

**Adding Sand to the Hourglass: A Scoping Review Examining the Interplay of Bilingualism  
and Cognitive Reserve in Persons with Dementia**

by

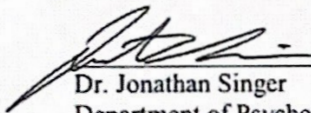
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AN HONORS THESIS

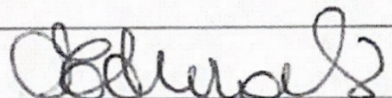
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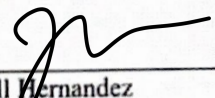
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My favorite page.

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## Abstract

**Background:** Bilingualism has been researched to investigate its role in cognitive reserve and possible delayed onset for individuals with Alzheimer's disease and Alzheimer's disease related dementias, yet mixed results exist.

**Aim:** This study aimed to identify and characterize studies published on bilingualism contributing to cognitive reserve/delayed onset, and sought to identify discrepancies between the mix of methods and results.

**Results:** 29 full-text articles met inclusion criteria. This review revealed a mixture of results regarding the hypothesis supporting bilingualism as a contributor to cognitive reserve in persons with dementia. Methods to investigate this topic revealed to be either evaluate cognitive function through neurological assessments as well as a combination of neurological assessments and brain imaging to evaluate structural differences between monolinguals and bilinguals.

**Conclusions:** 10 articles that were conducted only with neurological assessments presented evidence that does support the hypothesis. All articles that utilized neurocognitive function and brain imaging found evidence that bilingualism positively contributes to brain structure that encourages cognitive reserve. The remaining articles that found contrasting evidence that do not support the hypothesis may be attributed to definitions of "bilingual" within their study, mode of language proficiency investigated, sample size, duration of study, geographical setting, and type of dementia.

**Keywords:** cognitive reserve, Alzheimer's disease and Alzheimer's disease related dementias, bilingualism, neurocognitive assessments, brain imaging

## **Introduction**

Dementia, an umbrella term for multiple neurocognitive disorders (e.g., Alzheimer's Disease; Vascular Dementia) characterized by the inability to remember, think, and make decisions, currently affects approximately 57.4 million people worldwide (Nichols et al., 2019), and is most common in the elderly populations. Mild cognitive impairment immediately precedes formal diagnosis of dementia, and is thus a stage of interest in research regarding Alzheimer's disease and Alzheimer's disease related dementias (AD/ADRD). The global prevalence of dementia is projected to increase to about 152.8 million individuals by 2050 (Nichols et al., 2019). However, research has shown there are several protective factors against AD/ADRD, including cognitive leisure activities (e.g., reading; producing art; playing a musical instrument), educational attainment, diet, and bilingualism (Song et al., 2022, Zhang et al., 2021). The current paper specifically investigates bilingualism as a protective factor in persons with AD/ADRD and the underlying mechanism of this protective factor (i.e., cognitive reserve). The existing literature that examines bilingualism as a protective factor against AD/ADRD are widely contradictory in their findings, possibly due to inconsistent methodologies or geographic limitations. The current study aims to analyze the existing literature on bilingualism as a protective factor against AD/ADRD.

### **Cognitive Reserve**

Cognitive reserve was first noted as the relationship between brain pathology or brain damage and the clinical manifestation of that damage. Stern (2002) details the theory of cognitive reserve, explaining that no unanimous definition of cognitive reserve exists; rather, multiple models of the phrase are used to lay out the scope of the theory. These models include

passive and active models. Passive models define reserve as the amount of damage that can be sustained before reaching a threshold for clinical expression, whereas active models define reserve by the differences in how a task is processed. However, these two models may function together as well as affect each other. Though cognitive reserve may be hypothesized in the context of both brain damage and AD/ADRD, the current study focuses on the context of AD/ADRD.

The concept of brain reserve refers to the ability of the brain to function despite the presentation of AD-related pathologies, such as lesions. The brain reserve hypothesis claims that the greater the reserve, the more severe pathological changes are needed to cause functional impairment (Fratiglioni & Wang, 2007). For example, a healthy older adult and an older adult with AD have an equal ability to solve a math problem. Though the adult with AD has physical differences compared to the healthy adult (i.e., lesions in the brain), they are still able to function at a comparable level. The adult with AD displays brain reserve as the lesions would need to present more severely in order for them to show clinical functional impairment (e.g., forgetfulness, confusion, disorientation). There are two competing definitions related to brain reserve: neurological brain reserve versus behavioral brain reserve (Valenzuela & Sachdev, 2006). Neurological brain reserve may be examined by physical characteristics of the brain, such as intracranial volume (ICV). On the other hand, behavioral brain reserve entails more observation of cognitive function, such as problem solving (Valenzuela, 2008). As both measures may indicate presence of protection against AD/ADRD, both methods were considered in the current scoping review.

## **Bilingualism**

Researchers have struggled to define “bilingual,” and still today it lacks a unanimous definition (Dewaele, 2015). Early definitions were too restrictive, containing monolingual bias. For example, Dewaele (2015) outlines one definition to qualify as bilingual, which was for an individual to have “native-like control of two languages.” This definition is problematic because determination of “native-like” proficiency in a second language (L2) is impossible to operationalize. This definition only focuses on proficiency level and ignores nonlinguistic dimensions, thus exhibiting monolingual bias, as it does not evaluate bilingualism on a multidimensional continuum (Maftoon & Shakibafar, 2011, Dewaele, 2015). Development of research in the domain allowed for widening of the definition. In many of the studies reviewed in the current paper, the researchers used the definition: Patients that had spent the majority of their lives, at least from early adulthood, regularly using at least two languages, as referenced in Bialystok et al. (2007). An additional attempt at defining the word “bilingual” within the studies reviewed in this paper include numerical categorization based on responses from an interview or questionnaire, referred to as the bilingual index (BI). For example, after completing a questionnaire rating one’s second language proficiency, their answers were categorized by number and calculated to be between integers 0 and 1, with 0 representing monolingual and 1 representing bilingual (Perani et al., 2017). Lack of a unanimous definition of “bilingual” is problematic because the findings of each study may not be comparable as the participants in each respective study may have a completely different language usage as another, although both are labeled “bilingual.” This notion can be likened to the term “multilingual” (Cenoz, 2013). In addition, bilingualism has layers that must be understood and taken into consideration when interpreting the results.



One nuance to consider is the age of second language acquisition (SLA). Early SLA has been studied overtime and been shown to differ between later SLA, such as higher performance in the foreign language. The naturalistic method of SLA in early childhood is one factor that contributes to this higher performance, given that it follows the same development as a first language (L1) (Singleton, 2001). That is not to say that individuals that acquire their second language later is automatically unable to reach native-like proficiency. Singleton also details a research study done by Birdsong (1992) which found that 75% of participants who learned French in adulthood fell within the range of native speaker performance. However, as detailed in Table 1, several studies included in this review were not able to obtain the age of acquisition during the patient screening phase, which further limits our understanding of the role of SLA.

Additionally, the phrases “bilingual” and “multilingual” are often used interchangeably. It is not clear whether number of languages has a direct correlation with amount of cognitive reserve, especially since studies have narrowed their inclusion criteria to knowing two languages only, grouped 4+ languages together, and do not control for what languages were investigated. Further, geographical factors, social factors, and medium (e.g., writing, typing) must also be considered when investigating multilingualism (Cenoz, 2013). Lack of specificity in vocabulary and lack of control in number of languages known further hinder the ability to fully grasp an understanding of the advantage of multiple foreign languages known.

## **Methods**

This scoping review aimed to identify and characterize the studies published on the effect of bilingualism on persons with AD/ABRD.

### **Search strategy and data sources**

We followed procedures according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR). Studies were selected through a literature search consisting of six health-related electronic databases. The timeline encompasses existing literature between 2007 and 2022. The six databases include: PubMed, MEDLINE, CINAHL, Linguistics and Language Behavior Abstracts (LLBA), Education Resources Information Center (ERIC), and Abstracts in Social Gerontology. Keywords of each subtopic were entered linked with the Boolean AND operator (see Appendix A for the keywords). Of these six databases, various combinations of each keyword yielded 1,538 peer-reviewed articles, which were then filtered using inclusion and exclusion criteria. After screening of the articles, 31 articles were selected and included in this study. During the data extraction phase, two articles from the remaining 31 were found to not be experimental-based studies and were thus removed, leaving 29 final studies left for review. Results were entered as Research Information System files (i.e., standardized tag format) in Covidence, a web-based systematic review platform (Ryan et al., 2021).

### **Selection Strategy**

Inclusion criteria included experimental-based studies using patients with clinically diagnosed Alzheimer's Disease, probable AD, mild cognitive impairment (MCI), senile dementia of Alzheimer's type (SDAT), dementia with Lewy bodies (DLB), frontotemporal dementia (FTD) and/or subtypes, mixed dementia, amnesic AD, logopenic variant primary progressive aphasia (lvPPA), and/or cognitively normal (CN) older adults. Studies with CN adults were included as they were also investigating the question of whether language might be associated with protection from cognitive decline. This information is helpful in interpreting data of how much protection bilingualism may serve, by comparing CN adults with adults with

dementia. Additionally, each study was examined by how they categorized their participants based on language status. Studies that investigated monolinguals, bilinguals, and multilinguals were included.

Exclusion criteria consisted of scoping reviews, systematic reviews, literature extracted from a chapter of a book, literature contributing to a discussion forum, articles written in foreign languages, and short excerpts published in magazines. Experimental-based studies that were not directly investigating the relationship between knowledge of language(s) and its effect on cognitive reserve or brain atrophy and delay of onset of symptoms, such as focusing on education history, reliability of established tests, aphasia only, and studies on children were excluded.

### **Screening Process**

After duplicates were removed, the initial screening process examined each title and abstracts. Two reviewers independently screened each title and abstract for eligibility. Where discrepancies lied, a third reviewer made the final decision. Those deemed unrelated were excluded, yielding 1,418 titles. The remaining 120 titles were then examined by their full texts. The inclusion and exclusion criteria listed above were applied during the full text review stage. Those that did not meet our criteria were excluded, leaving 31 titles to be examined in this study. During the data extraction phase, two articles were found that did not fit into the criteria and were therefore removed, yielding the 29 titles collected and presented in this study.

### **Data Synthesis and Analysis**

To extract the data from each study, titles were entered into an Excel spreadsheet. For each title the journal name, year of publication, author(s), whether the study was qualitative, quantitative, or a mix of methods, cross-sectional or longitudinal, retrospective or prospective,

listed the purpose of study, the total number (N) of participants in the study, mean ages and standard deviations, mean ages at time of diagnosis, mean ages of presentation of symptoms, gender, race/ethnicity, languages discussed, neurocognitive/dementia measure, how they defined someone being bilingual, how they obtained language level, type of dementia studied, other measures used, quantitative description of results, and implications/conclusions. They were then categorized by their findings: investigation of neurocognitive assessments only, and both neurocognitive assessments and brain imaging.

### **Results**

A total of 2,527 records were reviewed. 989 studies were identified as duplicates and therefore excluded, yielding 1,538 records left for Title and Abstract Screening. After completion of the screening processes, 31 articles were left for data extraction. Upon further full-text review during data extraction, two articles were non-experimental based, and thus were excluded for a total of 29 articles (see Figure 1). All studies were quantitative (n=29; 100%). 18 articles (62%) were cross-sectional, whereas 3 articles (10%) were longitudinal. 8 articles (28%) used were categorized as both cross-sectional and longitudinal. Finally, 18 articles (62%) were prospective, 10 articles (34%) were retrospective, and 1 (4%) was categorized as using both methods.

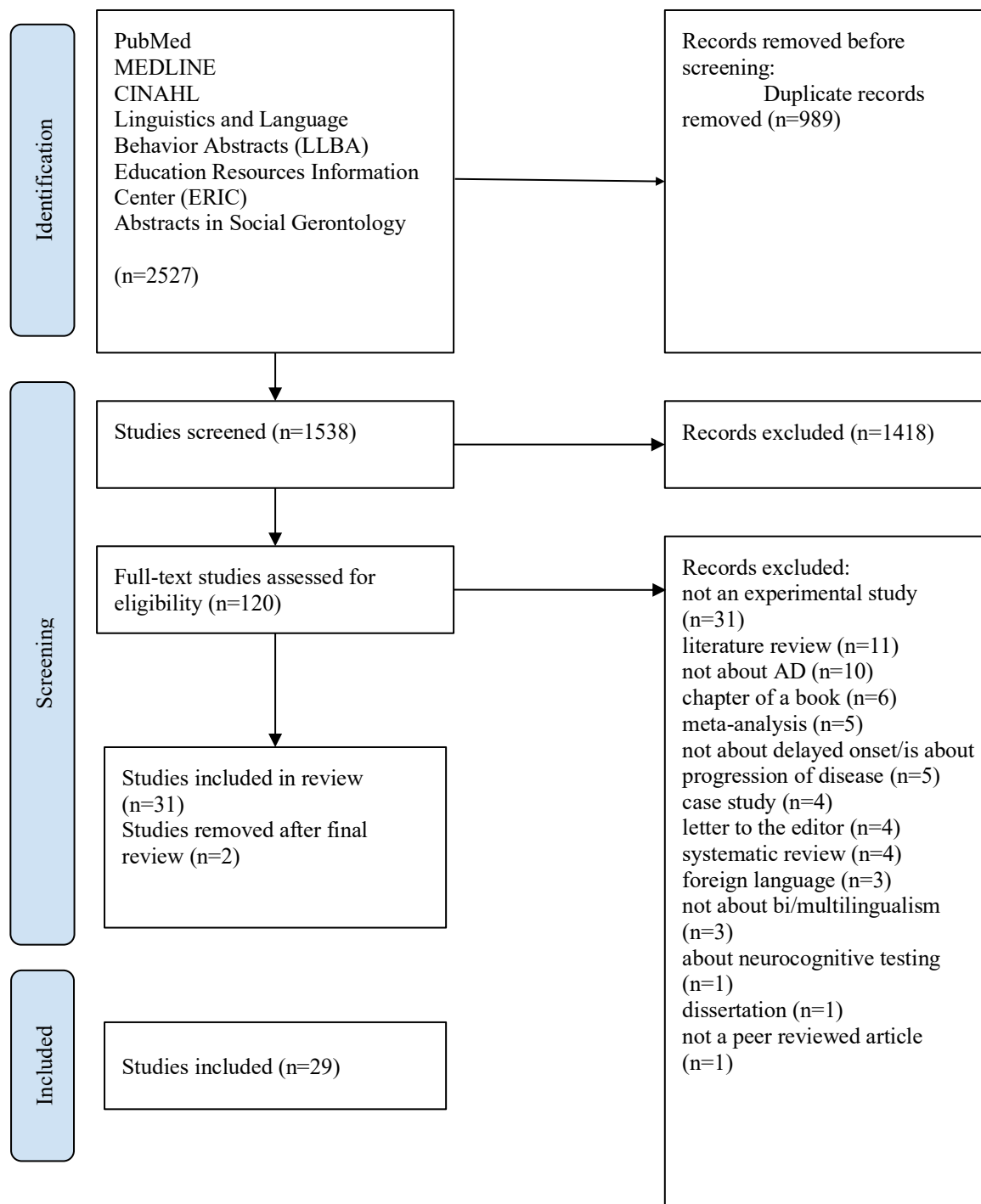


Figure 1. PRISMA-ScR flow diagram.

The current study focused on the effect of bilingualism on AD/ADRD. Consequently, there were various types of dementias examined across all studies. 11 studies (38%) examined

only “Alzheimer’s dementia” (as labeled as explicitly Alzheimer’s disease or probable AD), 3 studies (10%) examined only Mild Cognitive Impairment (MCI; may or may not have been further split into groups of amnesic MCI or non-amnesic MCI), and 4 studies (14%) included both dementias in their samples. Additionally, few studies (n=5; 17%) explored related dementias, including DLB, FTD and subtypes, VaD, mixed dementia, and lvPPA (detailed in Table 1). Only 3 articles (7%) included “healthy older individuals” in their studies. Two articles, Crane et al. (2010) and Estanga et al. (2017), only included healthy participants, and used their results to deduce conclusions about how they might apply to persons with dementia. Crane et al. (2010) used individuals aged 71-93 years at baseline age, and Yeung et al. (2014) used individuals older than 65 years old, and Estanga et al. (2017) used individuals aged 40-60 years old. Only one article (Yeung et al., 2014) categorized their participants as Intact, Cognitive Impairment with No Dementia (CIND), and dementia. Finally, 2 articles (7%) did not specify type of dementia.

A wide range of language groups were explored across all studies. The most common language found was English, as either a first language (L1) or a second/additional language (L2, L3). In no particular order, additional language groups (by geography) included European (Spanish, French, Belgian, Dutch, German, Welsh, Yiddish, Catalan, Italian, Hungarian), Asian (Mandarin Chinese, Cantonese, Japanese, Korean, Tagalog, Indian [Telugu, Dakkhini, Hindi], and Middle Eastern (Arabic, Hebrew, Farsi [Persian]). One article investigated the language of Euskera, which is native to Basque Country, located in the western Pyrenees, between the borders of Spain and France. For 8 articles, either the native languages, additional languages, and exhaustive list were not specified.

To evaluate the effect of bilingualism on the onset of AD/ADRD, two strategies were used across the collection of studies. 20 studies highlighted differences between monolingualism and bilingualism by comparing neurocognitive assessment scores. This technique targeted the relationship between language and cognitive function. Additionally, one study included in this category specifically collected data related to an AD biomarker (i.e., cerebrospinal fluid [CSF]). On the other hand, 9 articles sought to investigate the differences between monolingualism and bilingualism by using a combination of neurocognitive assessment scores and brain imaging. The brain imaging technique allowed the researchers to evaluate the physical differences of the brain, and compare their scores on neurocognitive measures.

18 of the 29 studies were categorized as prospective studies, 10 studies were categorized as retrospective, and 1 was categorized as utilizing both methods. The term “retrospective” refers to the studies being secondary data analysis (i.e., analyzing existing data from previous research, that is unrelated to the current study) (Boslaugh, 2007). Information such as demographic, linguistic ability, and dementia diagnosis age and symptoms were collected in this retrospective manner.

### **Neurocognitive Assessments Only**

There were 20 out of 29 articles that sought to determine the relationship between AD and bilingualism through using various combinations of paper-based neurocognitive measures. These assessments are as followed: Mini-Mental State Examination [MMSE] (n=16), Trail Making Test (n=7), Boston Naming Test (n=6), versions of the Wechsler Memory Scale (WMS) (n=5), clock-drawing test (n=5), the Wechsler Adult Intelligence Scale (WAIS) (n=3), Verbal Fluency (n=3), Addenbrooke’s Cognitive Examination-revised (ACE-r) (n=3), Color Trails Test (n=2), Color-Word Interference Test (n=2). The remaining examinations were only utilized by

one article, in combination with any of the previously listed. These examinations include: Weschler Abbreviated Scale of Intelligence (WASI), Montreal Cognitive Assessment (MoCA), and Victoria Stroop Task (VST). It is also important to note that some tests were translated into different languages, fit for their respective regions, and each patient took the test in their language preference.

10 of the 20 articles in this subsection found evidence that does support the hypothesis of bilingualism as a protective factor for cognitive reserve. 6 articles did not find evidence that supported this hypothesis. There were 3 articles that had mixed findings; evidence that supports the hypothesis for one case, but a lack of evidence for another. For example, Chertkow et al. (2010) concluded that significant protective effects were only apparent in individuals who spoke more than two languages (i.e., multilinguals), but bilinguals (only two languages) did not get that same significant protective effect. Finally, 1 article investigated the relationship between bilingualism and its influence on cerebrospinal fluid (specifically the AD biomarkers), which can be an indication of AD.

### **Neurocognitive Assessments and Brain Imaging**

There were 9 of 29 articles that sought the relationship between AD and bilingualism by administering both neurocognitive assessments and utilizing brain imaging. In these studies, the most common brain imaging procedures were magnetic resonance imaging (MRI) (n=5), [F]luorodeoxyglucose positron emission tomography (FDG-PET) (n=3), and computed tomography (CT) scans (n=2). Though there were multiple articles that included scans in their procedure, they were not all testing the same outcomes. For example, many studies (Schweizer et al., 2012, Costumero et al., 2020, Marin-Marín et al., 2020) examined brain atrophy, whereas others (Duncan et al., 2018, Raji et al., 2020, Torres et al., 2021) focused on structural



differences and brain volume. Additionally, some (Perani et al., 2017, Sala et al., 2022) focused on metabolic connectivity, such as glucose metabolism. Each of these imaging tests were compared between monolinguals and bilinguals, individuals with MCI and AD, and/or in one case (Marin-Marín et al., 2020), passive and active bilinguals. By assessing different parts of the brain, the physical state of the brain can help identify if there are deficits regarding cognitive functioning.

7 of the 9 articles in this subsection found evidence in their brain images that did support the hypothesis of bilingualism as a mechanism of cognitive reserve. The remaining 2 articles found results that indirectly suggest bilingualism as a contributor to cognitive reserve and note that their results must be considered with caution. For example, Raji et al. (2020) concluded that bilinguals did present larger volumes in the parts of the brain that were of interest, which addresses their primary investigation of whether bilingualism contributes to differences in brain structure against monolinguals. From here, they deduce that these larger volumes in bilinguals may suggest higher cognitive functioning when compared to their monolingual counterparts, supporting the hypothesis of bilingualism as a mechanism for cognitive reserve. Further, they note that their research must be extended using persons who are cognitively normal but at risk for development of AD in order to grasp a deeper understanding of the role of brain volume in cognitive reserve.

### **Discussion**

This scoping review investigated the protective effect of bilingualism against AD/ADRD. This study revealed there is mixed evidence on whether or not bilingualism is a mechanism for cognitive reserve in persons with dementia. About 20% (6 articles) of the literature did not find supporting evidence of the hypothesis of bilingualism as a source of cognitive reserve, whereas

the remaining 80% did find either strong evidence or suggestive evidence that bilingualism is a contributor to cognitive reserve. Further, two research methods were revealed: only administering various neurocognitive assessments to evaluate cognitive function, or utilizing a combination of neurocognitive assessments and brain imaging to investigate structural patterns in the brain. This study also was inclusive to various types of dementia, such as AD and MCI, as the most frequent. Finally, the literature collected included a wide range of languages, although not necessarily representative of the entire world (e.g., considerations of health care accessibility, research accessibility, culture).

### **Neurocognitive Assessments**

Among the articles that only evaluated scores of neurocognitive tests to measure cognitive function, a little over half (n=10; 53%) revealed strong evidence that bilingualism is a contributor to cognitive reserve for persons with dementia. Within these studies in agreement, a wide range of languages were covered. For example, Bialystok et al. (2014) included English, Farsi, French, Italian, Russian and Yiddish. Alladi et al. (2013) focused on the Indian languages of Telugu, Dakkhini, English, and Hindi. With additional languages investigated in the remaining articles, this common evidence that supports the hypothesis can be suggestive of a general pattern that may be present in any bilingual, not necessarily specific for one language or one country. Additionally, however, there were a couple cases that did investigate only two languages in their study, which allowed for a greater control of this aspect. For instance, Zheng et al. (2018) targeted the Chinese languages of Mandarin and Cantonese. This precise approach is a potent way to extrapolate the information provided by studies that do survey a large amount of languages in one study to get a deeper understanding of how the specific language may

influence the delay of onset or cognitive reserve. However, not many studies take this approach, and thus a research gap is revealed for future studies.

On the other hand, 6 articles concluded that evidence was not found that supported bilingualism being an effective mechanism for cognitive reserve. 3 articles found a mix of results. The possible attributes that may have led these researchers to this conclusion differs. For example, Crane et al. (2010) specifically studied the difference between written Japanese and spoken Japanese. For other articles in this category, the language assessments were loose: definitions of “bilingual” varied, language level information was obtained from differing sources, and exams that tested language skill were scored differently. Being that this article was the only one that emphasized the mode of language as part of the study (i.e., written and spoken), it may have contributed to the lack of evidence that supports the hypothesis. Additionally, Clare et al. (2016) addressed multiple aspects of their study that may have contributed to their lack of evidence. For example, they note that their study had a relatively smaller sample size, had a shorter duration of 3 years as opposed to their example of 4 years, and their geographical setting. In Wales, where their study took place, they note that both English and Welsh are equally present in the community. With constant use and exposure to both languages in everyday life, they may have a more automatic functioning of switching between languages versus someone who uses English 75% of their day and Spanish only 25%. The imbalance of language management may cause a bilingual to make more effortful decisions when switching between languages, as opposed to someone who is constantly exposed that bilingual environment (Gathercole et al., 2014). For those 3 articles that found mixed results within their own studies, an additional characteristic must be considered when analyzing their results: type of dementia. For example, DeLeon et al. (2020) found supporting evidence of the hypothesis in persons with lvPPA, but not

in those with amnesic AD. Their article claims they were the first study to address the topic with the intent of investigating specific variants of AD. There is not an abundance of existing literature that takes this same approach, so no firm conclusions can be drawn. However, they do bring to attention the importance of investigating these specific variants, so that there is a better understanding of how bilingualism might affect different diagnoses of AD/ADRD.

Further, 1 article researched the effect of bilingualism on the AD biomarkers in CSF. This study concluded that with their results, bilingualism may play a protective role aiding in resistance of development of AD, but encouraged future research to extrapolate their work and continue this investigation with the participation of persons with dementia, to understand the actual relationship between CSF and the expression of AD.

### **Neurocognitive Assessments and Brain Imaging**

There was greater consensus in findings from studies that used both neurocognitive assessments and brain imaging. However, there was a range of brain structures that were evaluated in each imaging technique. The four found among this collection of literature are as followed: brain atrophy (n=2), brain volume (n=2), metabolic connectivity (n=3), and white/gray matter (n=2). 7 of these articles did find evidence in their respective brain structures of interest that bilinguals had an advantage due to their multiple language maintenance. With the range in brain structures that were reported in this study, it is good indication that bilingualism does have a general positive effect on cognitive function based on the physical presentations of the brain. However, 2 articles did not directly investigate brain structure and cognitive function with bilingualism. Instead, both articles (Marin-Marín et al., 2020, Raji et al., 2020), used their findings of evidence that bilingualism does have an effect on brain structure in general to then deduce the relationship it may have on the cognitive function. Marin-Marín et al. (2020), for

instance, investigated white matter (WM) integrity in passive and active bilinguals with MCI. They found results that suggested bilingualism to contribute to a differential pattern of WM disintegration between both bilinguals. They continue by addressing that their results could be interpreted as contribution of bilingualism to CR. Thus, though they did not directly investigate the hypothesis of the current study, their conclusion may still contribute to the existing literature.

### **Additional Variables**

Throughout the collection of articles analyzed in this study, additional variables were often discussed that may have played a role in the outcomes. The four most common variables were educational attainment (n=21), immigration (n=10), cognitive level (n=7), and occupation (n=7). Other variables include executive function, age, sex, literacy, urban vs. rural dwelling, language preference, prescription of medication, culture, lifestyle, age of language acquisition, and cardiovascular risk factors. Each article that addressed their respective confounding variables wanted to ensure that their conclusions about bilingualism and cognitive reserve was truly about the bilingual aspect and not an alternative, regardless of their outcomes. For example, Costumero et al. (2020) specified that a strength of their study was their execution to control education, age, environment (i.e., the same city of residence), and cognitive status.

### **Limitations**

The current study must be interpreted with the understanding that limitations are present. First, among the screening process, articles that were published in foreign languages with no English translation available were excluded. Being that this topic is directly related to multilingualism, limiting the search to English-only articles does exclude any additional research conducted in different regions of the world, with different cultural lenses and health care systems. However, the databases used generate English articles by default. Further, the search

words used were only English words. Secondly, a limitation of this scoping review is the lack of information available in developing countries. An exception may be India, where Alladi et al. (2013) and Alladi et al. (2017) were conducted in. The worldwide nature of this topic suggests that each country or region may yield a wide range of results, but the lack of tools to be able to conduct the research, health care access, education, money, and other resources, impede the ability for these countries to contribute to the existing literature. Therefore, the ideas drawn from this review may only be generalized to larger, more developed societies.

### **Future Research**

Future research should be conducted to further the information known about this topic. There are several nuances that should be addressed, that lacked in this collection of articles. First, as noted by Zheng et al., 2018, the results of these exams may vary based on the language group. The similarities between two languages may produce a different effect on an individual who is bilingual in two unrelated languages. To deeper explore this idea, advanced research can dive into the nuances of dialects. Definitions of dialect must be established, as it may or may not be considered knowing a second language.

Additionally, advanced research should explore the effects of signed languages. Zero articles in this review mentioned any deductions about signed languages. It may be useful to know how a visual language may or may not alter the brain atrophy and cognitive function compared to a spoken language.

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## Appendix A

### List of Keywords

Initial search:

Alzheimer's Disease, Alzheimer's Disease and Related Dementias, AD, ADRD, AD/ADRD, Dementia, Alzheimer-type dementia, Cognitive decline, Cognitive disorders, Frontal Temporal Dementia, FTD, Lewy Body Dementia, LBD, Senile Plaques, Memory Disorders, cognitive impairment, mild cognitive impairment, neurodegenerative diseases

AND

Neurolinguistics, language pathology, language impairment, bilingual, multilingual, polylingual, multicultural, multidialectalism, multiple languages, monolingual, linguistic, language impairment, speech, sign language, Deaf, Child of Deaf Adult, CODA, codeswitching, interpreter, interpreter-mediation, verbal, nonverbal, linguistically diverse, proficiency, competency, fluency, first language acquisition (FLA), second language acquisition (SLA)

**Table 1. Articles examining the relationship between AD/ABRD and bilingualism investigating cognitive reserve/brain atrophy.**

Article Title	Journal Name	Year	Author(s)	Purpose of Study	Retrospective or Prospective	Method	Type of dementia	How they defined someone being bilingual	What languages are they discussing	Quantitative description of results	Other Possible Variables Examined	Notes
Bilingualism delays age at onset of dementia, independent of education and immigration status	Neurology	2013	Alladi, Suvarna; Bak, Thomas H; Duggirala, Vasanta; Surampudi, Bapiraju; Shailaja, Mekala; Shukla, Anuj Kumar; Chaudhuri, Jaydip Ray; Kaul, Subhash	The purpose of the study was to determine the association between bilingualism and age at onset of dementia and its subtypes, taking into account potential confounding factors.	retrospective	neurocognitive assessments only	AD, DLB (dementia with Lewy bodies), FTD, VaD, mixed dementia	"...those with an ability to meet the communicative demands of the self, and the society in their normal functioning in 2 or more languages in their interaction with the other speakers of any or all of these languages."	Telugu, Dakkhini, English, Hindi	bilinguals were found to be 4.5 years older at the time of occurrence of the first symptoms of dementia; 3.2 year delay for AD, 6 year delay for FTD, 3.7 year delay for VaD (the others had delays too but not statistically significant)	education, occupation, cardiovascular risk factors, urban vs. rural dwelling	limitations: age at onset of dementia cannot be validated bc it was provided by family members in the clinical setting; criteria for bilingualism was subjective; possible selection bias bc all participants were patients at clinic and not just from the community (reflects in the age); info for language acquisition for each person lacks so no conclusions for language combinations
Bilingualism delays the onset of behavioral but not aphasic forms of Frontotemporal Dementia	Neuropsychologia	2017	Suvarna Alladi, Thomas H Bak, Mekala Shailaja, Divyraj Gollahalli, Amulya Rajan, Bapiraju Surampudi, Michael Hornberger, Vasanta Duggirala, Jaydip Ray Chaudhuri, Subhash Kaul	To further explore the cognitive consequences of bilingualism, the study used Frontotemporal dementia (FTD) syndromes, to examine whether bilingualism modifies the age at onset of behavioural and language variants of Frontotemporal dementia (FTD) differently.	retrospective	neurocognitive assessments only	FTD and subtypes; behavioral variant FTD (bvFTD), two aphasic variants (progressive nonfluent aphasia (PNFA) and semantic dementia (SD)), and motor variants of FTD (frontotemporal dementia-motor neuron disease (FTD-MND), corticobasal degeneration (CBD), and progressive supranuclear palsy (PSP))	Bilingualism was defined as the ability to communicate in two or more languages in interaction with other speakers of these same languages	Telugu, Hindi, English, Dakkhini (most common combos: Telugu and Hindi; Telugu, English, and Hindi; Telugu and Dakkhini)	overall, bilinguals were 3.3 years older than monolinguals at first symptoms; bilingual pts bvFTD=5.7 year delay, no signif diff btwn mono and bis for PNFA, SD, FTD-MND, CBD, PSP; divided pts in behavioral and aphasic types: for behavioral bilinguals, they were 6.1 years older than monos, but for aphasic type, no sig difference	education, gender, occupation, urban vs rural dwelling, literacy	other factors noted: bilingualism (associated w/ age at onset of bvFTD), rural dwelling (2 years older in urban dwellings), literacy (illit avg age: 50.3; lit avg age 59.6); factors not significant for the other subtypes; no significant diff btwn bilinguals and multilinguals; limitations: retrospective nature, clinic-based pts, subjective measure of bilingualism
Does Bilingualism Influence Cognitive Aging?	Annals of neurology	2014	Thomas H. Bak, Jack J. Nissan, Michael M. Allerhand, Ian J. Deary	To address the confound of original differences' role in cognitive differences (i.e., childhood intelligence (CI)).	prospective	neurocognitive assessments only	no dementia specified, focuses on "cognitive aging"	"participants who reported being able to communicate in L2"	English, L2s not specified	results suggests a protective effect of bilingualism against age-related cognitive decline independently of CI; no other explanation for effects; no negative effects for bilingualism; types of bilingualism: early vs late showed differences (depending on childhood IQ); knowing 3 or more languages showed stronger effects than only 2 (differs from other studies)	age of language acquisition, frequency of use	limitations: bilingualism-associated confounding variables (immigration, ethnic/environmental differences, etc.)
Conversion of Mild Cognitive Impairment to Alzheimer's Disease in Monolingual and Bilingual Patients	Alzheimer disease and associated disorders	2020	Matthias Berkes, Ellen Bialystok, Fergus I. M. Craik, Angela Troyer, Cpsych, Morris Freedman	Conversion rates from mild cognitive impairment (MCI) to Alzheimer's Disease (AD) were examined considering bilingualism as a measure of cognitive reserve.	retrospective	neurocognitive assessments only	MCI/aMCI, AD	reported by participants: "knowledge of more than one language, regular use of a language in addition to English, and living in a non-English speaking country"	English, Yiddish (21), French (10), Hebrew (6), German (5), Romanian (5)	Bilinguals converted from MCI to AD in 1.9 years vs. monolinguals in 2.6 years; age of diagnoses of AD did not differ btwn bi and monos (different than usual results) but bis were older for MCI diagnoses (only applicable for those with immigration status); monos had higher MMSE scores than bis but bc of its limit, MoCA was used and the results of that were not statistically significant	education, immigration, sex, language group, AD genetic component	immigration was a factor for both mono and bilinguals, (in the years 1950s, 1960s, and 1970s); MRI was used mainly as a diagnostic factor since different hospitals used different MRI machines; MMSE has a "ceiling effect"
Effects of Bilingualism on the Age of Onset and Progression of MCI and AD: Evidence From Executive Function Tests	Neuropsychology	2014	Ellen Bialystok, Fergus I. M. Craik, Malcolm A. Binns, Lynn Ossher	Q1: Does the protection against onset of symptoms found for bilinguals in AD and MCI remain when a wide range of background and lifestyle factors is considered? Q2: To closely investigate the relationship of executive functioning in bis and monos to ensure that the protection is only about language practices and not executive function Q3: To determine whether differences in age of onset of MCI and AD are related to diff rates of decline depending on the appearance of symptoms	prospective	neurocognitive assessments only	probable AD, MCI	individuals spent the majority of their lives (beginning at least in early adulthood) speaking two or more languages fluently weekly or daily (based on LSBQ)	English, Farsi, French, Italian, Russian, Yiddish	delay of onset is approximately 6 years for bilinguals compared to monolinguals (MCI by 4.7 yrs, AD by 7.3 yrs); same for clinic visit ages (MCI by 3.5 yrs, AD by 7.2 yrs); delay is not associated with assessments of executive function; evidence is inconsistent with the hypothesis that patients diagnosed at an older age for AD means a faster deterioration of cognitive abilities	lifestyle variables (diet, smoking, alcohol consumption, physical activity, social activity)	some participants spoke more than two languages but were included in the bilingual group

Article Title	Journal Name	Year	Author(s)	Purpose of Study	Retrospective or Prospective	Method	Type of dementia	How they defined someone being bilingual	What languages are they discussing	Quantitative description of results	Other Possible Variables Examined	Notes
Bilingualism as a protection against the onset of symptoms of dementia	Neuropsychologia	2007	Ellen Bialystok, Fergus I.M. Craik, Morris Freedman	This study examined the effect of lifelong bilingualism on maintaining cognitive functioning and delaying the onset of symptoms of dementia in old age.	retrospective	neurocognitive assessments only	probable AD, other dementias, dementia due to other neurodegenerative disorders, cerebrovascular disease (diagnoses that did not include dementia like depression and MCI were excluded)	patients had spent the majority of their lives, at least from early adulthood, regularly using at least two languages	English, Polish (20), Yiddish (13), German (12), Romanian (8), Hungarian (7), more but not specified (these are the most common, notes that there were speakers of 25 different L1s)	bilinguals showed symptoms of dementia 4.1 years later than monos (other measures were equal), MMSE scores were equal between monos and bis (and men and women) meaning same cog impairment, bis had less years of school (probably b/c of WWII), higher occupation status, higher education, considered cultural differences (hypothesized that bis may have avoided medical attn more than monos, but actually found that bis sought medical attn sooner than monos (by about 0.8 years)	cultural differences, immigration, formal education, employment status	immigration was a factor here, results cannot be generalized to individuals who are not fluent in L2s bc this study only proves for true bilinguals
Multilingualism (But Not Always Bilingualism) Delays the Onset of Alzheimer Disease: Evidence From a Bilingual Community	Alzheimer disease and associated disorders	2010	Howard Chertkow, Victor Whitehead, Natalie Phillips, Christina Wolfson, Julie Atherton, Howard Bergman	We examined age at diagnosis of Alzheimer disease and age at symptom onset for all unilingual versus multilingual participants, and then for those who were nonimmigrant English/French bilinguals.	retrospective	neurocognitive assessments only	probable AD	3 levels: unilingual, bilingual, and multilingual; definitions varied: unilingual - spoke only one language, bi - spoke two (only considered French and English), multi - spoke 3+ languages (definitions were same as above two, based on Bialystok et al.; did not note when the L2 was learned	English, French	found a nonsignificant 1 year diff btwn uni and multilinguals for onset of symptoms, found a nonsig. 0.9 yr diff for age of diagnosis, found a significant diff that favored monos by 2.6 yrs when considering age of dementia diagnosis of nonimmigrant Eng/Fren bis, no diff in rate of decline btwn multi and uni, found a small but significant protective effect of more than 2 languages, but not for those who only know 2; found a protective effect of bilingualism in native Canadians whose L1 was French and also in immigrants to Canada, but not in native English speakers	education, immigrant/native status, and sex	limitations: did not consider the age of acquisition of L2+ (did not believe it was reliable to ask demented elderly this question), lack of info for immigration/native status, small sample size of the bilingual native-born group, cross-sectional nature of the study, use of age of diagnosis (not necessarily the age of onset of AD bc they could have avoided seeking medical attn so its an arbitrary marker for AD sometimes), possible misreports in first symptoms of memory loss
Bilingualism, executive control, and age at diagnosis among people with early-stage Alzheimer's disease in Wales	Journal of neuropsychology	2016	Linda Clare, Christopher J. Whitaker, Fergus I. M. Craik, Ellen Bialystok, Anthony Martyr, Pamela A. Martin-Forbes, Alexandra J. M. Bastable, Kirstie L. Pye, Catherine Quirm, Enlli M. Thomas, Virginia C. Mueller Gathercole, John V. Hindle	In this study, we aimed to provide new evidence regarding the possible impact of bilingualism in delaying the onset of AD and whether bilinguals diagnosed with AD retain any advantage in executive control processes, by comparing for the first time samples of older Welsh/English bilinguals and English monolinguals living in Wales who met diagnostic criteria for AD.	prospective	neurocognitive assessments only	AD (early-stages)	monolingual: speaking English for all or most of one's life and being fluent in English, but not in any other language; bilingual: speaking both Welsh and English for all or most of one's life and being fluent in both languages, but not in any other languages	English, Welsh	MMSE scores did not significantly differ between bis and monos, but bis generally had lower scores (indicating higher cognitive impairment); age at diagnosis was not significantly different (bis only 3 yrs later, not sig); performance of English-lang tests were not significantly diff	education, prescription of acetylcholinesterase-inhibiting medication (ACHEI), executive function	immigration was a confounding factor, but was not specifically studied; the result being non-significant could have ended up this way because of the small sample size; this study only occurred over 3 years rather than 4 (like in Bialystok's study in 2007), giving less time for more significant results to show up; one note made here is that in this region, like in Montreal, Eng and Welsh function simultaneously. This means that switching btwn languages is more of an automatic function for the individual rather than when acquiring an L2 later in life. This could explain the absence of a clear bilingual advantage
Delaying the onset of Alzheimer disease: bilingualism as a form of cognitive reserve	Neurology	2010	Fergus I. M. Craik, Ellen Bialystok, Morris Freedman	We present evidence that lifelong bilingualism is a further factor contributing to cognitive reserve.	retrospective	neurocognitive assessments only	probable AD	The criterion for classification as bilingual was having spent the majority of life, at least from early adulthood, regularly using at least 2 languages	English, not all the others were listed but Yiddish (24), Polish (12), Italian (11), Hungarian (9), French (7) were the most popular	bilingualism does postpone the onset of symptoms; 4.3 year difference in age for initial clinic visit (bilinguals were later), no differences in lang groups for MMSE scores, monos had more formal schooling than bis; reporting age at onset is subjective but low possibility to be skewed: bilinguals did report their onset about 5.1 yrs after monos; levels of cognitive impairment were equivalent at time of diagnosis for both monos and bis	immigration (loosely)	confounding factors are education and occupational status (this data shows that it would be in favor of monos since they have more years of education and higher occupational statuses which goes against their hypothesis); immigration is another possible factor for these results (there were more immigrant bilinguals than not, and more nonimmigrant monos than not, supporting the theory)

Article Title	Journal Name	Year	Author(s)	Purpose of Study	Retrospective or Prospective	Method	Type of dementia	How they defined someone being bilingual	What languages are they discussing	Quantitative description of results	Other Possible Variables Examined	Notes
Use of Spoken and Written Japanese Did Not Protect Japanese-American Men From Cognitive Decline in Late Life	The Journals of Gerontology: Series B: Psychological Sciences and Social Sciences	2010	Paul K. Crane, Jonathan C. Gruhl, Elena A. Erosheva, Laura E. Gibbons, Susan M. McCurry, Kristoffer Rhoads, Viet Nguyen, Keerthi Arani, Kama Masaki, Lon White	We sought to determine if midlife use of spoken and written Japanese was associated with lower rates of late life cognitive decline.	prospective	neurocognitive assessments only	healthy individuals only (excluded those who were diagnosed during the study, who dropped out, or who died)	Group 1: those who "neither spoke nor read Japanese" (only one person so they were excluded); Group 2: "spoke but did not read Japanese;" Group 3: "both spoke and read Japanese"	English, Japanese	did not find evidence that supports that multilingualism is associated w/ cognitive reserve; did not find that neither spoken Jap nor written Jap was associated with reduced rates of cognitive decline in late life; had to ask categorical questions to assess language ability	years of Japanese education, smoking status, income, apolipoprotein E (APOE) alleles (all variables were controlled)	limitations: Japanese language assessed were only self-reported; study was limited to only men; lack of information may have caused biases
Effects of bilingualism on age at onset in two clinical Alzheimer's disease variants	Alzheimer's & dementia: the journal of the Alzheimer's Association	2020	Jessica DeLeon, Stephanie Grasso, Arian Welch, Zachary Miller, Wendy Shwe, Gil D. Rabinovici, Bruce L. Miller, Maya L. Henry, Maria Luisa Gorno-Tempini	To explore the effect of bilingualism on age at onset with different clinical variants of Alzheimer's disease	retrospective	neurocognitive assessments only	amnestic AD, logopenic variant primary progressive aphasia (lvPPA)	Patients were classified as bilingual if their chart indicated that they regularly used two or more languages and/or they had the ability to communicate with native speakers in two or more languages; those who spoke more than two languages were considered bilingual; mono: if their charts did not state information regarding exposure to or experience with an L2	not specified besides, "...we note that our bilingual cohort is representative of the broader population of bilingual speakers in the U.S..."	bilingualism does show a significant 5-year delay in symptom onset in bilinguals for those w/ lvPPA, but not those with amnestic AD	sex, immigrant status, years of education	limitations: retrospective (limited data in characterization of patients); no objective data on L2 data (subjective data works well with this kind of study); bilinguals were most likely immigrants whereas monos prob weren't since this was a sample from the US (maybe its ok bc its representative of the US population and even after they thought about it it is still significant for those with lvPPA)
Degree of bilingualism predicts age of diagnosis of Alzheimer's disease in low-education but not in highly educated Hispanics	Neuropsychologia	2011	Tamar H. Gollan, David P. Salmon, Rosa I. Montoya, Douglas R. Galasko	The current study investigated the relationship between bilingual language proficiency and onset of probable Alzheimer's disease (AD) in 44 Spanish-English bilinguals at the UCSD Alzheimer's Disease Research Center.	prospective	neurocognitive assessments only	probable AD	To illustrate, a bilingual who names 3 pictures in one language and 6 in the other would be 50% bilingual, as would a person who names 30 in one and 60 in the other.	English, Spanish	supports prior conclusions of the cognitive advantages associated with bilingualism; benefit was robust only in bis w/ low education levels, those Spanish-dominant bis who showed the advantage also were generally lower educated, and immigrants as well; analyzing education as a primary factor here showed that it really is important to investigate	language preference, education level	limitations: bilinguals w/ lower education had lower DRS scores than those w/ high education levels (usually MMSE scores are used, which don't show a difference in lowly or highly educated individuals, meaning it really is bilingualism making the delay possible; using DRS point to different conclusions since it shows a difference here); small sample size of bis;
Multilingualism and Dementia Risk: Longitudinal Analysis of the Nun Study	Journal of Alzheimer's disease	2019	Erica E. Hack, Joel A. Dubin, Myra A. Fernandes, Sanduni M. Costa, Suzanne L. Tyas	To determine whether multilingualism is associated with delayed onset or reduced risk of dementia	prospective	neurocognitive assessments only	dementia (not specified) (dementia-free at baseline)	not specified; based on the Nun's opinions since they were in the records for something else (they had them so they could be assigned to international missions lol)	not specified; those who spoke 4 or 5 languages were put into the same group	multilingualism did not delay the onset of dementia; those who spoke 4+ languages had lower chances of developing dementia than monolinguals; amount of APOE E4 allele being present in the brain	multilingualism categorizations (number of languages spoken), all time indicators, occupation, education, baseline age, immigration status, APOE allele status; idea density, grammatical complexity (during sensitivity analysis)	limitations: self-reported measure of multilingualism (had no option to try objectively scaling it and also lacked info such as age of acquisition, etc.); is supported by the fact that the Nuns were comfortable to teach in abroad, so they probably categorized themselves fairly), small sample size (for the second phase analysis of linguistic abilities; perhaps a significant difference would result in a bigger sample),
Bilingualism Delays Expression of Alzheimer's Clinical Syndrome	Dementia and Geriatric Cognitive Disorders	2020	Mario F. Mendez, Diana Chavez, Golnoush Akhlaghipour	To evaluate the effects of bilingualism on the emergence of Alzheimer's clinical syndrome	prospective	neurocognitive assessments only	probable AD	not specified	various L1s: Farsi, Spanish, Mandarin Chinese, Tagalog, Arabic, Korean, Hebrew, Hindi, French, Russian, Bengali, Croatian, Greek, Hausa, Hungarian; English	bilingualism could increase cognitive reserve through the constant management of two simultaneously active and competing language, delay of onset is about 4 years, MMSE scores were better in bilinguals meaning their language ability led to their protected cognition	immigration, gender (loosely)	limitations: social diversity of language use (like adaptations to interactional contexts depending on language use such as formal/informal or social/academic, etc.), objective determination of L2 proficiency without relying on self-reports



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Comparative Effects of Education and Bilingualism on the Onset of Mild Cognitive Impairment	Dementia and Geriatric Cognitive Disorders	2017	Subasree Ramakrishnan, Shailaja Mekala, Annapurna Mamidipudi, Sireesha Yareeda, Rukmini Mridula, Thomas H. Bak, Suvarna Alladi, Subhash Kaul	This study aimed to compare the effects of education and bilingualism on the onset of cognitive decline at the stage of mild cognitive impairment (MCI).	prospective	neurocognitive assessments only	MCI; grouped into aMCI (91) and non-amnesitic MCI (24)	those with an ability to meet the communicative demands of the self, and the society in their normal functioning in 2 or more languages in their interaction with the other speakers of any or all of these languages	not specified, but lists a test that is adapted into Telugu, Hindi, Indian English, and Dakkhini for the Indian population and participants are Indian and nonimmigrants	bilingualism does delay onset of cog decline during preclinical stage of AD and education level is not significant; since bis were generally more educated and had better results, they compared same level educated ppl to make sure it was the bilingualism that was affecting the difference: found that bis were still significantly higher (by 7.7 yrs, but this was for the lower edus; higher edus didnt have a sig diff)	years of education	age range is much younger than Western studies because "memory clinic cohorts in developing countries like India are characterized by a higher proportion of early onset dementias (49.8%); restricting age limit to older would miss so many cases; no immigrants were present in this study; limitations: based on a hospital population where monos, illiterates, and low edus are underrepresented (selection bias), fewer women and most of them were in lower edu category, bilingualism info was not detailed to explore frequency of lang use, etc.
Bilingualism delays clinical manifestation of Alzheimer's disease	Bilingualism: Language and Cognition	2015	Evy Woumans, Patrick Santens, Anne Sieben, Jan Versijdt, Michaël Stevens, Wouter Duyck	The current study investigated the effects of bilingualism on the clinical manifestation of Alzheimer's disease (AD) in a European sample of patients	retrospective	neurocognitive assessments only	probable AD	using the Likert scale, bilinguals were categorized as such if they rated themselves as "good" or higher for all four L2 skills AND spoke the L2 at least weekly before and now	Belgian, Dutch, French	found a significant delay for bilinguals of 4.6 years in manifestation and 4.8 years in diagnosis shown by statistical analysis of linear regression models (with AD Manifestation Age and Diagnosis Age as the dependent variables); age of L2 acquisition did not influence the effect (having a higher occupation is correlated w/ younger manifestation and diagnosis but this is bc there are variables of stress and more related)	gender, education, occupation, initial MMSE, L1	this study DID take into account the age of acquisition; included education level in years and occupation
Is bilingualism associated with a lower risk of dementia in community-living older adults? Cross-sectional and prospective analyses	Alzheimer disease and associated disorders	2014	Caleb M. Yeung, Philip D. St. John, Verena Menec, Suzanne L. Tyas	The specific objectives of these analyses were: (1) to determine whether bilingualism is associated with dementia in a cross-sectional analysis of older adults; and (2) to determine whether bilingualism is associated with developing dementia in cognitively intact older adults over a 5-year period.	prospective	neurocognitive assessments only	categorized cognition as Intact (normal 3MS or 3MS <78 but a normal clinical examination), Cognitive Impairment with no dementia (CIND); 3MS <78 but clinical examination consistent with cognitive loss less severe than dementia), or Dementia (3MS <78 and a clinical examination consistent with dementia); subtypes of dementia were not considered	English Monolingual: those participants who spoke only English; English Bilingual: those participants who spoke English as a first language and who could speak a second language (mostly French); English as second language: those who were bilingual but who listed their first language as any other language other than English	English, French, Ukrainian, German/Low German, Polish, Icelandic, Yiddish, Italian, Dutch/Flemish	observed no effect of being bilingual on the risk of dementia in either analyses; bilingualism was not associated with higher cognitive test scores or changes in test scores; found a possible association between bilingualism and CIND (likely explained by the ESL group being more likely to experience difficulty with the 3MS exam as it was administered in English)	cognitive level, age, sex, education, literacy	limitations: data collected regarding participants' level of education pertained to their attainment, not quality; primarily European languages were represented in this population and no French-other multilinguals; did not have sufficient power to detect the impact of >2 languages due to few participants in this category; only a few biomedical factors were considered; somewhat old data (over 20 years old), but effect of bilingualism on dementia would be unlikely to change overtime
Bilingualism does not alter cognitive decline or dementia risk among Spanish-speaking immigrants	Neuropsychology	2014	Laura B. Zahodne, Peter W. Schofield, Meagan T. Farrell, Yaakov Stern, Jennifer J. Manly	The current study sought to test this hypothesis in a large, prospective, community based study of initially nondemented Hispanic immigrants living in a Spanish-speaking enclave of northern Manhattan.	prospective	neurocognitive assessments only	over the course of the study, 282 participants developed dementia (probable Alzheimer's disease, Alzheimer's with concomitant disease, Alzheimer's with stroke, Alzheimer's with Parkinson's, vascular dementia, dementia with Lewy bodies, other)	Monolinguals: participants who answered "not at all" to the English proficiency question; Bilinguals: participants who answered "not well," "well," or "very well" to the English proficiency question)	English, Spanish	found no difference in age of AD diagnosis among bis and monos; Native Spanish speaking immigrants to the US who became bilingual by learning English as adults are not protected against age-related cognitive decline or the development of dementia above and beyond other related variables (i.e. education); only showed bilingualism had higher performance on initial tests	country of origin, proportion of time spent in the US	several factors not considered: degree of engagement in their second language, age at which the L2 was acquired (though age of immigration was noted, and most participants acquired English upon arriving in the US), degree of typological similarity between a bilingual's two spoken languages (existing evidence suggests that different language pairs lead to distinct cognitive profiles among bilinguals due to differing cross-linguistic interference)

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Beneficial effect of bilingualism on Alzheimer's disease CSF biomarkers and cognition	Neurobiology of aging	2017	Ainara Estanga Mirian Ezcay-Torres, Almudena Ibañez, Andrea Izagirre, Jorge Villanua, Maite Garcia-Sebastian, M. Teresa Iglesias-Gaspar, Ane Otaegui-Arrazola, Ane Iriondo, Monserrat Clerigüe, Pablo Martínez-Lage	We assessed cognitive performance and CSF AD-biomarkers, and potential moderation effect of bilingualism on the association between age, CSF AD-biomarkers, and cognition.	prospective	neurocognitive assessments only	healthy volunteers; donated their CSF	bi: subjects who were able to communicate fluently at least in 2 languages and made regular use for both; early bi: learned both languages from birth or before school at age 6; late bi: learned L2 after 6 yo	Euskera (native to Basque Country and is complete unrelated to romance languages), Spanish	confirm there is a positive impact of bilingualism on cognitive function, executive function, and visual-spatial performance; findings suggest that bilingualism may play a protective role by bestowing brain structure that would be more resistant to development of pathologies, but since the participants were healthy, the mechanism of how bilingualism might influence the expression of AD pathology is unknown	education, educated intelligence	important to note that many immigrants moved to this region did it after the Spanish Civil war, so, although it would be expected that assimilation did not occur, it actually did, and those immigrants did learn Spanish; limitations: "Bilingual Language Profile" is subjective, study may be influenced other environmental, nutritional, or educational factors geographically associated with bilingualism during childhood but good not be given more info about, relatively small sample size of those who are in the GAP cohort (since its preclinical stages of AD)
The Protective Effect of Cantonese/Mandarin Bilingualism on the Onset of Alzheimer Disease	Dementia and Geriatric Cognitive Disorders	2018	Yifan Zheng, Qi Wu, Fengjuan Su, Yingying Fang, Jinheng Zeng, Zhong Pei	The present study aims to determine if Cantonese/Mandarin bilingualism can delay the onset of AD.	retrospective	neurocognitive assessments only	probable AD	Monolingual: patients who only spoke one language; Bilingual: the criterion for bilingualism was that individuals had spent the majority of their lives, beginning at least in early adulthood, speaking two languages fluently – ideally daily, but at least weekly	Cantonese, Mandarin	strongly indicates that constantly speaking both Cantonese and Mandarin from at least early adulthood does delay onset of AD; bilinguals had older age at AD onset and first clinic visit than both groups of monolinguals; bilinguals and Mandarin monolinguals had higher education levels and occupation status than Cantonese monolinguals (due to the dominance of Mandarin being used in China; differs than the study done in Canada where bilinguals had the higher education levels and occupation statuses)	education level, occupation	limitations: sample size was relatively small (sampling only one center and strict inclusion criteria), some unmeasurable behavioral factors favoring the bilinguals may be present in the study, playing a potential role in AD (such as environmental exposures or social environment), study only focused on Cantonese though there are several other dialects in other districts of China; other studies should extend the findings of this one
A cross-sectional and longitudinal study on the protective effect of bilingualism against dementia using brain atrophy and cognitive measures	Alzheimer's research & therapy	2020	Victor Costumero, Lidon Marin-Marín, Marco Calabria, Vicente Belloch, Joaquín Escudero, Miguel Baquero, Mireia Hernandez, Juan Ruiz de Miras, Albert Costa, Maria-Antònia Parcet, César Ávila	In this study, we used global parenchymal measures of atrophy and cognitive tests to investigate the protective effect of bilingualism against dementia cross-sectionally and prospectively, using a sample of bilinguals and monolinguals in the same clinical stage and matched on sociodemographic variables.	prospective	neurocognitive assessments and brain imaging	MCI	Monos: those who only speak Spanish; Bis: those who reported Catalan as their mother tongue and learned Spanish at school AND active use of both	Spanish, Catalan	bilingualism does promote CR and brain reserve; none other than years of schooling or participants were around the same age (bilinguals were only 7 months older bc MCI is before AD and other dementias); bilinguals showed greater brain atrophy than monos, but no diffs in cognitive function or age (cross-sectional part); monos showed greater brain atrophy than bis during the longitudinal portion	age, education, gender (tested a subsample of patients who had equal sociodemographic to confirm bilingualism was the only factor)	limitations: sample consisted of only those with MCI meaning rates of conversion to dementia varies, participant drop-out was 59.6% which made the remaining samples unbalanced, for the longitudinal part, the follow-up period was relatively short for a long-term disease like AD meaning these results are more short-term effects, the two languages tested are very similar but this could be a pro and a con (proved similar results anyways)
Structural brain differences between monolingual and multilingual patients with mild cognitive impairment and Alzheimer disease: Evidence for cognitive reserve	Neuropsychologia	2018	Hilary D. Duncan, Jim Nikelski, Randi Pilon, Jason Steffener, Howard Chertkow, Natalie A. Phillips	We aim to contribute to the literature examining whether bilingualism relates to gray matter differences, and whether these structural brain differences may be linked to cognitive reserve.	retrospective	neurocognitive assessments and brain imaging	MCI ("amnesic" or "amnestic plus" MCI), AD	MCI diagnosis was carried out by trained neurologists or geriatricians using standardized criteria as outlined by Gauthier et al. (2006)	English, French, and a variety of others for those who spoke 3+ (Yiddish, Hebrew, Greek, Arabic, etc.)	multilingual MCI and AD patients showed increased brain matter in the form of thicker cortex and higher grey matter density compared to matched monolinguals in language and cognitive control (LCC) brain areas, evidence for the contribution of bilingualism to cognitive reserve in AD patients but not MCI patients, both AD and MCI patients show positive correlations between episodic memory scores and certain brain regions outside of the medial temporal region, largely replicated the LCC area results within a group of non-immigrant MCI patients (indicates immigration did not influence results)	immigration status	limitations: data was gathered retrospectively (limited information on language history), lack of data from healthy older adults that could of provided baselines to compare level of neurodegeneration in the Diagnosis Groups, relatively small sample size (this study should be counted as preliminary)

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Bilingualism as a Contributor to Cognitive Reserve? Evidence from Cerebral Glucose Metabolism in Mild Cognitive Impairment and Alzheimer's Disease	Frontiers in psychiatry	2016	Magdalena Eva Kowoll, Christina Degen, Lina Gorenc, Anika Kuntzelmann, Iven Fellhauer, Frederik Giesel, Uwe Haberkorn, Johannes Schröder	To elucidate the underlying cerebral correlates, regional glucose uptake was compared between bilinguals and monolinguals with mild cognitive impairment (MCI) and beginning-stage Alzheimer's disease (AD) by using [ <sup>18</sup> F]fluorodeoxyglucose (FDG) positron emission tomography (PET).	prospective	neurocognitive assessments and brain imaging	MCI, probable AD	patients were classified as bilingual if they "... had spent the majority of their lives, at least from early adulthood, regularly using at least two languages"	mixed: 9 diff L1s, most common were German (7), Hungarian (2); 7 diff L2s, most common were German (8), English (3)	lower glucose uptake in bilinguals vs monos with MCI or early AD; no sig diff btwn monos and bis meaning they are pretty similar in neuropsychological deficits; brain imaging showing glucose uptake/metabolism; concluded that bilingualism does help compensate changes and contribute to CR	years of education	
Effects of bilingualism on white matter atrophy in mild cognitive impairment: a diffusion tensor imaging study	European journal of neurology	2020	L. Marin-Marín, V. Costumero, V. Belloch, J. Escudero, M. Baquero, M.-A. Parcet, C. Ávila	To explore the relationship between dementia and bilingualism through the factor of white matter (WM) diffusion.	prospective	neurocognitive assessments and brain imaging	MCI	categories of bilinguals: "actives" are those who understand and speak both languages while "passives" are those who only understand it but not speak	Catalan, Spanish	results suggest that bilingualism contributes to a differential pattern of WM disintegration due to MCI in fibers related to bilingualism and memory; can be further interpreted to support the hypothesis that AD manifestation is delayed, BUT their results should be considered with caution as their results for recall and other tests were not significant	education, cognitive level, age, sex	
The impact of bilingualism on brain reserve and metabolic connectivity in Alzheimer's dementia	Proceedings of the National Academy of Sciences of the United States of America	2017	Daniela Perani, Mohsen Farsad, Tommaso Ballarini, Francesca Lubian, Maura Malpetti, Alessandro Fracchetti, Giuseppe Magnani, Albert March, and Jubin Abutalebi	We studied brain metabolism, a direct index of synaptic function and density, and neural connectivity to shed light on the effects of bilingualism in vivo in Alzheimer's dementia (AD).	prospective	neurocognitive assessments and brain imaging	probable AD	based on the bilingual index (BI) from the result of the questionnaire and interviews: 0 means completely monolingual and 1 is perfect bilingual	German, Italian	supports the cognitive reserve and delay of onset of dementia; in the scans, found that bilingualism not only does that but also contributes to physical changes in the brain ("neural protective effects"); cerebral hypometabolism was much more extended in bis with AD than monos	education, global cognitive status (i.e. MMSE scores), equivalent scores of neuropsychological tests of four cognitive domains (verbal memory, visuospatial memory, language, and attention functions)	
Brain Structure in Bilingual Compared to Monolingual Individuals with Alzheimer's Disease: Proof of Concept	Journal of Alzheimer's disease	2020	Cyrus A. Raji, Somayeh Meysame, David A. Merrill, Yerna R. Porter, Mario F. Mendez	Compare MRI measured brain volumes in matched bilinguals versus monolinguals with AD.	prospective	neurocognitive assessments and brain imaging	probable AD	not described in detail besides "...all of these patients were immigrants who used English primarily outside the home"	English, native languages not specified	bis demonstrated larger thalamic, ventral diencephalon and brainstem volumes compared to monos with AD (increased brain volumes in multiple regions); no correlation btwn left and right hippocampal asymmetry or temporal lobe asymmetry; may suggest increased CR in bilinguals but must be explored further	age, cognitive function (MMSE scores)	
Lifelong bilingualism and mechanisms of neuroprotection in Alzheimer dementia	Human brain mapping	2022	Arianna Sala, Maura Malpetti, Mohsen Farsad, Francesca Lubian, Giuseppe Magnani, Giulia Frasca Polara, Jean-Benoit Epiney, Jubin Abutalebi, Frédéric Assal, Valentina Garibotto, Daniela Perani	Here, we aim to study the effects of lifelong bilingualism as a dichotomous and continuous phenomenon, on brain metabolism and connectivity in individuals with Alzheimer's dementia.	prospective	neurocognitive assessments and brain imaging	probable AD/Alzheimer's dementia	multiplying the scores for conversation and reading of L2 to each other yielded an index that ranked "how bilingual" one was, on a scale from 1-25	German, Italian, French, English	found results that support bilingualism having a cognitive reserve effect in the brain images that show more severe hypometabolism in the brain than monolinguals (higher education and occupation correlate with more severe hypometabolism and is related to more cog reserve) and also higher connectivity/metabolism in bilinguals	years of education, severity of cognitive impairment, demographic variables	limitations: some of the participants were used in a previous study in the monolinguals section (the two studies are completely unrelated but they did this to reduce chances of false negatives and positives using a smaller sample size)
Bilingualism as a contributor to cognitive reserve: Evidence from brain atrophy in Alzheimer's disease	Cortex; a journal devoted to the study of the nervous system and behavior	2012	Tom A. Schweizer, Jenna Ware, Corinne E. Fischer, Fergus I. M. Craik, Ellen Bialystok	To analyze levels of brain atrophy in monolinguals and bilinguals with AD who have comparable levels of cognitive performance and years of education.	prospective	neurocognitive assessments and brain imaging	probable AD	"...if he/she was fluent in a second language and had used both languages consistently throughout most of his or her life"	not specified	bilingual patients with AD show substantially greater amounts of brain atrophy in regions associated w/ disease pathology (such as cerebral atrophy and even more specifically the temporal horn ratio) than monos; atrophy did not differ in other regions that aren't affected by AD; means that bilingualism does provide CR and supports hypothesis	years of education, gender mix (ratio of m:w in each group), cognitive status	

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The Contribution of Bilingualism to Cognitive Functioning and Regional Brain Volume in Normal and Abnormal Aging	Bilingualism: Language and Cognition	2021	Valeria L. Torres, Mónica Rosselli, David A. Loewenstein, Merike Lang, Idaly Vélez-Uribe, Fernanda Arruda, Joshua Conniff, Rosie E. Curiel, Maria T. Greig, Warren W. Barker, Miriam J. Rodriguez, Malek Adjouadi, David E. Vaillancourt, Russel Bauer, Ranjan Duara	We examined the association between bilingualism, executive function (EF), and brain volume in older monolinguals and bilinguals who spoke English, Spanish, or both, and were cognitively normal (CN) or diagnosed with Mild Cognitive Impairment (MCI) or dementia.	prospective (group 1) and retrospective (group 2)	neurocognitive assessments and brain imaging	MCI, cognitively normal (CN), dementia (group 1); CN, MCI	0 on BI means monolingual, 1 means bilingual; lower scores of category fluency were reported as AD	English, Spanish	found that bilingualism does contribute to brain plasticity by the result of bis being associated with higher GMV in frontal regions related to language and EF; did not fully support it increases cognitive reserve (was not telling in ages or no reduced GMV in memory-related regions); EF scores were not influenced by bilingualism (despite diff in scores); bilingual group had overall reduced interference on the Stroop test while monos had higher scores on the Digit Span Backwards and category fluency	immigration, occupation	limitations: overrepresentation of females and MCI participants; longitudinal neuropsychological performance was not assessed for V2 data in the demetia group, so they were excluded; retrospective nature of assessing age of when cognitive decline began (and limited amnt of ppl that did have that info); this study suggests that "inhibitory requirements of bilingualism may not be confined to lang control but shares resources with general EF processes;" unique mode of diagnosis criteria (LASSI-L)