals and monolinguals did not differ on demographic variables (i.e., sex, education, handedness, occupation) or neuropsychological tests. Bilinguals were more likely to have positive immigrant status.

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disease variants	bilingual. Objective diagnosis of Alzheimer's disease - established clinical imaging criteria for diagnosis. Retrospective cohort study design.	Groups were monolinguals and bilinguals with both type of Alzheimer's disease (i.e., 4 groups were compared). *Covariates:* clinical variant of Alzheimer's disease, immigrant status; sex, years of education, neuropsychological battery and MMSE (matched).			Significant interaction of clinical variant and bilingual status on age at symptom onset: 5-year delay in age at symptom onset was found for bilinguals (versus monolinguals) with lvPPA but not amnestic Alzheimer's disease. When monolinguals versus bilinguals are compared without separating by clinical variant no differences in age of symptom onset were found.
Desjardins et al., 2020; **What does language have to do with it? The impact of age and bilingual experience on inhibitory control in an auditory dichotic listening task**	61 participants: 4 groups (15 young English monolinguals, 16 young Spanish-English bilinguals; 15 older English monolinguals, 15 older Spanish-English bilinguals). Young aged 18 to 25 years, old aged 47 to 62 years. All participants were right-handed and	Bilingualism (Spanish-English): L1 is Spanish, L2 learned since age of three years. Subjective (Likert scale) - Language Experience and Proficiency Questionnaire. Balanced bilinguals. *Covariates:* education, handedness, MMSE, SES.	Inhibition: Auditory (forced-attention dichotic consonant vowel listening task) and visual (Simon task). *these tasks are not linguistic.	ANOVA	Younger participants performed better than older participants on the Simon and Auditory task. There were no significant differences found between monolinguals and bilinguals on any tasks suggesting no advantage in inhibition of attention. Bilinguals did not demonstrate a global processing advantage compared to monolinguals.

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	had no history of neurological disease (MMSE). Did not differ in working memory or SES. Education was the same across and within groups. Cross-sectional study design.				
Filippi et al., 2020; **Develop-mental trajectories of metacognitive processing and executive function from childhood to older age**	330 normal individuals ages 7 to 80 years old (childhood, young-adulthood, mid-adulthood, older adulthood). 50% were English monolinguals and 50% were bilinguals/multilinguals (many different languages); Cross-sectional study design.	Monolingualism (English but all reported a low-level knowledge of some Indo-European languages). Multilingualism - subjective (all reported speaking at least two languages from birth) *Covariates:* Education, occupation, household income (used to create a SES score). Background measures of vocabulary, working memory, non-verbal reasoning.	Executive function (accuracy and response times): inhibition, monitoring and updating (Simon task); planning and problem solving (Tower of London task). Metacognition was also measured.	T-tests; ANOVAs; correlation analyses	Non-significant differences between monolinguals and bilinguals on age, SES, and background tests were similar. For the Simon task multilinguals did not differ significantly from monolinguals on reaction time and accuracy. This was the case for all age groups. Monolinguals and multilinguals did not differ in accuracy on the Tower of London task. The only significant result favoured monolinguals who were on average 2.6 seconds faster than multilinguals (response time).

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
Ljungberg et al., 2020; **The bilingual effects of linguistic distances on episodic memory and verbal fluency**	Participants from the Betula Prospective Cohort Study. Cognitively healthy older adults (mean age = 57.5 in both groups). Highly educated, more females than males. Prospective study; Analyses suggest cross-sectional approach.	Language distance; Similar (Bilingual Swedish-English) to dissimilar (Bilingual Swedish-Finnish). Subjective proficiency was used to measure L2. Monolingual group *Covariates*: L1 was Swedish for all participants (reduces impact of culture and social factors also). Matched on proficiency in L2, age, gender, years of education.	Executive function: Verbal fluency (categorical and letter versions). Global cognition: MMSE Episodic memory (recognition) was also measured.	Propensity score matching; ANOVA; Bayesian analyses	Verbal letter fluency: significant effect of group. The average score of monolinguals was significantly lower than English-Swedish (similar) but not significantly lower than of the Finnish-Swedish (dissimilar). The two bilingual groups did not differ significantly from each other. Similar speakers performed significantly better than monolinguals on episodic recall tasks. No differences in the categorical fluency task were found. Although non-significant, for all tasks a linear trend was observed that indicated better mean performance for similar bilinguals compared to dissimilar bilinguals and in turn higher than monolinguals.
Massa et al., 2020; **Age related effect on language control and**	64 healthy young and older monolinguals and bilinguals.	Bilingualism (French-Italian); Subjective – Questionnaire asked language skills, frequency (daily or weekly),	Executive function; Domain-general task approach consisting of six	ANOVA	Bilinguals showed an advantage in language-based executive tasks only (verbal fluency [phonemical] and Stroop). Overall advantage

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
executive control in bilingual and monolingual speakers: Behavioural and electrophysiological evidence	Participants had at least 12 years of education Cross-sectional study design.	dominant language (established through proficiency). Monolingualism (French or Italian); minimal exposure to an L2. *Covariates:* (matched on) age, education, MMSE.	tasks to assess inhibition (Stroop, Antisaccade, Stop Signal) and cognitive flexibility (Card Sorting, TMT, verbal fluency). Language control; Picture naming with BNT. Brain response; ERP were measured using EEG (with BNT only).		was not supported as language groups did not differ on non-linguistic tasks. Older adults performed worse on executive function tasks compared to younger adults. BNT performance was not different between language groups. Behavioural and ERP provides evidence of greater cognitive flexibility in older bilinguals.
Morrison et al., 2020; **ERP measures of the effects of age and bilingualism on working memory performance**	116 healthy, cognitively normal participants. (26 young adult monolinguals, 28 young adult bilinguals, 31 older adult monolinguals and 31 older adult bilinguals).	Bilingualism (English-French); Subjective – rated proficiency of L2 on Likert scale. Monolinguals were English speakers with some understanding of common French terms). Other languages other than French and English were excluded. Frequency of use was also recorded.	Behavioural measure of executive function (working memory); Delayed match-to-sample task (reaction time and accuracy). Brain response; ERP were measured using EEG.	n-way ANOVAs	Older adults had similar accuracy to young adults but showed higher reaction time with increased load. Bilingualism was not associated with differences in behavioural performance (reaction time or accuracy). Age did not interact with language. ERP differences were seen for older adults on difficult tasks

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
	Cross-sectional study design.	*Covariates:* age.			(high load) suggesting the use of compensatory mechanisms to maintain similar performance to young adults. Bilinguals had smaller N2 and lager P3b amplitudes suggesting they may have more resources available to complete task.
Nichols et al., 2020; **Bilingualism affords no general cognitive advantages: A population study of executive function in 11,000 people**	11,041 participants (aged 18–87 years) from an online study. Matched sample n = 744; Data was cleaned for tests score regarding technical errors and "performance outliers". Participants were volunteers. Cross-sectional study design.	Bilingualism (two or more languages); Subjective – Questionnaire asking number of languages spoken, which languages spoken. All participants spoke English. In matched analysis bilinguals were from UK, Canada, United States, Australia only. This was done to account for testing language. *Covariates:* age, gender SES, education, handedness, country of origin, languages spoken at home (participants were also matched on these factors in a second analysis).	Executive function (inhibition, working memory, problem-solving, planning, selective attention, reasoning, verbal short-term memory, cognitive flexibility); Battery of 12 executive function tasks from the Cambridge Brain Sciences library completed by participants online Executive function domains/factors; memory, reasoning and verbal ability	t-test; chi-square; regression analysis (matched and unmatched sample). Models picked were based on best fit, removing all covariates except age and its interaction with language in	In unmatched sample different models were used for each test (outcome). Overall, bilinguals showed an advantage over monolinguals in the digit span task (memory-based task) (beta = 0.05, effect size < 0.01). Monolinguals showed a small advantage in four tests and two factors (verbal and reasoning). Age was the only significant predictor. The age*languagegroup was non-significant indicating that there is no protection aging age-related decline. In the matched sample, only age was a significant predictor of test performance. There was no age*languagegroup interaction indicating that

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
			(created from the 12 tests). *note all tests are English only. Not all of these tests directly assess executive function.	the final model	bilingualism did not protect differentially by age.
Rieker et al., 2020; **The effect of bilingualism on cue-based vs. memory-based task switching in older adults**	20 monolingual and 20 bilingual older adults. All participants were cognitively healthy, no presence of neurological or psychological disorders. Cross-sectional study design.	Bilingualism (German-Spanish); balanced bilinguals, exposed to L2 environment for 40+ years. Objective - bilingual language profile questionnaire Monolinguals; speak Spanish only language with no mastery of a foreign language (A1 level). *Covariates*: sex, age, education, MMSE, depression (no significant differences between monolinguals and bilinguals)	Executive function: Task-switching (cue-based and memory-based tasks). Cued-based is similar to dual-language management and requires greater cognitive control.	t-test; ANOVA	Bilingual performance did not vary across cued versus memory-based conditions. Monolinguals showed a significant increase in response latency and decreased accuracy in the cued condition compared to the memory condition (i.e., when shifting was unpredictable and externally triggered). Supports that bilinguals have a flexible adjustment to environmental cues as performance did not change across tasks. Monolinguals require more effort to shift in unpredictable situations. Both language groups performed similarly on working memory tasks.

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
Ware et al., 2020; **Meta-Analysis reveals a bilingual advantage that is dependent on task and age**	170 studies were included. Studies included consisted of healthy adults and children, bilinguals versus monolingual comparisons, executive function task completion. Meta-analysis.	Bilingualism: studies had to compare monolinguals to bilinguals. When studies exampled speakers of three or more languages, relevant information on bilinguals was extracted.	Executive function tasks: Stroop Task, Simon Task, Attentional Network Task, Flanker Task, Trail Making Test, Task-Switching Paradigms, and/or Card Sort Tasks.	Meta-Analysis	The bilingual advantage was found but was dependent on age and executive function task. Bilinguals were significantly faster and more accurate than monolinguals on four out of seven tasks. The bilingual advantage on executive function tasks was greater for older adults 50+ years (versus younger adults). Publication bias effect was only found when using one method to assess this bias but not both methods, thus not universally found.
Weyman et al., 2020; **Extensive experience with multiple languages may not buffer age-related declines in executive function**	163 participants were recruited from *Amazon Mechanical Turk*. Young adults and older adults from 24 countries. 81 monolingual and 83 bilinguals. Majority of older adults were from the United States, young adults were from	Bilingualism (English and at least one of 33 L2); Subjective – Questionnaire asking proficiency on Likert scale for reading, writing, speaking and listening. Monolinguals (English). *Covariates:* geographic location, age.	Executive function; “Task-pure” for inhibition (Stop Signal), memory updating (letter memory task) and attention switching/set-shifting (colour shape task [switch cost]).	ANOVA	Young adults versus older adults had faster reaction time on the inhibition task, recalled more words on the memory task. On the colour shape task, there was no difference performance between the two age groups. For all three executive function tasks, there was no significant difference by language and no interaction (age*language).

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
	countries other than the United States. Almost all had higher education. Majority of bilinguals spoke two languages, with 10 speaking three and four speaking four. Cross-sectional study design.				Results do not support a bilingual advantage.
Berkes et al., 2021; **Poorer clinical outcomes for older adult monolinguals when matched to bilinguals on brain health**	Monolinguals matched to cognitively healthy bilinguals on white matter; 32 participants per group. Propensity score matching was used to match bilinguals to monolinguals. (32 bilinguals, 161 monolinguals; monolinguals reduced to 32 with propensity score matching).	Monolingualism versus bilingualism; matched on white matter integrity (MRI) Objective - Language and social background questionnaire (for bilinguals only) Subjective - testing language, ethnicity, race (determined English monolingual status) *Covariates:* sex, age, education, white matter brain integrity (matched;	Cognitive health: MMSE, cognitive profile score: cognitive normal or MCI/AD (MCI and AD were not differentiated). Re. the cognitive profile score: Cognitive impairment in the matched monolingual sample is based on reference to the unmatched monolingual	Propensity score matching; t-test; ANOVA;	No significant differences between the bilingual and white matter matched monolingual groups on the covariates of interest. Results cannot be explained by these variables. After matching for white matter and covariates, bilinguals had a significantly higher MMSE score than monolinguals (i.e., higher cognitive performance) ($p<0.001$). The matched monolingual sample had significantly poorer clinical

Author/Title	Study population & study design	Exposure & covariates	Outcome	Methods	Results
	Cross-sectional study design.	propensity score matching)	sample using a null distribution		outcomes/advanced clinical decline (e.g., higher scores on the cognitive profile score that reflect MCI/AD) than what was predicted by the null distribution. Therefore, matched monolinguals were more cognitively impaired than would be expected in an average population/by chance.

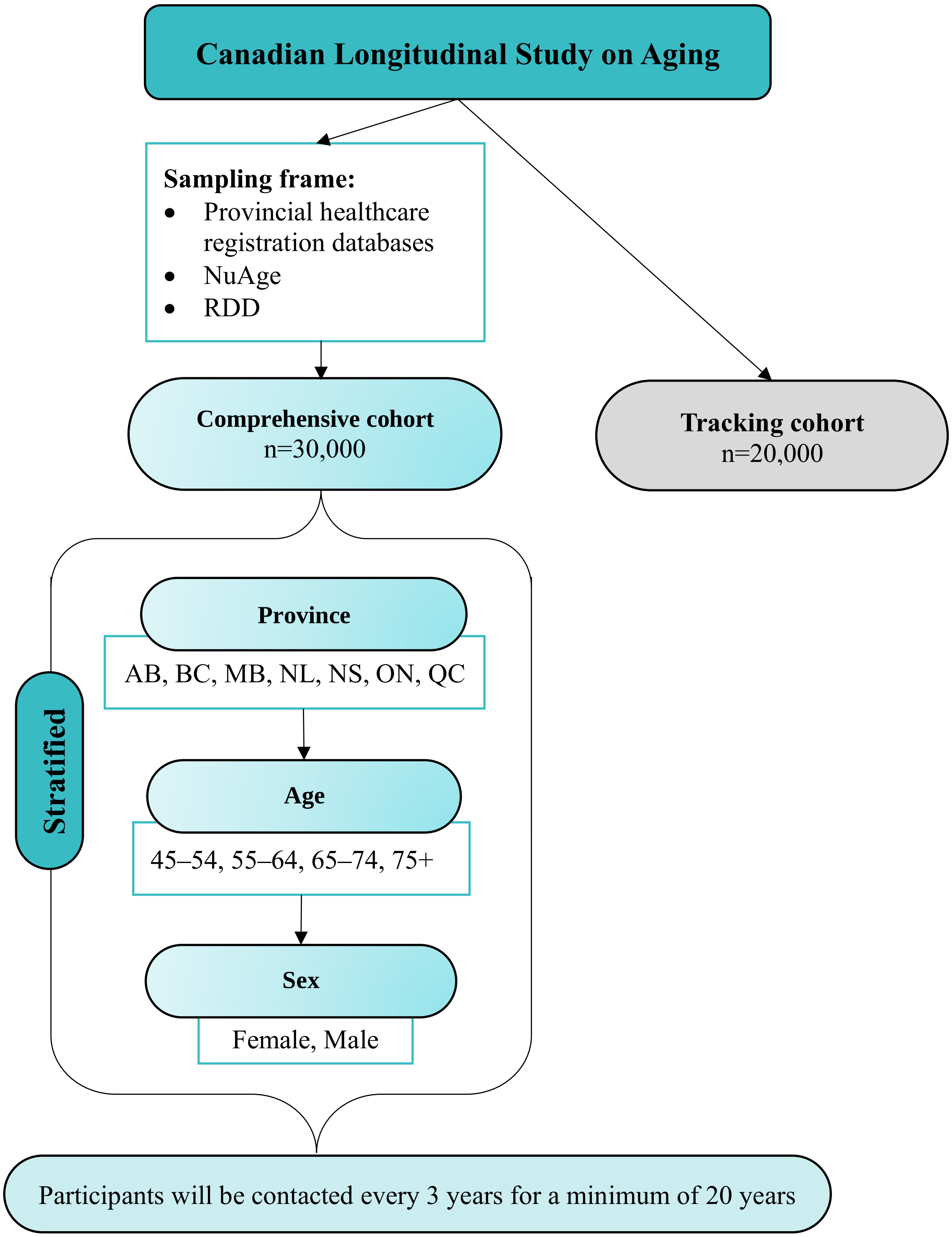
Acronyms used: ACC (anterior cingulate cortex); AD (Alzheimer's disease); AoA (age of acquisition); APOE (Apolipoprotein E); BNT (Boston Naming Test); CERAD-NP (Consortium to Establish a Registry for Alzheimer's Disease neuropsychological assessment battery); CI (confidence interval); CIND (cognitive impairment no dementia); D-KEFS (Delis-Kaplan Executive Function System); DLPFC (dorsolateral prefrontal cortex); DSM (Diagnostic and Statistical Manual of Mental Disorders); EEG (electroencephalogram); ERP (event-related potential); ESL (English as a second language); fMRI (functional magnetic resonance imaging); GMV (grey matter volume); ICD (International Classification of Diseases); lvPPA (logopenic variant primary progressive aphasia) L1 (first language); L2 (second language); MCI (mild cognitive impairment); MMSE (Mini-Mental State Examination); MoCA (Montréal Cognitive Assessment); MRI (magnetic resonance imaging); NART (National Adult Reading Test); OR (odds ratio); PASA (posterior-anterior shift in aging); PFC (prefrontal cortex); SALSA (Sacramento Area Latino Study on Aging); SART (Sustained Attention to Response Task); SELVT (Spanish-English Verbal Learning Test); SES (socioeconomic status); TMT (Trail Making Test); WCST (Wisconsin Card Sorting Test); 3MS (Modified Mini-Mental State)

Appendix D: CLSA Comprehensive Cohort Response Rates and Study Design

Table D-1 *Canadian Longitudinal Study on Aging Comprehensive Cohort Recruitment Response Rates by Province*

	AB	BC	MB	NB	NL	NS	ON	PEI	QU	SK	Canada
Comprehensive cohort											
Overall Response Rate	0.11	0.09	0.10	N/A	0.12	0.09	0.09	N/A	0.10	N/A	0.10

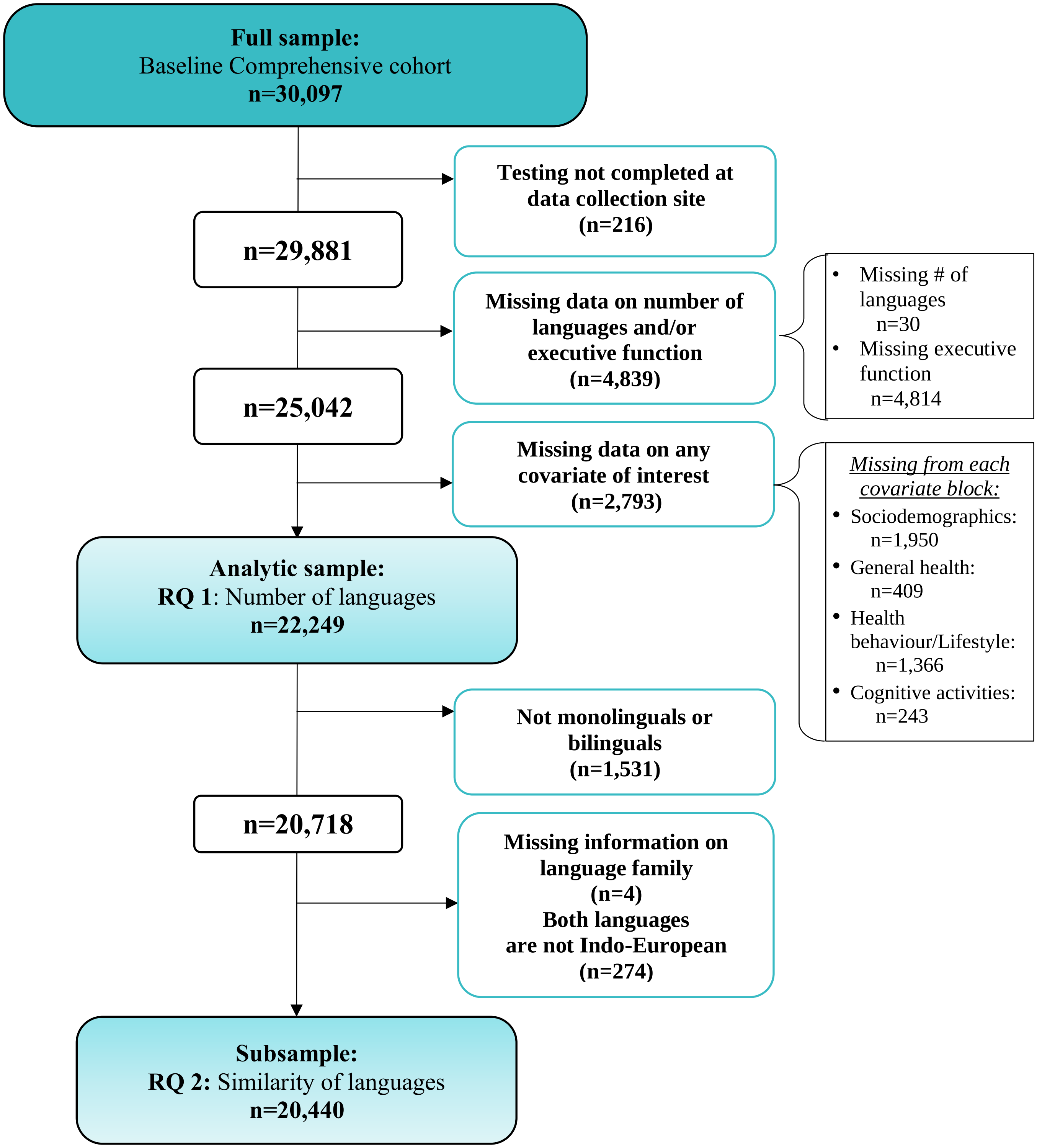
Figure D-1 *Canadian Longitudinal Study on Aging Study Design: Comprehensive Cohort*



NuAge: The Québec Longitudinal Study on Nutrition and Aging
RDD: Random digit dialing

Appendix E: Analytic Sample and Subsample

Figure E-1 *Development of the Analytic Sample and Subsample*



Appendix F: Language Family and Subgroup Classification

Table F-1 *Canadian Longitudinal Study on Aging Languages from the Indo-European Family: Classification by Indo-European Subgroup*

Language family	Language subgroup	Languages in the CLSA
Indo-European	Germanic	English, German, Dutch, Flemish, Yiddish, Danish, Icelandic, Norwegian, Swedish, Afrikaans, NIE[1]
	Indo-Iranian	Hindi, Persian (Farsi), Punjabi, Gujarati, Konkani, Marathi, Sinhala, Urdu, Nepali, Kurdish, Pashto, NIE[1]
	Romance	French, Italian, Portuguese, Spanish, Romanian, Catalan NIE[1]
	Slavic	Polish, Ukrainian, Russian, Bosnian, Bulgarian, Croatian, Czech, Serbian, Serbo-Croatian Slovak, Slovenian, NIE[1]
	Greek	Hellenic
	Celtic	Gaelic languages, Welsh, NIE[1]
	Albanian	Albanian
	Armenian	Armenian
	Baltic	Latvian, Lithuanian

[1]NIE: Not indicated elsewhere (e.g., romance language indicated but not listed elsewhere)

Appendix G: Description of Executive Function Tests

The following appendix provides a summary of the five executive function tests (AFT, COWAT, MAT, Stroop-V, and TPMT) used to derive the measure of low executive function in this study.

The AFT is a test of verbal fluency that requires executive function as well as semantic control (Friesen et al., 2015). It is sensitive to normal cognitive decline and age-related changes (Tierney et al., 2005). To complete the AFT, participants were required to name as many animals as possible in 60 seconds. Animal names provided by participants must have met the CLSA's definition of an animal to be considered an acceptable response. Animal names were coded based on their taxonomy into seven-digit codes (CLSA, 2015). Two coding methods can be used to derive a strict or lenient AFT score. Strict scoring utilizes the first six digits of the classification code, thus only accepting animal names that come from different species (e.g., birds, dogs, fish). Lenient scoring utilizes all seven coding digits, consequently accepting all animal names including subspecies (e.g., bird, parrot, pheasant). With each method, the total animals named is used as the AFT score. This study used the lenient scoring method when calculating participant AFT scores.

The COWAT, like the AFT, is also a measure of verbal fluency, though it requires phonological knowledge (i.e., letter-sound associations) as opposed to semantic control (Marsh et al., 2019). As a letter naming task, the COWAT requires participants to generate as many words that begin with a specific letter in 60 seconds. This test consisted of three individual rounds for the letters F, A and S. From each round, participants were given one point for each unique word. Thus, only one point was given for sister words (i.e., words with the same root word but different suffixes). Scores for each 60 second round of testing were combined to provide an overall score (Strauss et al., 2006).

The MAT is a measure of mental flexibility that is highly sensitive to cognitive change and dementia (McComb et al., 2011). Involving two components, part A required participants to count aloud from 1 to 20 and to recite the alphabet aloud as quickly as possible. This section of the MAT was used to ensure that participants can perform both tasks independently. The second component, part B, required participants to alternate between reciting aloud a number then a letter (i.e., 1A, 2B, 3C) as quickly as possible for a duration of 30 seconds. Part B was not administered if the first component could not be completed. The MAT was scored based on part B only, where the number of correct alternations in the time allotted determined the score. Total scores can range from 0–51.

The Stroop-V is a measure of inhibition, attention and mental flexibility (Scarpina & Tagini, 2017). This version of the Stroop test consists of three off-white cards that correspond to the three test components (Tuokko et al., 2020). For the first section, “Dots”, participants were asked to name the colour of ink in which dots appear on the card. Second, in the “Word” component, participants were required to name the ink colour of the common words on the card. In the last component, “Colour”, participants were instructed to name the colour of the ink in which colour words are written. These colour words were printed in non-corresponding colours of ink creating an interference condition, the “colour-word interference effect”. The Stroop-V test was scored based on time (in seconds) until completion and based on the number of errors made. An interference ratio for the Stroop-V task was calculated by dividing the time required to complete the Colour task by the time required to complete the Dots task (Tuokko et al., 2020). This interference score was known as the Stroop-V score in this thesis. On the Dots task, a score of < 7 seconds or > 30 seconds, and on the Colour task, a score of < 7 seconds or > 137 seconds was removed. These time spans were applied to reflect pre-established standards for feasibility and potential measurement error (Strauss et al., 2006).

The TPMT, although a measure of prospective memory, also places demands on the executive function domain (Simard et al., 2019). For this task, the participants, early in the interview, were shown an envelope containing cards and a clock with hands indicating 8:00. The participant was instructed to interrupt whatever was occurring at 8:15 (i.e., after 15 minutes) and give the interviewer the card labeled with number 17. Performance on the TPMT was scored based on the three components: intention to perform, accuracy of response, and the need for reminders. Each component was scored from zero to three. All three scores were totalled to obtain a final score out of a maximum of nine points (Simard et al., 2019).

Appendix H: Covariates

Figure H-1 *Concept Map of Factors that May Influence the Association Between Multilingualism and Executive Function*

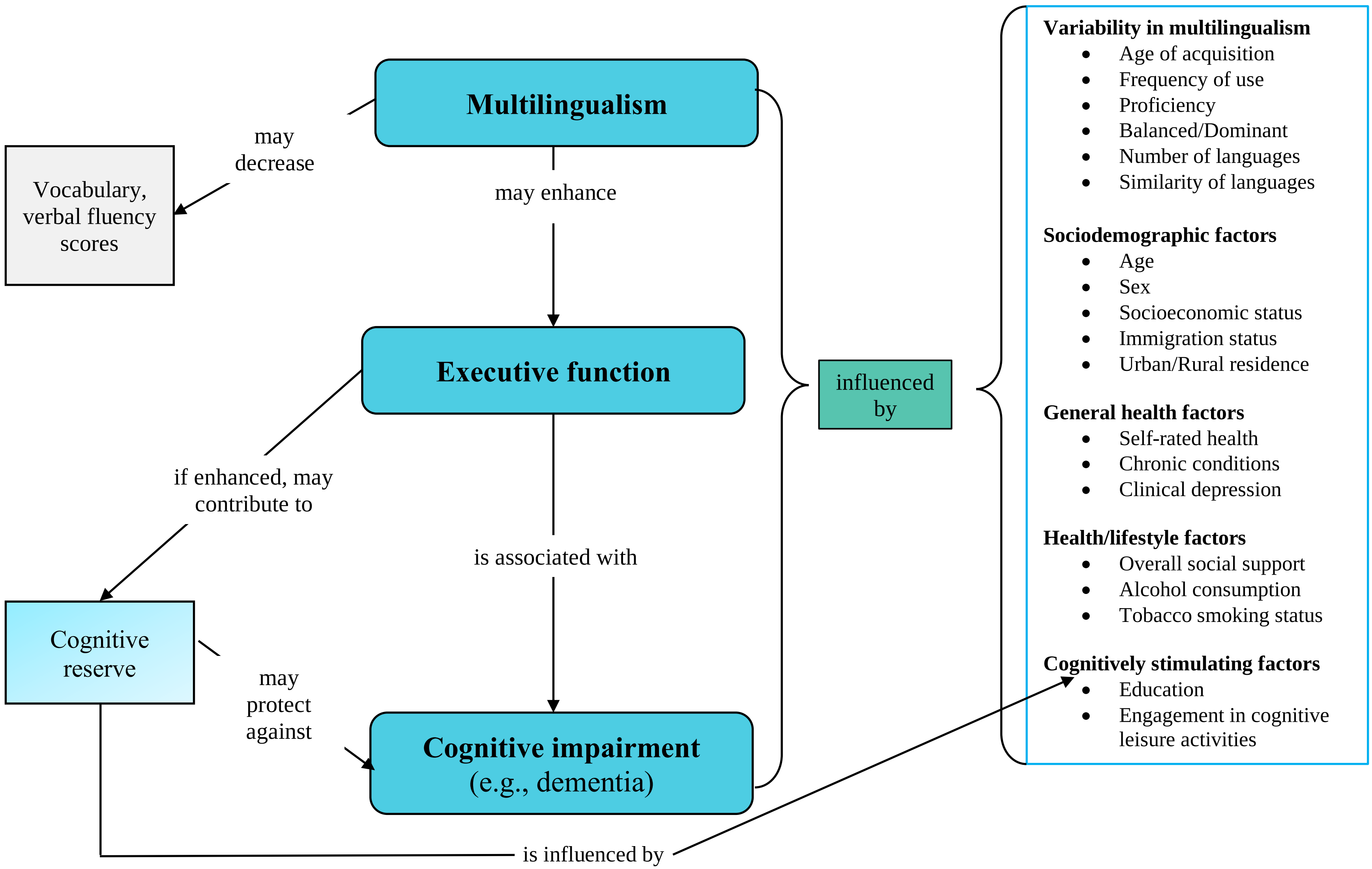


Table H-1 *Description of Covariates*

	Covariates[3]	Categories	CLSA question/How the variable will be derived
Base criteria/ sampling design	Age group	45–54 years 55–64 years 65–74 years 75 years and older	Grouped based on the CLSA sampling strata.
	Sex	Male Female	"What is your Sex?"
	Province	British Columbia Alberta Manitoba Ontario Québec Newfoundland & Labrador Nova Scotia	Recorded at recruitment.
Socio-demographics	Residence	*Rural* (rural) *Urban* (urban core, urban fringe, urban population center outside census metropolitan areas and census agglomerations, secondary core, postal code link to dissemination area.)	Derived from participant's postal code, where urban has a population over 100,000; rural greater than 10,000 but less than 100,000. For the purposes of the CLSA, areas with an urban/rural mix (i.e., 'postal code link to dissemination area') are considered as urban.
	Annual household income	<\$20,000 ≥\$20,000 but <\$50,000 ≥\$50,000 but <\$100,000 ≥\$100,000 but <\$150,000 ≥\$150,000	"What is the estimated total household income received by all household members, from all sources, before taxes and deductions, in the past 12 months?"
	Country of birth	Canada Not Canada	"In what country were your born?"
	Language spoken most often at home: English or French	No Yes	Derived from "What is the language that you speak *most* often at home?" A measure of frequency of English or French use (i.e., assuming that those who answer yes will speak English or

	Covariates[3]	Categories	CLSA question/How the variable will be derived
			French more often than those who do not speak another language at home).
	First language learned: English and/or French	No Yes	Derived from "What is the language that you first learned at home in childhood that you can still understand?" A measure of first language learned (i.e., is the first language learned English and/or French).
General health	Self-rated health	Excellent/Very good Good Fair/Poor	Derived from "In general, would you say your health is excellent, very good, fair or poor?"
	Chronic conditions	None (absence of any conditions) 1+ (presence of any conditions)	Derived from "Has your doctor told you that you have (condition)?" with yes/no response about many chronic conditions. Eleven broad self-reported medical conditions were combined. Conditions: high blood pressure/hypertension; diabetes/borderline diabetes/blood sugar too high; cancer; under-active thyroid/hypothyroidism/myxedema; over-active thyroid/hyperthyroidism/Grave's disease; chronic obstructive pulmonary disease/emphysema/chronic bronchitis; kidney disease/failure; stroke-related conditions (i.e., stroke, transient ischemic attack [TIA]); peripheral vascular disease; asthma; cardiac conditions (i.e., heart disease/congestive heart failure, myocardial infarction/heart attack, angina/chest pain due to heart disease).
	Depressive symptoms	Absence (< 10) Presence (≥ 10)	A CLSA derived variable: Positive screen for depressive symptoms. Modified from the CESD-10[1]. This is an indicator for a positive screen for depressive symptoms. Based on the CESD-10 score cut-off of 10 or more.
Health behaviours/ lifestyle	Overall social support availability	High (> 3) Low (≤ 3)	Modified from the MOS-SSS[2]. Average score of all 19 items in the MOS-SSS which asked how often the type of support was available when needed: 1 (none of the time), 2 (a little of the time), 3 (some of the time), 4 (most of the time), 5 (all of the time).

	Covariates[3]	Categories	CLSA question/How the variable will be derived
	Tobacco smoking status	*Never smoker* (no; not at all) *Former smoker* (yes; not at all) *Current smoker* (yes; daily or occasionally)	Derived from "Have you smoked 100 cigarettes in your life?"; "At the present time, do you smoke cigarettes?"
	Alcohol use	*Never drinker* (no or not in the last year/never) *Occasional drinker* (less than once a month) *Regular drinker* (almost every day, 4–5 times a week, 2–3 times a week, once a week, 2-3 times a month, once a month)	A CLSA derived variable. Derived from "Have you ever drank alcohol?"; "How often during the past 12 months?"
Cognitively stimulating activities	Education	Less than secondary school graduation Secondary school graduation Some post-secondary education Post-secondary degree/diploma	A CLSA derived variable. A four-level variable based on the question, "What is the highest degree, certificate, or diploma you have obtained?"
	Cognitive leisure activities	Every day Several times a week Several times a month Several times a year Once a year or less	"How much time do you spend doing the following activities taking into account both work and leisure time? Playing board games, cards, crossword puzzles, jigsaw puzzles, or sudoku".

[1] Center for Epidemiologic Studies Short Depression Scale
[2] Medical Outcomes Study – Social Support Survey
[3] All covariates are measured at baseline

Appendix I: Data Analysis Plan

Table I-1 *Analytic Plan for Assessing the Association Between Multilingualism and Low Executive Function*

Model[1]	Statistical method	Variables
Test for interaction terms using BWE[2]	Logistic regression	*Exposure variable:* Number of languages *Outcome variable:* Low executive function *Interaction terms:* Number of languages*(Sociodemographics: Age group, sex, province, urban/rural residence, immigration status, annual household income, language spoken most often at home, first language learned; General health: Self-rated health, chronic conditions, depression; Health behaviours/lifestyle: Overall social support availability, tobacco smoking status, alcohol use; Cognitively stimulating activities: Education, cognitive leisure activities) *Covariate chunks:* Sociodemographics: Age group, sex, province, urban/rural residence, immigration status, total annual household income, language spoken most often at home, first language learned; General health: Self-rated health, chronic conditions, depression; Health behaviours/lifestyle: Overall social support availability, tobacco smoking status, alcohol use; Cognitively stimulating activities: Education, cognitive leisure activities
Base model[3]	Logistic regression	*Exposure variable:* Number of languages *Outcome variable:* Low executive function *Covariates:* Age group, sex, province
Model A	Logistic regression	*Exposure variable:* Number of languages *Outcome variable:* Low executive function *Covariate chunks:* Sociodemographics: Age group, sex, province, urban/rural residence, immigration status, total annual household income, language spoken most often at home, first language learned
Model B	Logistic regression	*Exposure variable:* Number of languages *Outcome variable:* Low executive function *Covariate chunks:*

Model[1]	Statistical method	Variables
		Sociodemographics: Age group, sex, province, urban/rural residence, immigration status, total annual household income, language spoken most often at home, first language learned; General health: Self-rated health, chronic conditions, depression
Model C	Logistic regression	*Exposure variable:* Number of languages *Outcome variable:* Low executive function *Covariate chunks:* Sociodemographics: Age group, sex, province, urban/rural residence, immigration status, total annual household income, language spoken most often at home, first language learned; General health: Self-rated health, chronic conditions, depression Health behaviours/lifestyle: Overall social support availability, tobacco smoking status, alcohol use
Model D	Logistic regression	*Exposure variable:* Number of languages *Outcome variable:* Low executive function *Covariate chunks:* Sociodemographics: Age group, sex, province, urban/rural residence, immigration status, total annual household income, language spoken most often at home, first language learned; General health: Self-rated health, chronic conditions, depression; Health behaviours/lifestyle: Overall social support availability, tobacco smoking status, alcohol use; Cognitively stimulating activities: Education, cognitive leisure activities
	Stratified by participation in cognitive leisure activities	
Stratum: *Every day* Model D	Logistic regression	*Exposure variable:* Number of languages *Outcome variable:* Low executive function *Covariate chunks:* Sociodemographics: Age group, sex, province, urban/rural residence, immigration status, total annual household income, language spoken most often at home, first language learned; General health: Self-rated health, chronic conditions, depression; Health behaviours/lifestyle: Overall social support availability, tobacco smoking status, alcohol use;

Model[1]	**Statistical method**	**Variables**
		Cognitively stimulating activities: Education
Stratum: *Several times a week* Model D	Logistic regression	*Exposure variable:* Number of languages *Outcome variable:* Low executive function *Covariate chunks:* Sociodemographics: Age group, sex, province, urban/rural residence, immigration status, total annual household income, language spoken most often at home, first language learned; General health: Self-rated health, chronic conditions, depression; Health behaviours/lifestyle: Overall social support availability, tobacco smoking status, alcohol use; Cognitively stimulating activities: Education
Stratum: *Infrequent* Model D	Logistic regression	*Exposure variable:* Number of languages *Outcome variable:* Low executive function *Covariate chunks:* Sociodemographics: Age group, sex, province, urban/rural residence, immigration status, total annual household income, language spoken most often at home, first language learned; General health: Self-rated health, chronic conditions, depression; Health behaviours/lifestyle: Overall social support availability, tobacco smoking status, alcohol use; Cognitively stimulating activities: Education

[1] Reflects the model used for number of languages as an exposure. Repeated for similarity of languages spoken

[2] Backwards elimination with $\alpha=0.05$ used for testing interaction terms

[3] The base model adjusted for age, sex and province due to the complex study design of the CLSA

Appendix J: Univariate Descriptive Statistics

The following appendix provides the unweighted statistics parallel to the results presented in section 4.0.

Univariate statistics for all three samples (the full sample [n=30,097], number of languages analytical sample [n=22,249], and similarity of languages subsample [n=20,440]) are presented in Tables J1 and J2.

For objective one, the unweighted bivariate results (frequencies and percentages) cross-tabulating the number of languages spoken by executive function are presented in Table J3. Bivariate results describing the association between covariates and executive function are presented in Table J4 (sociodemographics), Table J5 (general health), Table J6 (health behaviours/lifestyle), and Table J7 (cognitively stimulating activities). These results use the number of languages analytical sample and are parallel to the weighted descriptive results presented in sections 4.2.1 to 4.2.2.

For objective two, the unweighted bivariate results (frequencies and percentages) cross-tabulating the similarity of languages spoken by executive function are presented in Table J8. Bivariate results describing the association between covariates and executive function are presented in Table J9 (sociodemographics), Table J10 (general health), Table J11 (health behaviours/lifestyle), and Table J12 (cognitively stimulating activities). These results use the similarity of languages subsample and are parallel to the weighted descriptive results presented in sections 4.3.1 to 4.3.2.

Table J-1 *Exposure and Outcome Univariate Statistics in the Unweighted Full Sample, Number of Languages Analytical Sample and Similarity of Languages Subsample, Canadian Longitudinal Study on Aging*

	Unweighted full sample n=30,097		**Unweighted number of languages analytic sample** n=22,249		**Unweighted similarity of languages subsample** n=20,440	
Characteristic	**n**	**%**	**n**	**%**	**n**	**%**
Number of languages						
1	19,761	65.72	15,065	67.71	15,065	73.70
2	7,993	26.58	5,653	25.41	5,375	26.30
3	1,701	5.66	1,134	5.50	-	-
4	446	1.48	294	1.32	-	-
5+[1]	166	0.55	103	0.46	-	-
Similarity of languages[2]						
Monolingual	19,761	72.38	-	-	15,065	73.70
Dissimilar bilingual	6,600	24.17	-	-	4,689	22.94
Similar bilingual	941	3.45	-	-	686	3.36
Executive function						
Not low	23,200	92.38	20,745	93.24	19,034	93.12
Low[3]	1,915	7.62	1,504	6.76	1,406	6.88

[1] 5 to 11 languages
[2] Monolinguals are speakers of one language; dissimilar bilinguals are bilinguals whose two spoken languages are from different Indo-European family subgroups; similar bilinguals are bilinguals whose two spoken languages are from the same Indo-European language family subgroup
[3] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants

Table J-2 *Covariate Univariate Statistics in the Unweighted Full Sample, Number of Languages Analytical Sample and Similarity of Languages Subsample, Canadian Longitudinal Study on Aging*

	Unweighted full sample n=30,097		**Unweighted number of languages analytic sample** n=22,249		**Unweighted similarity of languages subsample** n=20,440	
Characteristic	**n**	**%**	**n**	**%**	**n**	**%**
Age group						
45-54 years	7,595	25.24	6,041	27.15	5,493	26.87
55-64 years	9,856	33.75	7,545	33.91	6,954	34.02
65-74 years	7,362	24.46	5,278	23.72	4,874	23.85
75+ years	5,284	17.56	3,385	15.21	3,119	15.26
Sex						
Male	14,777	49.10	11,020	49.53	10,097	49.40
Female	15,320	50.90	11,229	50.47	10,343	50.60
Province						
Alberta	2,957	9.82	1,906	8.57	1,749	8.56
British Columbia	6,254	20.78	4,942	22.21	4,431	21.68
Manitoba	3,113	10.34	2,322	10.44	2,194	10.73
Newfoundland	2,214	7.36	1,762	7.92	1,715	8.39
Nova Scotia	3,078	10.34	2,363	10.62	2,257	11.04
Ontario	6,418	21.32	4,820	21.66	4,333	21.20
Québec	6,063	20.14	4,134	18.58	3,761	18.40
Residence						
Urban	27,673	91.95	20,420	91.78	18,725	91.61
Rural	2,424	8.05	1,829	8.22	1,715	8.39
Annual household income						
< $20,000	1,566	5.56	1,118	5.02	1,027	5.02
$20,000 – $49,999	6,360	22.59	4,758	21.39	4,405	21.55
$50,000 – $99,999	9,907	35.19	7,865	35.35	7,245	35.45
$100,000 – $149,999	5,524	19.62	4,524	20.33	4,139	20.25
≥$150,000	4,799	17.04	3,984	17.91	3,624	17.73
Country of birth						
Canada	24,644	81.89	18,458	82.96	17,630	86.25
Not Canada	5,451	18.11	3,791	17.04	2,810	13.75

	Unweighted full sample n=30,097		Unweighted number of languages analytic sample n=22,249		Unweighted similarity of languages subsample n=20,440	
Language spoken most often at home: English or French						
No	733	2.44	393	1.77	118	0.58
Yes	29,334	97.56	21,856	98.23	20,322	99.42
First language learned: English and/or French						
No	2,970	9.87	1,946	8.75	1,052	5.15
Yes	27,127	90.13	20,303	91.25	19,388	94.85
Self-rated health						
Excellent/very good	18,415	61.23	13,845	62.23	12,695	62.11
Good	8,877	29.52	6,503	29.23	5,978	29.25
Fair/poor	2,782	9.25	1,901	8.54	1,767	8.64
Presence of chronic conditions						
None	9,387	31.53	7,273	33.69	6,620	32.39
1+	20,381	68.47	14,976	67.31	13,820	67.61
Depressive symptoms[1]						
Absence	25,203	84.09	18,880	84.86	17,363	84.95
Presence	4,768	15.91	3,369	15.14	3,077	15.05
Tobacco smoking status						
Never	14,265	47.52	10,480	47.10	9,502	46.49
Former	13,186	43.93	9,905	44.52	9,188	44.95
Current	2,567	8.55	1,864	8.38	1,750	8.56
Alcohol use						
None in the past year	3,427	11.67	2,471	11.11	2,243	10.97
Occasional user	3,705	12.61	2,736	12.30	2,495	12.21
Regular user	22,239	75.72	17,042	76.60	15,702	76.82
Overall social support availability[2]						
High	27, 520	93.32	20,887	93.88	19,220	94.03
Low	1,971	6.68	1,362	6.12	1,220	5.97
Education						
Less than high school	1643	5.47	1,107	4.98	1,077	5.27

	Unweighted full sample n=30,097		**Unweighted number of languages analytic sample** n=22,249		**Unweighted similarity of languages subsample** n=20,440	
High school diploma	2839	9.45	2,021	9.08	1,942	9.50
Some post-secondary	2238	7.45	1,658	7.45	1,582	7.74
Post-secondary degree/diploma	23,327	77.64	17,463	78.49	15,839	77.49
Cognitive leisure activities						
Every day	10,624	35.55	7,915	35.57	7,360	36.01
Several times a week	5,503	18.42	4,151	18.66	3,827	18.72
Several times a month	4,068	13.61	3,069	13.79	2,845	13.92
Several times a year	3,255	10.89	2,471	11.11	2,260	11.06
Once a year or less	6,433	21.53	4,643	20.87	4,148	20.29

[1] Center for Epidemiological Studies Short Depression Scale (CES-D 10); a cut-point of ≥10 indicates the presence of depressive symptoms
[2] Modified from the Medical Outcomes Study – Social Support Survey; a score of less than 3 out of 5 indicates low social support availability

Table J-3 *Distribution of Number of Languages Spoken by Executive Function Status in the Unweighted Number of Languages Analytical Sample, Canadian Longitudinal Study on Aging*

Multilingualism	Executive function[1]					
	Low (n=1,504)		*Not low* (n=20,745)		*Total* (n=22,249)	
	n	**%**	**n**	**%**	**n**	**%**
Number of languages						
1	1,116	74.20***	13,949	67.24	15,065	67.71
2	315	20.94	5,338	25.73	5,653	25.41
3	47	3.13	1,087	5.24	1,134	5.10
4	15	1.00	279	1.34	294	1.32
5+[2]	11	0.73	92	0.44	103	0.46

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function
[2] 5 to 11 languages
Pearson chi-square *p<0.05; **p<0.001; ***p<0.0001

Table J-4 *Distribution of Sociodemographic Covariates by Executive Function Status in the Unweighted Number of Languages Analytical Sample, Canadian Longitudinal Study on Aging*

Sociodemographics	Executive function[1]					
	Low (n=1,504)		*Not low* (n=20,745)		*Total* (n=22,249)	
	n	**%**	**n**	**%**	**n**	**%**
Age group						
45-54 years	120	7.98***	5,921	28.54	6,041	27.15
55-64 years	245	16.29	7,300	35.19	7,545	33.91
65-74 years	445	29.59	4,833	23.30	5,278	23.72
75+ years	694	46.14	2,691	12.97	3,385	15.21
Sex						
Male	736	48.94	10,284	49.57	11,020	49.53
Female	768	51.06	10,461	50.43	11,229	50.47
Province						
Alberta	123	8.18***	1,783	8.59	1,906	8.57
British Columbia	251	16.69	4,691	22.61	4,942	22.21
Manitoba	184	12.23	2,138	10.31	2,322	10.44
Newfoundland	164	10.90	1,598	7.70	1,762	7.92
Nova Scotia	195	12.97	2,168	10.45	2,363	10.62
Ontario	299	19.88	4,521	21.79	4,820	21.66
Québec	288	19.15	3,846	18.54	4,134	18.58
Residence						
Urban	1,395	92.75	19,025	91.71	20,420	91.78
Rural	109	7.25	1,720	8.29	1,829	8.22
Annual household income						
< $20,000	210	13.96***	908	4.38	1,118	5.02
$20,000 – $49,999	645	42.89	4,113	19.83	4,758	21.39
$50,000 – $99,999	454	30.19	7,411	35.72	7,865	35.35
$100,000 – $149,999	121	8.05	4,403	21.22	4,524	20.33
≥$150,000	74	4.92	3,910	18.85	3,984	17.91
Country of birth						
Canada	1,212	80.59*	17,246	83.13	18,458	82.96
Not Canada	292	19.41	3,499	16.87	3,791	17.04
Language spoken most often at home: English or French						
No	49	3.26***	344	1.66	393	1.77
Yes	1,455	96.74	20,401	98.34	21,856	98.23
First language learned: English and/or French						
No	202	13.43***	1,744	8.41	1,946	8.75
Yes	1,302	86.57	19,001	91.59	20,303	91.25

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function

Pearson chi-square *p<0.05; **p<0.001; ***p<0.0001

Table J-5 *Distribution of General Health Covariates by Executive Function Status in the Unweighted Number of Languages Analytical Sample, Canadian Longitudinal Study on Aging*

General health	Executive function[1]					
	Low (n=1,504)		*Not low* (n=20,745)		*Total* (n=22,249)	
	n	**%**	**n**	**%**	**n**	**%**
Self-rated health						
Excellent/very good	668	44.41***	13,177	63.52	13,845	62.23
Good	566	37.63	5,937	28.62	6,503	29.23
Fair/poor	270	17.95	1,631	7.86	1,901	8.54
Presence of chronic conditions						
None	237	15.76***	7,036	33.92	7,273	32.69
1+	1,267	84.24	13,709	66.08	14,976	67.31
Depressive symptoms[2]						
Absence	1,134	75.40***	17,746	85.54	18,880	84.86
Presence	370	24.60	2,999	14.46	3,369	15.14

[1]≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function
[2] Center for Epidemiological Studies Short Depression Scale (CES-D 10); a cut-point of ≥10 indicates the presence of depressive symptoms
Pearson chi-square *p<0.05; **p<0.001; ***p<0.0001

Table J-6 *Distribution of Health Behaviours/Lifestyle Covariates by Executive Function Status in the Unweighted Number of Languages Analytical Sample, Canadian Longitudinal Study on Aging*

Health behaviours/lifestyle	Executive function[1]					
	Low (n=1,504)		*Not low* (n=20,745)		*Total* (n=22,249)	
	n	**%**	**n**	**%**	**n**	**%**
Tobacco smoking status						
Never	622	41.36***	9,858	47.52	10,480	47.10
Former	729	48.47	9,176	44.23	9,905	44.52
Current	153	10.17	1,711	8.25	1,864	8.38
Alcohol use						
None in the past year	299	19.88***	2,172	10.47	2,471	11.11
Occasional user	285	18.95	2,451	11.81	2,736	12.30
Regular user	920	61.17	16,122	77.72	17,042	76.60
Overall social support availability[2]						
High	1,336	88.83***	19,551	94.24	20,887	93.88
Low	168	11.17	1,194	5.76	1,362	6.12

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function
[2] Modified from the Medical Outcomes Study – Social Support Survey; a score of less than 3 out of 5 indicates low social support availability
Pearson chi-square *p<0.05; **p<0.001; ***p<0.0001

Table J-7 *Distribution of Cognitively Stimulating Activity Covariates by Executive Function Status in the Unweighted Number of Languages Analytical Sample, Canadian Longitudinal Study on Aging*

Cognitively stimulating activities	Executive function[1]					
	Low (n=1,504)		*Not low* (n=20,745)		*Total* (n=22,249)	
	n	**%**	**n**	**%**	**n**	**%**
Education						
Less than high school	269	17.89***	838	4.04	1,107	4.98
High school diploma	215	14.30	1,806	8.71	2,021	9.08
Some post-secondary	128	8.51	1,530	7.38	1,658	7.45
Post-secondary degree/diploma	892	59.31	16,571	79.88	17,463	78.49
Cognitive leisure activities						
Every day	480	31.91***	7,435	35.84	7,915	35.57
Several times a week	246	16.36	3,905	18.82	4,151	18.66
Several times a month	191	12.70	2,878	13.87	3,069	13.79
Several times a year	126	8.38	2,345	11.30	2,471	11.11
Once a year or less	461	30.65	4,182	20.16	4,643	20.87

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function

Pearson chi-square *p<0.05; **p<0.001; ***p<0.0001

Table J-8 *Distribution of Similarity of Languages Spoken by Executive Function Status in the Unweighted Similarity of Languages Subsample, Canadian Longitudinal Study on Aging*

Multilingualism	Executive function[1]					
	Low (n=1,406)		*Not low* (n=19,034)		*Total* (n=20,440)	
	n	**%**	**n**	**%**	**n**	**%**
Similarity of Languages[2]						
Monolingual	1,116	79.37***	13,949	73.28	15,065	73.70
Dissimilar bilinguals	218	15.50	4,471	23.49	4,689	22.94
Similar bilinguals	72	5.12	614	3.23	686	3.36

Pearson chi-square *p<0.05; **p<0.001; ***p<0.0001

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function

[2] Monolinguals are speakers of one language; dissimilar bilinguals are bilinguals whose two spoken languages are from different Indo-European family subgroups; similar bilinguals are bilinguals whose two spoken languages are from the same Indo-European language family subgroup

Table J-9 *Distribution of Sociodemographic Covariates by Executive Function Status in the Unweighted Similarity of Languages Subsample, Canadian Longitudinal Study on Aging*

Sociodemographics	Executive function[1]					
	Low (n=1,406)		*Not low* (n=19,034)		*Total* (n=20,440)	
	n	**%**	**n**	**%**	**n**	**%**
Age group						
45-54 years	108	7.68***	5,385	28.29	5,493	26.87
55-64 years	230	16.36	6,724	35.33	6,954	34.02
65-74 years	412	29.30	4,462	23.44	4,874	23.85
75+ years	656	46.66	2,463	12.94	3,119	15.26
Sex						
Male	685	48.72	9,412	49.45	10,097	49.40
Female	721	51.28	9,622	50.55	10,343	50.60
Province						
Alberta	114	8.11***	1,635	8.59	1,749	8.56
British Columbia	215	15.29	4,216	22.15	4,431	21.68
Manitoba	179	12.73	2,015	10.59	2,194	10.73
Newfoundland	163	11.59	1,552	8.15	1,715	8.39
Nova Scotia	190	13.51	2,067	10.86	2,257	11.04
Ontario	274	19.49	4,059	21.32	4,333	21.20
Québec	271	19.27	3,490	18.34	3,761	18.40
Residence						
Urban	1,301	92.53	17,424	91.54	18,725	91.61
Rural	105	7.47	1,610	8.46	1,715	8.39
Annual household income						
< $20,000	196	13.94***	831	4.37	1,027	5.02
$20,000 – $49,999	605	43.03	3,800	19.96	4,405	21.55
$50,000 – $99,999	425	30.23	6,820	35.83	7,245	35.45
$100,000 – $149,999	112	7.97	4,027	21.16	4,139	20.25
≥$150,000	68	4.84	3,556	18.68	3,624	17.73
Country of birth						
Canada	1,185	84.28*	16,445	86.40	17,630	86.25
Not Canada	221	15.72	2,589	13.60	2,810	13.75
Language spoken most often at home: English or French						
No	22	1.56***	96	0.50	118	0.58
Yes	1,384	98.44	18,938	99.50	20,322	99.42
First language learned: English and/or French						
No	133	9.46***	919	4.83	1,052	5.15
Yes	1,273	90.54	18,115	95.17	19,388	94.85

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function

Pearson chi-square *p<0.05; **p<0.001; ***p<0.0001

Table J-10 *Distribution of General Health Covariates by Executive Function Status in the Unweighted Similarity of Languages Subsample, Canadian Longitudinal Study on Aging*

General health	Executive function[1]					
	Low (n=1,406)		*Not low* (n=19,034)		*Total* (n=20,440)	
	n	**%**	**n**	**%**	**n**	**%**
Self-rated health						
Excellent/very good	630	44.81***	12,065	63.39	12,695	62.11
Good	523	37.20	5,455	28.66	5,978	29.25
Fair/poor	253	17.99	1,514	7.95	1,767	8.64
Presence of chronic conditions						
None	222	15.79***	6,398	33.61	6,620	32.39
Any	1,184	84.21	12,636	66.39	13,820	67.61
Depressive symptoms[2]						
Absence	1,068	75.96***	16,295	85.61	17,363	84.95
Presence	338	24.04	2,739	14.39	3,077	15.05

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function
[2] Center for Epidemiological Studies Short Depression Scale (CES-D 10); a cut-point of ≥10 indicates the presence of depressive symptoms
Pearson chi-square *p<0.05; **p<0.001; ***p<0.0001

Table J-11 *Distribution of Health Behaviours/Lifestyle Covariates by Executive Function Status in the Unweighted Similarity of Languages Subsample, Canadian Longitudinal Study on Aging*

Health behaviours/lifestyle	Executive function[1]					
	Low (n=1,406)		*Not low* (n=19,034)		*Total* (n=20,440)	
	n	**%**	**n**	**%**	**n**	**%**
Tobacco smoking status						
Never	577	41.04***	8,925	46.89	9,502	46.49
Former	688	48.93	8,500	44.66	9,188	44.95
Current	141	10.03	1,609	8.45	1,750	8.56
Alcohol use						
None in the past year	274	19.49***	1,969	10.34	2,243	10.97
Occasional user	266	18.92	2,229	11.71	2,495	12.21
Regular user	866	61.59	14,836	77.94	15,702	76.82
Overall social support availability[2]						
High	1,255	89.26***	17,965	94.38	19,220	94.03
Low	151	10.74	1,069	5.62	1,220	5.97

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function
[2] Modified from the Medical Outcomes Study – Social Support Survey; a score of less than 3 out of 5 indicates low social support availability
Pearson chi-square *p<0.05; **p<0.001; ***p<0.0001

Table J-12 *Distribution of Cognitively Stimulating Activity Covariates by Executive Function Status in the Unweighted Similarity of Languages Subsample, Canadian Longitudinal Study on Aging*

Cognitively stimulating activities	Executive function[1]					
	Low (n=1,406)		*Not low* (n=19,034)		*Total* (n=20,440)	
Education						
Less than high school	265	18.85***	812	4.27	1,077	5.27
High school diploma	196	13.94	1,746	9.17	1,942	9.50
Some post-secondary	124	8.82	1,458	7.66	1,582	7.74
Post-secondary degree/diploma	821	58.39	15,018	78.90	15,839	77.49
Cognitive leisure activities						
Every day	456	32.43***	6,904	36.27	7,360	36.01
Several times a week	233	16.57	3,594	18.88	3,827	18.72
Several times a month	182	12.94	2,663	13.99	2,845	13.92
Several times a year	119	8.46	2,141	11.25	2,260	11.06
Once a year or less	416	29.59	3,732	19.61	4,148	20.29

[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function

Pearson chi-square *p<0.05; **p<0.001; ***p<0.0001

Appendix K: Model Fit Statistics

Table K-1 *Area Under the Receiver Operating Characteristic Curve Statistics for Objective One: The Association Between Number of Language Spoken and Executive Function*

Model	**AUC (ROC)**[1]
Base Model	0.7587
Model A: *Base Model + Sociodemographics*	0.8034
Model B: *Model A + General health*	0.8138
Model C: *Model B + Health behaviours/lifestyle*	0.8168
Model D: Model C + *Cognitively stimulating activities*	0.8290

Abbreviations: AUC (ROC) = area under the receiver operating characteristic curve
[1]Mann-Whitney U statistic

Table K-2 *Area Under the Receiver Operating Characteristic Curve Statistics for Objective Two: The Association Between Similarity of Language Spoken and Executive Function*

Model	**AUC (ROC)**[1]
Base Model	0.7630
Model A: *Base Model + Sociodemographics*	0.8038
Model B: *Model A + General health*	0.8133
Model C: *Model B + Health behaviours/lifestyle*	0.8162
Model D: Model C + *Cognitively stimulating activities*	0.8284

Abbreviations: AUC (ROC) = area under the receiver operating characteristic curve
[1]Mann-Whitney U statistic

Appendix L: Fully Adjusted Model Stratified by Cognitive Leisure Activities — Supplementary Tables Showing all Covariates

Table L-1 *Weighted Fully Adjusted Logistic Regression Model Assessing the Association Between Number of Languages Spoken and Low Executive Function Stratified by Cognitive Leisure Activities — Showing Exposure and all Covariates*

	Cognitive leisure activities stratum		
	Everyday[1]	*Several times a week*[2]	*Infrequently*[3]
	OR (95% CI)	OR (95% CI)	OR (95% CI)
	Low executive function[4]		
Number of languages (Ref.: Monolingual)			
2	0.76 (0.55-1.05)	1.00 (0.64-1.58)	**0.57 (0.45-0.72)**
3	0.49 (0.24-1.00)	0.52 (0.21-1.26)	**0.38 (0.21-0.70)**
4	0.81 (0.31-2.10)	0.51 (0.06-4.21)	**0.20 (0.09-0.44)**
5+	2.59 (0.75-8.99)	0.66 (0.04-9.85)	0.54 (0.18-1.61)
Age group (Ref.: 45–54 years)			
55–64 years	1.61 (0.91-2.83)	1.05 (0.57-1.94)	**1.61 (1.19-2.17)**
65–74 years	**3.91 (2.24-6.82)**	**5.01 (2.90-8.67)**	**3.55 (2.62-4.80)**
75+ years	**11.20 (6.45-19.47)**	**10.62 (6.07-18.57)**	**9.25 (6.75-12.67)**
Sex (Female vs. Male [Ref.])	1.11 (0.88-1.42)	1.05 (0.74-1.47)	**0.77 (0.63-0.95)**
Province (Ref.: Ontario)			
Alberta	1.27 (0.78-2.06)	1.72 (0.88-3.37)	0.93 (0.59-1.46)
British Columbia	**0.65 (0.45-0.95)**	0.76 (0.44-1.30)	**0.65 (0.49-0.87)**
Manitoba	0.98 (0.67-1.45)	1.07 (0.60-1.92)	1.12 (0.82-1.55)
Québec	0.75 (0.53-1.07)	0.75 (0.42-1.34)	0.87 (0.65-1.16)
Newfoundland	**1.67 (1.11-2.53)**	**2.93 (1.72-4.98)**	1.20 (0.84-1.71)
Nova Scotia	1.35 (0.92-1.96)	1.19 (0.67-2.13)	1.25 (0.89-1.75)
Residence (Rural vs. Urban [Ref.])	1.49 (0.98-2.26)	1.14 (0.58-2.25)	0.98 (0.67-1.44)
Annual household income (Ref.: ≥$150,000)			

	Cognitive leisure activities stratum		
	Everyday[1]	*Several times a week*[2]	*Infrequently*[3]
	OR (95% CI)	OR (95% CI)	OR (95% CI)
	Low executive function[4]		
< $20,000	**4.25 (2.25-8.02)**	**5.27 (2.19-12.67)**	**4.68 (2.90-7.54)**
$20,000 – $49,999	**2.95 (1.66-5.25)**	**3.39 (1.50-7.64)**	**3.73 (2.49-5.57)**
$50,000 – $99,999	**1.85 (1.06-3.24)**	1.87 (0.84-4.18)	**1.90 (1.28-2.82)**
$100,000 – $149,999	1.68 (0.90-3.16)	1.23 (0.50-3.02)	1.08 (0.68-1.71)
Country of birth (Not Canada vs. Canada [Ref.])	0.94 (0.67-1.32)	0.81 (0.50-1.31)	1.04 (0.81-1.34)
Language spoken most often at home: English or French (No vs. Yes [Ref.])	0.60 (0.21-1.74)	1.78 (0.46-6.81)	**2.91 (1.69-5.02)**
First language learned: English and/or French (No vs. Yes [Ref.])	**1.56 (1.01-2.41)**	1.72 (0.74-3.97)	**2.69 (1.86-3.90)**
Self-rated health (Ref.: Excellent/Very good)			
Good	**1.69 (1.33-2.16)**	**1.58 (1.12-2.23)**	1.23 (1.00-1.51)
Fair/Poor	**1.69 (1.22-2.35)**	**2.86 (1.71-4.79)**	**1.78 (1.35-2.34)**
Presence of chronic conditions (1+ vs. None [Ref.])	**1.52 (1.07-2.14)**	0.77 (0.51-1.16)	**1.32 (1.04-1.69)**
Depressive symptoms[5] (Presence vs. Absence [Ref.])	1.32 (0.99-1.77)	1.15 (0.78-1.72)	**1.34 (1.05-1.70)**
Overall social support availability[6] (Low vs. High [Ref.])	1.05 (0.69-1.60)	1.10 (0.64-1.87)	0.97 (0.70-1.34)
Tobacco smoking status (Ref.: Never)			
Former	0.93 (0.73-1.18)	0.82 (0.58-1.16)	1.08 (0.88-1.33)
Current	1.18 (0.77-1.80)	0.93 (0.51-1.71)	**1.39 (1.02-1.91)**
Alcohol use (Ref.: Non-user)			
Occasional user	0.85 (0.59-1.22)	1.37 (0.81-2.31)	**0.71 (0.51-0.98)**
Regular user	**0.58 (0.43-0.78)**	1.01 (0.65-1.55)	**0.63 (0.49-0.81)**
Education (Ref.: Less than high school)			
High school diploma	0.75 (0.50-1.13)	0.85 (0.48-1.51)	**0.57 (0.39-0.84)**
Some post-secondary	**0.43**	**0.45**	**0.49**

	Cognitive leisure activities stratum		
	Everyday[1]	*Several times a week*[2]	*Infrequently*[3]
	OR (95% CI)	OR (95% CI)	OR (95% CI)
		Low executive function[4]	
	(0.27-0.69)	**(0.22-0.88)**	**(0.32-0.73)**
Post-secondary degree/diploma	**0.48** **(0.34-0.66)**	**0.43** **(0.26-0.70)**	**0.43** **(0.32-0.59)**

Abbreviations: OR = odds ratio, CI = confidence interval, Ref. = reference
[1] Unweighted n=7,915
[2] Unweighted n=4,151
[3] Unweighted n=10,183
[4] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants
[5] Center for Epidemiological Studies Short Depression Scale (CES-D 10); a cut-point of ≥10 indicates the presence of depressive symptoms
[6] Modified from the Medical Outcomes Study – Social Support Survey; a score of less than 3 out of 5 indicates low social support availability

Table L-2 *Weighted Fully Adjusted Logistic Regression Model Assessing the Association Between Similarity of Languages Spoken and Low Executive Function Stratified by Cognitive Leisure Activities — Showing Exposure and all Covariates*

	Cognitive leisure activities stratum		
	Everyday[1]	*Several times a week*[2]	*Infrequently*[3]
	OR (95% CI)	OR (95% CI)	OR (95% CI)
		Low executive function[4]	
Similarity of Languages[5] (Ref.: Monolingual)			
Dissimilar bilinguals	0.75 (0.54-1.05)	1.04 (0.66-1.64)	**0.54 (0.41-0.70)**
Similar bilinguals	0.72 (0.35-1.47)	0.91 (0.20-4.06)	**0.49 (0.29-0.83)**
Age group (Ref.: 45–54 years)			
55–64 years	1.46 (0.83-2.59)	1.09 (0.58-2.05)	**1.72 (1.25-2.37)**
65–74 years	**3.57 (2.04-6.24)**	**5.12 (2.93-8.94)**	**3.71 (2.69-5.12)**
75+ years	**10.27 (5.90-17.90)**	**10.79 (6.06-19.23)**	**10.05 (7.20-14.03)**
Sex (Female vs. Male [Ref.])	1.09 (0.85-1.40)	1.02 (0.72-1.46)	**0.77 (0.63-0.95)**
Province (Ref.: Ontario)			
Alberta	1.26 (0.76-2.08)	1.38 (0.67-2.81)	1.04 (0.65-1.66)
British Columbia	**0.62 (0.43-0.92)**	0.69 (0.39-1.21)	**0.63 (0.47-0.85)**
Manitoba	0.99 (0.67-1.47)	0.99 (0.55-1.80)	1.17 (0.84-1.64)
Québec	0.76 (0.53-1.10)	0.72 (0.40-1.29)	0.89 (0.65-1.20)
Newfoundland	**1.66 (1.10-2.52)**	**2.73 (1.60-4.66)**	1.27 (0.88-1.82)
Nova Scotia	1.33 (0.90-1.94)	1.12 (0.62-2.03)	1.30 (0.91-1.84)
Residence (Rural vs. Urban [Ref.])	1.43 (0.93-2.18)	1.25 (0.64-2.44)	1.02 (0.69-1.51)
Annual household income (Ref.: ≥$150,000)			
< $20,000	**4.57 (2.39-8.74)**	**5.40 (2.23-13.07)**	**5.04 (3.04-8.35)**
$20,000 – $49,999	**3.23 (1.80-5.77)**	**3.24 (1.45-7.21)**	**3.89 (2.54-5.95)**
$50,000 – $99,999	**1.98 (1.11-3.50)**	1.77 (0.80-3.94)	**2.03 (1.33-3.09)**
$100,000 – $149,999	1.83	1.10	1.14

	Cognitive leisure activities stratum		
	Everyday[1]	*Several times a week*[2]	*Infrequently*[3]
	OR (95% CI)	OR (95% CI)	OR (95% CI)
	Low executive function[4]		
	(0.96-3.47)	(0.44-2.75)	(0.71-1.85)
Country of birth (Not Canada vs. Canada [Ref.])	0.95 (0.67-1.37)	0.74 (0.44-1.23)	1.04 (0.80-1.35)
Language spoken most often at home: English or French (No vs. Yes [Ref.])	0.61 (0.11-3.35)	0.13 (0.02-1.15)	**4.11 (1.97-8.56)**
First language learned: English and/or French (No vs. Yes [Ref.])	1.65 (0.95-2.89)	1.98 (0.48-8.15)	**2.86 (1.87-4.37)**
Self-rated health (Ref.: Excellent/Very good)			
Good	**1.69 (1.32-2.15)**	**1.59 (1.12-2.27)**	1.22 (0.98-1.52)
Fair/Poor	**1.63 (1.17-2.28)**	**2.95 (1.73-5.03)**	**1.88 (1.41-2.49)**
Presence of chronic conditions (1+ vs. None [Ref.])	**1.54 (1.08-2.18)**	0.73 (0.48-1.10)	1.28 (0.99-1.65)
Depressive symptoms[6] (Presence vs. Absence [Ref.])	1.31 (0.97-1.77)	1.07 (0.71-1.61)	**1.29 (1.01-1.65)**
Overall social support availability[7] (Low vs. High [Ref.])	1.03 (0.66-1.58)	1.08 (0.62-1.89)	1.04 (0.74-1.46)
Tobacco smoking status (Ref.: Never)			
Former	0.94 (0.74-1.20)	0.83 (0.58-1.18)	1.02 (0.82-1.26)
Current	1.20 (0.78-1.85)	0.89 (0.48-1.66)	1.27 (0.92-1.77)
Alcohol use (Ref.: Non-user)			
Occasional user	0.80 (0.55-1.16)	1.45 (0.84-2.51)	0.72 (0.51-1.01)
Regular user	**0.58 (0.43-0.78)**	0.98 (0.62-1.55)	**0.65 (0.50-0.85)**
Education (Ref.: Less than high school)			
High school diploma	0.72 (0.47-1.09)	0.81 (0.45-1.47)	**0.49 (0.33-0.73)**
Some post-secondary	**0.41 (0.26-0.67)**	**0.44 (0.22-0.87)**	**0.48 (0.32-0.73)**
Post-secondary degree/diploma	**0.49 (0.35-0.68)**	**0.44 (0.27-0.72)**	**0.42 (0.30-0.57)**

Abbreviations: OR = odds ratio, CI = confidence interval, Ref. = reference
[1] Unweighted n=7,360
[2] Unweighted n=3,827
[3] Unweighted n=9,253

	Cognitive leisure activities stratum		
	Everyday[1]	*Several times a week*[2]	*Infrequently*[3]
	OR (95% CI)	OR (95% CI)	OR (95% CI)
		Low executive function[4]	

[4] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants
[5] Monolinguals are speakers of one language; dissimilar bilinguals are bilinguals whose two spoken languages are from different Indo-European family subgroups; similar bilinguals are bilinguals whose two spoken languages are from the same Indo-European language family subgroup
[6] Center for Epidemiological Studies Short Depression Scale (CES-D 10); a cut-point of ≥10 indicates the presence of depressive symptoms
[7] Modified from the Medical Outcomes Study – Social Support Survey; a score of less than 3 out of 5 indicates low social support availability

Appendix M: Missing Data Statistics

Table M-1 *Cross-tabulation of Multilingualism (Number of Languages) by Missingness on Executive Function, Canadian Longitudinal Study on Aging*

	Unweighted**		Weighted	
	Executive Function[1]			
	Not missing	Missing	Not missing	Missing
Number of Languages	%	%	%	%
1	67.64	56.37	63.83	49.66
2	25.19	33.31	28.29	38.58
3	5.26	7.71	5.90	8.83
4	1.40	1.83	1.63	2.31
5+	0.51	0.77	0.35	0.62
*p-value**	<0.0001		<0.0001	

Note: percentages reflect the proportion of those with and without missing executive function data
* Pearson chi-square test for unweighted data and Rao-Scott chi-square test for weighted data
** n=29,851, excluding those with missing multilingualism data (n=30) and based on testing not being completed at a data collection site (n=216)
[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function

Table M-2 *Cross-tabulation of Executive Function by Missingness on Multilingualism (Number of Languages), Canadian Longitudinal Study on Aging*

	Unweighted**		Weighted	
	Number of Languages			
	Not missing	Missing	Not missing	Missing
Executive Function[1]	%	%	%	%
Not low	92.38	92.00	93.00	91.13
Low	7.62	8.00	7.00	8.87
*p-value**	0.7155		0.7854	

Note: percentages reflect the proportion of those with and without missing multilingualism data
* Fisher's Exact test for unweighted data and Rao-Scott chi-square test for weighted data
** n= 25,067, excluding those with missing executive function data (n=4,814) and based on testing not being completed at a data collection site (n=216)
[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function

Table M-3 *Cross-tabulation of Executive Function by Missingness on the Covariates of Interest, Canadian Longitudinal Study on Aging*

	Unweighted**		**Weighted**	
	Any covariate of interest			
	Not missing	Missing	Not missing	Missing
Executive Function[1]	%	%	%	%
Not low	93.24	85.58	93.74	86.97
Low	6.76	14.42	6.26	13.03
*p-value**	<0.0001		<0.0001	
	Sociodemographic covariates			
Not low	92.73	86.94	93.30	88.23
Low	7.27	13.06	6.70	11.77
*p-value**	<0.0001		<0.0010	
	General health covariates			
Not low	92.44	87.32	93.05	88.33
Low	7.56	12.68	6.96	11.67
*p-value**	<0.010		0.7854	
	Health behaviours/lifestyle covariates			
Not low	92.82	82.29	93.35	84.11
Low	7.18	17.71	6.65	15.89
*p-value**	<0.0001		<0.0001	
	Cognitively stimulating activity covariates			
Not low	92.47	81.63	93.07	80.95
Low	7.53	18.37	6.93	19.05
*p-value**	<0.0001		<0.0001	

Note: percentages reflect the proportion of those with and without missing data
* Pearson chi-square test for unweighted data and Rao-Scott chi-square test for weighted data
** n=25,067, excluding those with missing executive function data (n=4,814) and based on testing not being completed at a data collection site (n=216)
[1] ≥1.5SD below the mean of a weighted cognitively healthy subsample of participants indicates low executive function

Appendix N: Ethics

As the CLSA was formed and funded under the CIHR's Institute of Aging, it is required to conduct ethical research as defined by the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans – TCPS 2. The CIHR Advisory Committee on Ethical, Legal and Social Issues for the CLSA has been established by CIHR to ensure these regulations are followed and to uphold the "accountability, transparency and integrity" of the CLSA throughout the study's duration (CLSA, n.d.). The CLSA protocol has been reviewed and approved by 13 research ethics boards located across Canada (CLSA, n.d.). Written informed consent was obtained from all participants and participants were advised that they may withdraw from the study at any time. Participant names are removed in all data sets, replaced by numeric codes to maintain participant confidentiality.

This study falls within the broader study of "The association between multilingualism and cognitive function in the Canadian Longitudinal Study on Aging". The research team applied for the CLSA data in February 2020 and received approval of the request in May 2020. The baseline data used in this thesis were available for analyses in November 2020. This broader study received ethics approval by the University of Waterloo's Office of Research Ethics on June 2, 2020 (ORE# 41238). The author is listed as a student investigator on this study. Only those researchers who have signed data access agreements with the CLSA were given data access.