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Does Language Distance Modulate the Contribution of Bilingualism to Cognitive Reserve in Seniors? A Systematic Review

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Abstract

We report a systematic review and exploratory meta-regression investigating the hypothesis that the effects of bilingualism on cognitive reserve are modulated by the distance between the pair of languages a bilingual uses. An inclusive multiple database search was performed in order to identify all relevant published research conducted in bilingual seniors. A combination of qualitative and quantitative synthesis methods were used in order to investigate our research questions. Results suggest that healthy bilingual seniors speaking more distant language pairs show improved monitoring performance on cognitive tasks. Evidence regarding a modulatory influence of language distance (LD) on the age of dementia diagnosis was inconclusive due to the small number of published studies meeting our inclusion criteria. We recommend more detailed reporting of individual differences in bilingual experience to assess the impact of LD and other variables on typical cognitive aging and the development of dementia. Linguistic differences in samples should also be considered as a constraint on bilingual advantages in future studies. Preregistration: PROSPERO CRD42021238705; OSF DOI 10.17605/OSF.IO/VPRBU.

Keywords

language distance, language similarity, bilingualism, aging, cognitive reserve, dementia, Alzheimer's disease, executive function, cognitive control

Introduction

The prevalence of dementia is growing across the globe. The number of older adults (seniors) is expected to reach 1.5 billion by 2050, with one in every 6 individuals exceeding the age of 65 at that point in time.[1] These changes, together with improved life expectancy, increase the risk that seniors presenting with cognitive decline or dementia[2,3] will generate a significant burden on healthcare systems worldwide. Thankfully, research supports individual differences in the trajectories of healthy aging, suggesting that modifiable factors may prevent or delay dementia onset.[4] Among these are improvements in education, exercise, nutrition, healthcare, and other lifestyle factors that are associated with decreased incidence of dementia in some regions of the world.[4] This potential has been captured in the concept of *cognitive reserve*, which describes individual variability in clinical status,

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functional capacity, and cognitive performance that seems preserved despite structural and functional brain changes due to aging, injury, and neurodegenerative disease.[5] One such lifestyle factor is bilingualism - the experience of speaking two or more languages - hypothesized by several researchers to be a contributing factor to cognitive reserve.[6] Evidence in support of this hypothesis is highly contested because bilingual language status is correlated with other non-linguistic factors such as access to health care, level of education, and socioeconomic status (SES). Of primary interest to the present review is a corollary to the bilingual reserve hypothesis which is that bilingualism may reduce the burden of dementia via the preservation of cognitive reserve for a longer period, manifesting as fewer cognitive impairments or a later incidence of dementia. Our goal is to address such hypotheses directly by examining reported evidence of a bilingual advantage in seniors with and without dementia. Specifically, we asked whether any reported advantages depend on the distance between languages spoken in the sample groups; the language distance (LD). The rationale for this analysis comes from conflicting reports that the bilingual advantage is more prevalent if the LD is high and other evidence suggesting the opposite, i.e., the bilingual advantage is less prevalent when LD is low.

Brain Reserve, Brain Maintenance, and Cognitive Reserve

The conceptualization of reserve, within the context of typical aging and dementia, is characterized by 3 related components: brain reserve, brain maintenance, and cognitive reserve.[5] Brain reserve and maintenance refer to neurobiological mechanisms influencing brain structure before (reserve) and during (maintenance) healthy aging. Cognitive reserve is measured via self-reported proxies, i.e., education, occupation, leisure, physical activities; as well as recently functional neuroimaging techniques.[5] Observed differences in cognitive and clinical outcomes in patients with dementia can be tested for modulatory effects of cognitive reserve on an individual basis. As cognitive reserve reflects differences in life experience, heterogeneity in the data is a characteristic finding. Some estimates of cognitive reserve such as education and literacy are not contentious,[7,8] while others, e.g., bilingualism, are debated[9,10]

Evidence shows that bilingualism impacts on cognitive processing and underlying neural substrata.[6,11-13] Reported benefits are assumed to result from managing languages simultaneously.[6,14-18] By definition, bilinguals manage competition within and between languages naturally in discourse, and this ability is supported by cognitive control.[16,19] Cognitive control allows a bilingual to monitor and detect linguistic cues, inhibit a non-target language, and activate a target language for switching between languages.[17,18] Due to neural overlap between brain structures involved in language and domain-general control, the bilingual experience of adaptive language control is proposed to generalize to non-linguistic cognitive benefits that support resilience against cognitive decline and dementia.[6,10,16,19-21]

Cognitive benefits of bilingualism are reported for executive functions which are a range of top-down, higher-order cognitive processes that support goal-directed behaviors.[22,23] Neural substrates of executive function include neural circuits in the prefrontal cortex,[24] as well as the frontoparietal, frontotemporal, frontostriatal, and fronto-cingulate networks. It has been hypothesized that the requirement for bilinguals to inhibit a non-target language during discourse should result in improved executive functions, specifically inhibition.[19] Critically, bilingual benefits on inhibitory control are assumed to be modulated by the interactional context. Thus, if speaking two languages is assumed to place greater demands on cognitive control, it is possible that LD between languages will modulate any bilingual benefits[19] (but cf.).[25] However, in light of null effects of bilingualism on inhibitory control, recent work has shifted to the process of attention as the most likely locus for the emergence of benefits.[26]

Bilingualism and Dementia

Within the study of seniors with dementia, there is some evidence that bilingualism contributes to cognitive reserve from research conducted in samples diagnosed with mild cognitive impairment (MCI) and Alzheimer's disease (AD). For example, the age at onset of these conditions is a proxy of cognitive reserve as it can be an indicator of how an individual tolerates the disease before presenting with functional and cognitive changes. Evidence supports that symptoms of these disorders can be delayed by 4-6 years in bilinguals when compared to monolinguals after controlling for correlated factors such as SES, immigration, and education.[6,27-32] Additional indirect evidence suggests that bilinguals and multilinguals with MCI may have greater cognitive reserve in this domain.[33] Bilinguals convert from MCI to AD faster than monolinguals, suggesting that bilinguals do not present cognitive decline until they reach higher levels of neurodegeneration.[34] In addition, some studies reported that speaking more than two languages (multilingualism) is also associated with better outcomes in these domains.[29,35]

Systematic reviews and meta-analyses that specifically focused on the protective effects of bilingualism against MCI and dementia report mixed findings. Some report evidence that suggests protective effects of bilingualism, particularly in delaying symptom onset and age of clinical diagnosis for both MCI[36,37] and AD,[36-39] whereas other studies report no support.[40,41] These mixed findings are not surprising given individual differences in bilingual language experience, as well as the highly correlated non-linguistic variables that need to be controlled. Other methodological issues include different inferences that can be drawn from retrospective or prospective studies (see,[40] cf.[36,37]) sample size, demographic differences outside of the English-speaking world (Anglosphere), and methods of statistical analysis. Notably, the question of whether the reported protective effects of bilingualism are influenced by linguistic features remains open.[42]

The hypothesis that bilingualism enhances cognitive reserve in healthy seniors has been investigated using a range of different methodologies.[43-45] Studies have focused on the influence of bilingualism on executive functions[10] and their neural correlates.[16,46] One signature of cognitive reserve is a dissociation between brain and cognitive measures that is identifiable when samples are matched based on one measure and compared based on the other.[5,44] Two patterns have emerged in studies making these comparisons:[44] 1) when monolinguals and bilinguals are matched on cognitive abilities, bilinguals present with a greater degree of neuropathology; 2) when matched for neuropathology, bilinguals outperform monolinguals on cognitive tasks. Bilinguals also have better clinical and cognitive outcomes compared to monolinguals at similar levels of white matter impairment.[43] In order to examine the hypothesis that bilingualism confers a cognitive advantage and therefore a delay in onset of dementia, a number of meta-analyses and systematic reviews including healthy elderly adults are available. However, these reviews reach different conclusions. For example, while some report evidence of better executive functioning in older bilinguals compared to older monolinguals[47-49] and less age-related cognitive decline,[38] others argue that this evidence is artefactual, weak or null when controlling for publication bias and therefore reject any bilingual advantage.[25,50-53]

Such reviews suggest that any benefits of bilingualism are moderated by age or task[47] (c.f.[50,51,53]), as well as the statistical control over publication bias (see Paap et al[54] and Ware et al[47] for contrasting views). Similarly, the individual characteristics of bilingual samples are under-reported, lacking descriptions of potential moderators such as the age of language acquisition, language proficiency, and the language of testing.[49,51,53] Another potential moderator is the linguistic similarity between reported languages. However, it has been entirely overlooked.[42]

Language Distance: A Potential Modulator of Bilingual Effects

Language distance (LD) can be defined according to typological differences between spoken and written languages and falls on continua in several domains (grammar, phonology, speech, writing system). There is a large scientific literature suggesting a modulatory effect of LD on the neural substrates of oral and written language processing.[55-65] For example, Tan and colleagues[66] argue that because Chinese and English writing systems are so different, they are processed in different parts of the brain. Ramanujan[65] argued this extends to South Asian languages (Hindi) and reported that written word translation activates the anterior cingulate cortex (ACC) differently during bi-literate Chinese, Dutch, and Hindi written language processing. Differences in grammatical processing across languages after brain damage are also evident in aphasia including bilingual aphasia[67] and classic reports of acquired dyslexia and dysgraphia.[68,69] Other studies suggest no differential effect of LD on neural function.[70] The LD hypothesis is therefore open to further investigation. Weekes[71] re-defined this debate as language dependent and language independent effects on brain and cognitive function but did not consider the impact on domain-general control mechanisms.

Two hypotheses have been proposed to explain how LD could potentially modulate executive functions for bilinguals at the cognitive level.[72] The first hypothesis assumes that speaking similar languages should *enhance* inhibitory control via suppression of overlapping linguistic representations, i.e., the *cross-linguistic interference hypothesis*.[73,74] This leads to the prediction that linguistically similar languages would generate the greatest advantage. The alternative hypothesis assumes that speaking similar languages requires *less* cognitive control because shared representations produce facilitatory effects during target language selection, i.e., the *cross-linguistic facilitation hypothesis*.[75-77] This hypothesis predicts that speaking dissimilar languages is more likely to stimulate attentional control, switching demands, and monitoring of working memory.[78] The interference hypothesis predicts effects for similar language pairs only. In second language learning, Antoniou[45] has conceptualized two similar mechanisms: the *processing complexity effect*, according to which learning typologically different languages leads to greater cognitive improvements because native-language knowledge is redundant, and the *interference inhibition effect*, according to which cognitive improvements result from learning typologically similar languages, e.g., presence of cognates in languages.[65]

Operationalizing Language Distance. Typologists use formal dimensions to classify languages according to modality (e.g., oral vs signed), lexical representation, phonetics, phonology, orthography, grammar, and syntax, and these can be used to categorize language pairs as similar of different, e.g., Chinese and English have similar morphosyntax but differ in phonetics, phonology, and orthography.[62] These dimensions are debated in comparative linguistics including phylogenetic studies and historical linguistics, with methods proposed to calculate language similarity according to the history of spoken languages[79–82] and there is no agreed "gold standard" measure of LD. However, for the present purpose some reported studies of bilingual samples can be classified in terms of the *relative distance* between language pairs. For example, Chinese is relatively more distant to English than Dutch is to English[65] along multiple dimensions. If LD refers to writing systems alone, the classification is more obvious i.e., more similar for Dutch-English.

Quantitative definitions of LD have also been proposed. For example, Chiswick and Miller[83] asked whether English language learners have more difficulty according to similarity with their native language. It is not clear, however, whether LD is equivalent in both directions e.g., does a native speaker of English learning German have the same difficulty as a native speaker of German learning English?[84] More definitive quantifications of LD are derived from statistical and computational approaches in which lists of selected words are compared on the percentage of common cognates (lexicostatistics)[85] or Levenshtein distance.[82] These methods offer advantages but also have disadvantages since they are not exhaustive.

Cross-linguistic corpora have been developed for the purpose of classifying LD[81,86] but mostly for Indo-European languages limiting their utility in less-studied languages. In a recent advancement, Beaufils and Tomin[87] developed a "Genetic Proximity Calculator" to calculate relatedness values, i.e., genetic proximity for language-pairs, that is freely available on eLinguistics.net. Their model quantifies LD based on comparisons of consonants between words in two languages to yield a cognate score. Consonants are used because they evolve more slowly than vowels and therefore the method is more robust to study LD.

Language Distance and Executive Function: Predictions for Reserve. To date, no studies have directly investigated the modulatory influence of LD on cognitive reserve in healthy elders or those diagnosed with dementia. It is notable that most studies conducted with seniors use bilingual samples without control over language pairs spoken, precluding an analysis of this kind[88,89] (see also the supplementary materials of Lehtonen et al).[50] Additionally, no previous reviews have examined this question in bilingual seniors. While some previous reviews have investigated the modulatory influence of LD on bilingual effects, these have been limited to data from younger samples.

Two studies of younger bilinguals support the cross-linguistic interference hypothesis. Coderre and van Heuven[73] compared English monolingual speakers, same-script bilinguals (German-English, Polish-English) and different-script bilinguals (Arabic-English) and found script similarity modulated Stroop Task performance. Similarly, Radman et al[74] compared same-script (French-English) and different script bilinguals (Persian-English) and found that French-English speakers were faster on switching tasks, suggesting greater executive control.

Other studies of young bilinguals report opposite findings. Linck et al[78] examined the effects of script similarity on inhibitory control and found the group using dissimilar scripts (Japanese-English) outperformed the group using the same script (Spanish-English). Yang et al[90] compared Spanish-English bilinguals with bi-script bilinguals (Chinese-English) and reported an advantage for the bi-scriptal group even when differences in literacy, immersion, and vocabulary scores are controlled. Similar findings were also reported by Yang and Lust (cited in)[90] comparing bi-scriptal (Korean–English) bilinguals to French–English and Spanish–English bilinguals.

The above evidence is contrary to the cross-linguistic interference hypothesis but can be explained by the processing complexity effect since learning typologically different languages is expected to enhance cognitive function. However, between group differences, including bi-scriptalism, may also explain the different performance across samples.

For the same reasons, it is premature to reject the cross-linguistic interference hypothesis based on results from between group analyses when control over individual demographic differences is incomplete.

Ghazi-Saidi and Ansaldo[91] reported results from an fMRI study comparing picture-naming in a second language (French) with young adult bilinguals speaking distant languages (Persian and French) and similar languages (Spanish-French). They found that brain activation of cognitive control areas (left inferior frontal gyrus, middle frontal gyrus, bilateral cingulate gyri) was greater during picture-naming for bilinguals who spoke distant language pairs. This evidence contradicts the cross-linguistic interference hypothesis although that hypothesis was not specifically put forward to account for brain activity which can be facilitatory or inhibitory. Ramanujan,[65] using written word translation, reported a different pattern of results whereby the ACC was found to be more active for similar script (Dutch-English) bilinguals than different script (Chinese-English and Hindi-English) bilinguals – consistent with the cross-linguistic interference hypothesis and, incidentally, contrary to the language facilitation hypothesis.

Some studies report null effects (n = 4) or ambiguous/inconclusive evidence for effects of LD with samples of children, young adults[2,52,92-94] and older adults.[88,95] Barac and Bialystok[92] compared monolingual English speakers, bilinguals using dissimilar languages (Chinese-English), bilinguals using similar languages (French-English and Spanish-English) and found no modulatory influence of LD on measures of executive function performance. Similarly, Paap et al[52] reported no effects of script similarity for a range of cognitive measures in a sample of 160 English-mixed second language bilinguals. Kirk et al[95] evaluated executive control in older adults, exploring the effects of variables associated with dialects between English monolinguals, 2 groups of English monolinguals speaking Scottish dialects, Gaelic-English non-immigrant bilinguals and immigrant bilinguals (Bengali, Gujarati, Hindi, Malay, Punjabi, Urdu-English). Results showed no effects of cultural or ethnic backgrounds or dialect in the monolingual samples. Similarly, Sörman et al[88] found no effects of bilingualism on cognitive control and thus no effects of LD. The sample was 193 bilingual seniors who spoke similar languages (Swedish – English) or more distant languages (Swedish – Finnish). However, there was no comparison with a monolingual group and bilingualism was self-rated proficiency in L2 (English) only with no objective measures.

Additional evidence relevant to LD modulation comes from Bialystok et al (2005)[93] using magneto-encephalography (MEG). The authors compared Simon task performance for 10 English monolinguals, 10 French–English bilinguals (relatively close languages) and 10 Cantonese–English bilinguals (relatively distant languages). Cantonese-English bilinguals had the fastest reaction times. However, due to small sample size this effect was attributed to sampling error. Between groups analyses in this study only also precluded strong conclusions.

Oschwald et al[72] compared young German monolinguals; German Swiss - German bidialectal bilinguals (very similar language pairs); German - same Indo-European ancestry language bilinguals, (similar language-pairs); and German - different language bilinguals (dissimilar language-pairs). Although the results showed no evidence of bilingual advantages, there was some evidence of a modulatory effect of LD, i.e., the inverse relationship between language similarity and performance on cognitive tasks except for working memory, which was better in the bidialectal bilingual group with the closest language similarity.

Laketa et al[94] compared speakers of dissimilar languages (Turkish-Albanian) and 2 similar languages (Bosnian-Albanian and Albanian-Greek). An advantage in monitoring capacity (faster reaction times and overall accuracy) was found in a group of similar language speakers (Bosnian-Albanian) compared to dissimilar language speakers and monolinguals. As Albanian-Greek bilinguals were no different to Turkish-Albanian bilinguals and monolinguals, there was no support for the cross-linguistic interference hypothesis. Although the results from the Bosnian-Albanian group were compatible with the interference hypothesis and interference inhibition effect, they should be interpreted with caution due to the between-subjects design.

The Present Study

The goal of this review was to investigate the hypothesis that LD modulates the cognitive advantages of bilingualism in seniors including possible delays in the onset or diagnosis of dementia. We operationalized LD using the measure developed by Beaufils and Tomin[87] because it allows for combinations of a range of language-pair samples reported in the literature and treats LD as a continuous variable thus supporting quantitative analyses of published data using regression models. To that end, this review performed a meta-regression to investigate whether LD modulates widely studied measures of cognitive reserve: executive function in healthy elders and the age of dementia diagnosis.

Materials and Methods

Preregistration and all steps of the review process were carried out in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines.[96] A copy of the PRISMA checklist can be found under Supplementary Materials. The protocol was preregistered on PROSPERO (CRD42021238705) and Open Science Framework (DOI 10.17605/OSF.IO/VPRBU).

Deviation From Pre-registered Protocol

Attempts were made to conduct the review as described in the pre-registered protocol. However, a number of changes were required based on findings from preliminary searches. Because the review was focused on the modulatory influence of LD on the contribution of bilingualism to cognitive reserve, a decision was made to include studies with bilingual samples only, thus excluding those with multilingual samples. For this reason, the term *bilingual* replaces *multilingual* in the review. Because LD measures were computed based on a specific pair of languages, a decision was made to include studies using samples of bilinguals who all reported speaking the same pair of languages. In addition, because preliminary searches found a majority of studies did not report data on literacy (reading and writing proficiency), the modulatory influence of these variables was not assessed in the review. Finally, a decision was made to limit the focus of the review to differences in executive function and age of diagnosis of dementia based because other inclusion and exclusion criteria would limit the number of studies identified to a meaningless number. Aside from changes noted, all pre-registered steps were followed according to the original protocol and with full peer review.

Research Questions

Our primary research question as described in the pre-registration was “does LD modulate the contribution of bilingualism to cognitive reserve in seniors?” Research sub-questions were: 1) do healthy bilingual seniors who speak more distant languages differ in executive function abilities compared to those who speak more similar languages? 2) does LD predict the age of diagnosis for dementia in bilingual seniors?

Literature Search

The goal of the literature search was to identify a complete collection of primary studies that examined the influence of LD on the primary research questions. Searches were conducted using four online databases: PubMed, Scopus, Proquest, and Web of Science. These databases were selected due to their extensive indexing of relevant journals in the biomedical and behavioral sciences, including those journals publishing previous research syntheses on our research topic. Three separate search strings were created in order to capture as much of the relevant literature as possible. To prevent accidently missing a relevant published article, we employed a more inclusive search strategy. Searches on each database and

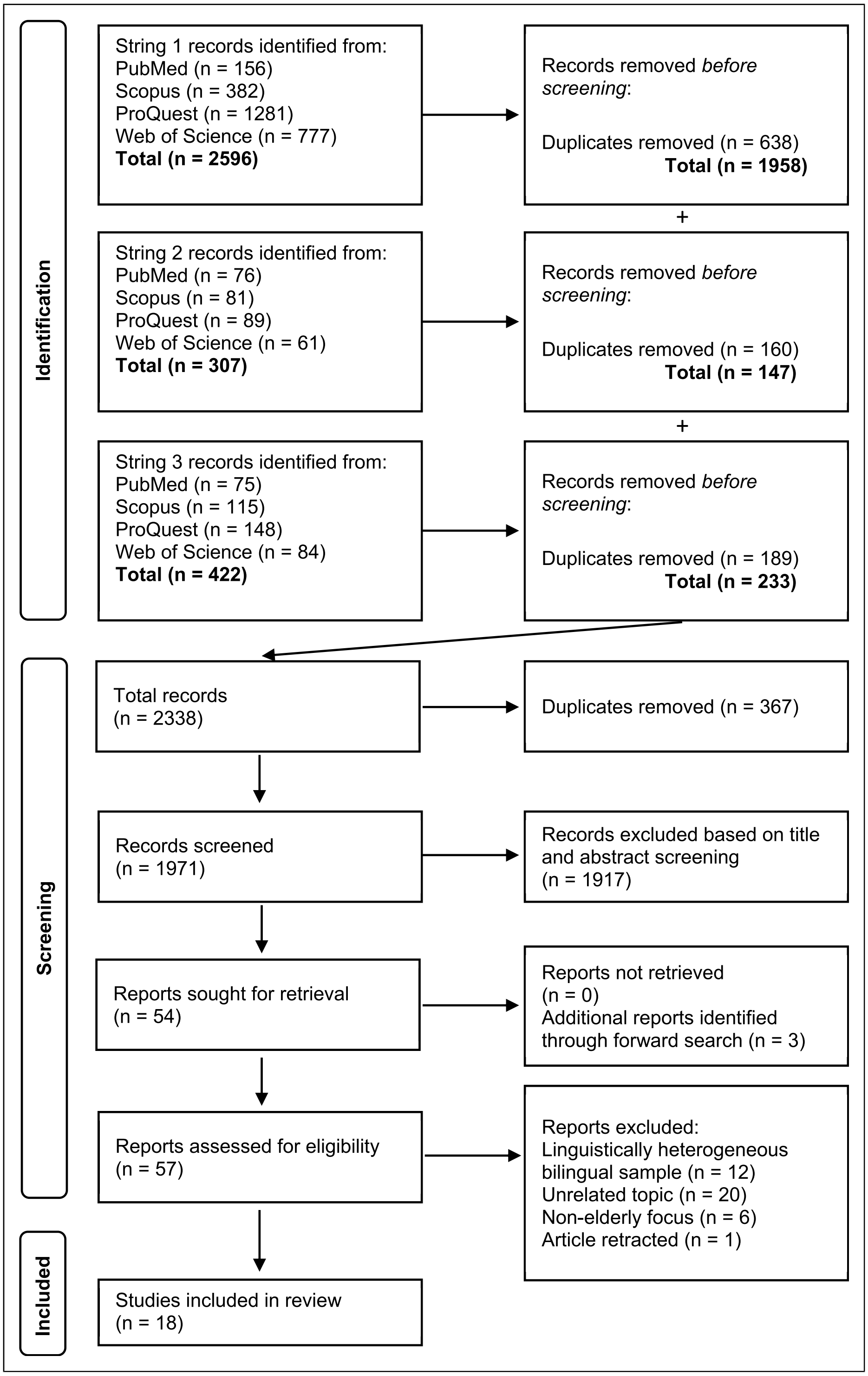

Figure 1. PRISMA flow diagram.

subsequent removal of duplicate articles were conducted by two independent researchers. Modified keywords (elder, elders, eldest) as well as different spellings (aging, ageing) were included to increase inclusivity of our searches. Final search strings for each database can be found in Supplementary Materials. Search fields were limited to article titles and abstracts and were limited to articles published on or after January 1st, 2000. This date range was selected in order to cover a sufficiently broad portion of the extant literature, and to capture work that immediately preceded the landmark paper supporting a link between bilingualism and improved executive function.[97] Searches were completed on March 2, 2021. The first search string included combinations of the keywords: bilingual, multilingual, "cognitive control", "Simon task", "attentional network task", "flanker task", "executive function", "executive control", attention, "attentional control", inhibition, "inhibitory control", shifting, monitoring, "working memory", aging, elder, older, senior, "older adult", "mild cognitive impairment", "cognitive decline", Alzheimer, and dementia. The keywords were selected to capture all relevant literature on the effect of bilingualism on executive function in healthy older adults, as well as those with dementia or cognitive impairment. The second search string included combinations of the keywords: bilingual, multilingual, "neural reserve", "cognitive reserve", aging, elder, older, senior, "older adult", "mild cognitive impairment", "cognitive decline", Alzheimer, and dementia. These keywords were selected to capture existing research on seniors assessing the presence of cognitive benefits associated with bilingualism. The third and final search string was identical to the second string, but included the additional keywords: phonology, orthography, semantics, morphology, grammar, syntax, and writing. The decision to include these keywords in a separate search string was to avoid missing studies that assessed the benefits of bilingualism in older adults but did not explicitly explore differences in language systems. Use of multiple similar search strings supported the goal of performing the most exhaustive search possible but presented us with unique challenges. While most research syntheses use a single search string to address a single research question, our search strategy resulted in the use of multiple search strings where relevant articles for multiple research questions could have been identified. For this reason, results from all search strings were combined into a single spreadsheet. After combining results from all strings, a duplicate records search was manually performed by two independent reviewers.

Eligibility Criteria

Studies had to meet the following criteria to be included in the systematic review: 1) randomized control trials, cohort studies, longitudinal studies, cross-sectional studies; 2) published in English; 3) published in a peer-reviewed journal; 4) published on or after January 1st, 2000; 5) focus on adults who are aged 60 years or older 6) included studies were conducted with bilingual samples compared with a monolingual comparison group; 6) reported one or more of the following outcomes: a) cognitive assessments; b) age of onset of cognitive decline; or, c) age of onset of dementia; d) age of clinical diagnosis of dementia. Exclusion criteria were: 1) article was a systematic review or meta-analysis; 2) unpublished research (e.g., thesis); 3) bilinguals reported using a heterogeneous mix of language pairs; 4) cognitive impairment due to non-age-related neurodegeneration (e.g., brain damage, disease, drug use, etc.); 5) articles where no full text was available.

Study Screening and Selection

Initially, two independent reviewers screened all non-duplicate search results by first reading the article title and abstract. In the event of a disagreement, both reviewers met and discussed their interpretation and application of inclusion and exclusion criteria until reaching agreement. After initial screening, the full text for all candidate articles was downloaded from the Internet. Full text screening of all candidate articles was subsequently performed by the same independent reviewers, with disagreements settled through further discussion. After the final selection of relevant articles, a forward search was further performed in order to see if any relevant more recent studies cited articles identified for inclusion. If articles were found, they were evaluated using the same inclusion/exclusion criteria above prior to consideration.

Risk of Bias Assessment

Risk of bias was assessed using checklists from the Joanna Briggs Institute.[98] For each criterion, a rating of either "Met", "Not Met", "Unclear", or "NA" was assigned for each included study. Assessment was completed by two independent reviewers with inter-reviewer reliability calculated across 20% of included studies. Disagreements between researchers were settled through discussion. No studies were excluded from the present review based on the result of our risk of bias assessment.

Data Extraction

A customized spreadsheet designed and piloted by two independent reviewers was used for data extraction. The following data were extracted from each of the included studies: 1) publication year; 2) authors; 3) county of study; 4) number of experiments included; 5) number of participants in each sample; 6) average age of each sample; 7) language(s) used by each sample; 8) language proficiency for all reported languages; 9) age of acquisition; 10) immigration status; 11) means and standard deviations for all outcomes of interest; 12) additional control variables. Inter-reviewer reliability was calculated across 20% of included research studies. Corresponding authors were contacted in the event a study did not report data needed for quantitative synthesis.

Synthesis and Analysis

A combination of quantitative and qualitative synthesis methods was used. This hybrid approach was selected due to the expectation that application of our inclusion and exclusion criteria, especially those related to linguistic makeup of bilingual samples, would result in the identification of a small number of studies for each research question. For some questions, we expected the number of identified studies would not support a quantitative synthesis at all. We also anticipated a high level of task heterogeneity across studies when assessing differences in executive function between elderly monolingual and bilingual samples. Included studies were grouped into one of two categories based on their stated aims: 1) bilingualism and executive function; 2) bilingualism and age of onset/age of diagnosis of dementia. It should be noted that, unlike a meta-analysis, the aim of the review was to investigate if LD influenced outcomes associated with cognitive reserve, not whether bilingualism conferred an advantage per se. For this reason, we did not compute a summary effect size for any outcome of interest.

Measures and Calculation of Effect Sizes. Effect sizes were calculated using extracted sample sizes, means, and SDs. Executive function task selection and the measures included for each task followed the guidance outlined in a prior meta-analysis,[50] and aligned with models of executive function.[22] To summarize briefly, measures of attention included tasks that assessed the ability to direct and maintain focus on stimuli such as the Sustained Attention to Response Task (SART),[99] elevator counting from the Test of Everyday Attention (TEA),[100] and dichotic listening tasks.[101] Given the nature of these tasks, accuracy data were extracted for analysis. Inhibition included measures of withholding a dominant response[102] as well as those that required ignoring competing information such as the Go-No Go task, the Simon task,[103] the Flanker task[104] and the Stroop.[105] When possible, interference scores were included, but incongruent trials RTs were used in the event these data were unavailable. Monitoring, which was operationalized as the ability to monitor conflict during information processing[106] included mixing costs from switching tasks and global RTs from inhibition tasks. Global RTs from switching tasks were included in the event mixing costs were not available. Shifting included paradigms that required participants to shift between tasks or mental sets such as the Wisconsin Card Sort Task[107] (WCST), the Trail-Making Test (TMT)[108] or Task Switching paradigms. For the WCST, we included perseverative errors if available, or number of completed categories as a substitute. Differences in performance between Trail B and Trail A, or, if unavailable, Trail B performance were included from the TMT. Switching costs from Task Switching paradigms were included whenever available and were substituted with switch trial RT if unavailable. Finally, working memory, which we defined as the ability to maintain and update information during processing,[109] included tasks such as span tasks (forward and backward) and N-back tasks. For studies on dementia, we extracted the average age of participants at either the onset of symptoms or diagnosis. A complete list of included tasks can be found in Table 1. The number of measures included per study differed based on the number of tasks administered and whether or not data were reported.

In studies where multiple monolingual groups were included (e.g., both English and French monolingual groups), data were pooled before the calculation of effect sizes. Data were only pooled if both groups were exclusively monolingual. We calculated Hedges' g as our measure of effect size for all studies included in our quantitative synthesis. Hedges' g was chosen because a sample size weighted pooled standard deviation is used in the calculation, correcting for biases associated with small sample size.[124] When calculating effect sizes, scores from monolingual samples were included as the control group, while scores from bilingual samples were the treatment group. In order to simplify data analysis, effect sizes from tasks where lower scores in bilingual samples were indicative of better performance (e.g., interference effect RT on a Simon task) had their corresponding signs reversed. This allowed for all positive effect sizes to reflect superior performance by the bilingual sample on any given task. Finally, effect sizes were weighted using the inverse variance method.

Quantifying Language Distance. In order to investigate the influence of LD on cognitive reserve, we set out to identify a method that would allow us to quantify the LD between diverse pairs of languages. The decision was made to adopt the genetic proximity measure, calculated using the free online "Genetic Proximity Calculator" provided by eLinguistics.net.[87] This tool provides a numerical value representing the distance between any two languages from a collection of 220 based on a comparison of 18 cognates and sound correspondence. Comparisons can be made between languages irrespective of whether they have the same writing system, and comparisons are not limited to language pairs with English. Genetic proximity values for comparisons between any two languages range from 0 to 100 with higher scores representing higher degrees of distance (i.e., decreased genetic proximity). For each identified study, the genetic proximity value for a pair of languages reported in the bilingual sample was calculated for inclusion in our analyses.

Meta-Regression. Data were analyzed using Linear Mixed-effects Models (LMEM) via the lmer function from the lme4 package (Version 1.1-27.1)[125] in R (Version 4.0.5 R Core Team, 2021).[126] Readers interested in an accessible introduction to these analysis tools are pointed to the instructional guide by Winter.[127] LMEM allows for variability within and between studies during analysis. The multilevel nature of LMEM supports the clustering of multiple effect sizes extracted from a single study, addressing the violation of the assumption of independence. For each model, weighted effect sizes were included as outcome variables and genetic proximity values were entered as predictors in the fixed-effects structure. Random-effects structures included random intercepts for each included study. Models were initially fit, and then refit after

Table 1. Summary of Characteristics of Included Studies.

Study	Location	Sample	Avg Age	Languages	LD	AoA	Proficiency	Included outcome(s)
Chertkow et al, 2010[29]	Canada	ML: 356, BL: 86	ML: 76.7 (7.8), BL: 77.6 (7.2)	English, French	48.7	Early	High	Age at diagnosis
Lawton et al., 2015[110]	USA	ML: 54, BL: 27	>60	English, Spanish	57	Not reported	Not reported	Age at diagnosis
Clare et al., 2016[111]	UK	ML: 49, BL: 24	ML: 78.8 (7.96), BL: 80.76 (6.94)	English, Welsh	66.5	Early	High	Age at diagnosis
Zheng et al., 2018[112]	China	ML: 68, BL: 61	ML: 67.3 (9.5), BL: 74.71 (9.44)	Mandarin, Cantonese	45.1	Early	High	Age at diagnosis
Bialystok et al, 2004[97]	Canada and India	ML: 10, BL: 10	ML: 71.6 (7.5), BL: 72.3 (8.7)	Tamil, English	96.5	Early	High	2-Color Simon
Salvatierra & Rosselli, 2010[113]	USA	ML: 42, BL: 58	ML: 63.40 (8.4), BL: 64.84 (7.3)	Spanish, English	57	Late	High	2-Color Simon, 4-Color Simon
Soveri et al,[101] 2011	Finland	ML: 14, BL: 16	ML: 67.6 (3.8), BL: 66.0 (4.0)	Finnish, Swedish	90.6	Early	High	Digit span (FW; BW), Dichotic listening
Kousaie et al., 2014[a] [114]	Canada	ML: 61, BL: 36	ML: 72.4 (6.5), BL: 66.0 (4.0)	English, French	48.7	Early	High	WCST, Digit span (FW; BW), SART, Verbal Stroop, Arrow Simon
Ansaldo et al., 2015[115]	Canada	ML: 10, BL: 10	ML: 74.5 (7.1), BL: 74.2 (7.4)	English, French	48.7	Late	High	Verbal Stroop, Trail making task, Digit span (FW + BW)
Antón et al., 2016[116]	Spain	ML: 24, BL: 24	ML: 68.75 (4.42), BL: 69.38 (4.58)	Spanish, Basque	97.8	Early	High	Verbal Stroop, Number Stroop
Blumenfeld et al., 2016[117]	USA	ML: 15, BL: 15	ML: 69.3 (2.1), BL: 70.3 (9.5)	English, Spanish	57	Late	High	Digit span (FW)
Clare et al., 2016 [111]	UK	ML: 49, BL: 50	ML: 72.55 (8.06), BL: 74.32 (9.03)	English, Welsh	66.5	Early	High	Spatial span (FW; BW), TEA, D-KEFS, Simon, Go-No go, Verbal Stroop
Keijzer & Schmid, 2016[118]	Holland and Australia	ML: 16[1], BL: 29	ML: 76.31, BL: 77.93	Dutch, English	27.2	Late	High	Digit span (BW), WCST, Verbal Stroop, 4-Color Simon
Berroir et al., 2017[119]	Canada and Spain	ML: 10, BL: 10	ML: 74.5 (7.1), BL: 74.2 (5.2)	English, French	48.7	Early	High	Digit span (FW; BW), Trail making task,Verbal Stroop
Zunini et al., 2019[120]	Canada and Spain	ML: 18, BL: 18	ML: 71.72 (3.54), BL: 71.39 (4.03)	English, French	48.7	Early	High	Digit span (FW; BW), WCST, Letter-number sequence, Switching task
Hui et al., 2020[121]	Hong Kong	ML: 12, BL: 38	ML: 67.8 (3.8), BL: 67.0 (4.5)	Cantonese, English	90.1	Mix	Mix	Verbal Stroop
Morrison & Taler, 2020[122]	Canada	ML: 28, BL: 29	ML: 73.46 (4.68), BL: 72.27 (4.50)	English, French	48.7	Late	High	Digit span (FW; BW), Letter-number sequence, WCST, Verbal Stroop, DMS
Rieker et al., 2020[123]	Spain	ML: 20, BL: 20	ML: 72.25 (6.38), BL: 72.65 (9.12)	Spanish, German	65.5	Late	High	Switching task

Notes: 1: Only the first study was included in the present review; 2: Only included age of diagnosis as executive function tasks were administered to a sample of patients with dementia. Only participants who completed the whole assessment were included. 3: only English monolingual group was included because Dutch monolingual group was actually multilingual;
Abbreviations: LD: language distance; ML: Monolingual; BL: Bilingual; AoA: Age of Acquisition; FW: Forward; BW: Backward; D-KEFS: Delis–Kaplan Executive Function System; TEA: Test of Everyday Attention; SART: Sustained Attention to Response Task; WCST: Wisconsin Card Sorting Test.
[a]Separate monolingual groups were combined into a single group.

removal of absolute standardized residuals exceeding 2.5 standard deviations in order to address non-normal residual distribution.[128] Degrees of freedom for *t*-tests were computing using Satterthwaite approximations.[129]

Results

Descriptive Results

The results of our search and selection process are summarized in a PRISMA flow diagram (Figure 1). After screening, a total of 18 studies were identified for inclusion in the review. Characteristics of included studies can be found in Table 1. Supplementary materials including data and code used in the present review can be accessed via Open Science Framework (https://osf.io/vprbu/).

In total, 113 separate effect sizes were extracted from included studies. The number of included effect sizes differed based on the specific measure, with 4 effect sizes representing age of diagnosis of dementia, 9 representing attention, 26 representing inhibition, 23 representing monitoring, 22 representing shifting, and 29 representing working memory. It should be noted that only one study meeting our criteria for inclusion provided data on age of onset.[112] This was determined through subjective patient and caregiver interview during the initial clinic visit at which point patients were diagnosed with AD. Three additional studies meeting our inclusion criteria reported age of diagnosis. Given the small number of studies meeting our eligibility criteria, the decision was made to focus on age of diagnosis as it was reported in all four eligible studies. Due to a mean difference of 0 between monolingual and bilingual groups for one measure of cognitive shifting, one effect size was removed bringing the total included to 112, and the total representing shifting to 21. The total numbers of bilingual and monolingual participants were respectively 561 (363 healthy older adults and 198 individuals with dementia) and 856 (329 healthy older adults and 527 individuals with dementia). Samples from included studies reported using 10 unique language pairs with average LD of 68.51 (*SD* 24.47). The most frequently reported language pair was English and French, found in 1/3 of all studies. This is likely due to the large number of studies conducted in Canada where English and French both have official language status. Furthermore, English was the dominant language in 60% of all reported language pairs sampled. Across studies, there were only two instances of language pairs in which separate writing systems were used (i.e., Tamil–English and Cantonese–English). Finally, the majority of studies in samples with early bilinguals demonstrated or reported high proficiency in a second language. It is important to note that, while reported second language proficiency was high in all but two studies,[110,121] no studies included samples of bilinguals with low proficiency. For this reason, no additional studies were removed prior to analysis.

RQ1: Language Distance and Executive Function in Healthy Seniors

To best capture the multiple theoretical models used to describe executive function, we constructed separate unified and domain specific models. Unified models (i.e., Unity Model) considered each included measure as an index of the same overarching construct of executive function.[22] Under these conditions, all effect sizes were entered into the same model as outcomes, with random intercepts for each study in order to capture inter-study variability and address issues related to the inclusion of multiple effect sizes from a single study. Domain specific models (i.e., Domain Model) were identical to unified models, but included interactions between LD and executive function domain which was sum coded as a factor with five levels, one for each of the domains: attention, inhibition, monitoring, shifting, and working memory. The selection of domains was based on theoretical models of bilingual language processing[102] and previous research syntheses.[50]

Trimming of standardized residuals exceeding 2.5 standard deviations prior to final fitting of the Unity Model resulted in removal of three effect sizes. In total, 105 effect sizes across 14 studies were included in the final model. Model residuals were normally distributed ($W = 0.99$, $p = 0.632$). Under the conditions of the Unity Model, LD did not significantly influence reported effect size $t(12.64) = 1.152$, $p = .271$. Domain Model trimming resulted in the removal of two effect sizes with absolute standardized residuals exceeding 2.5 standard deviations. In total, 106 effect sizes across 14 studies were included in the final model. Model residuals were normally distributed ($W = 0.99$, $p = 0.754$). In the Domain Model, a significant interaction between LD and the monitoring domain was identified with higher levels of LD associated with higher reported effect sizes $t(76.80) = 2.543$, $p = .013$.

RQ2: Language Distance and Dementia Diagnosis

Due to the small number of studies identified during our search, we were unable to synthesize findings for our second research question quantitatively. Four studies met inclusion criteria and comprised the following language-pairs: Mandarin-Cantonese,[112] LD = 45.1; French-English,[50] LD = 48.7; English-Spanish,[130] LD = 57 and English-Welsh, LD = 66.5. Lawton et al. (2015)[130] didn't report the age of acquisition and proficiency of their sample. The other studies were conducted with early and high-proficiency bilinguals. The four studies analyzed the protective effects of bilingualism by comparing age at clinical onset of AD[29,111,112] or dementia.[110] Zheng et al[112] compared age at the first visit for diagnosis between monolinguals and bilinguals. From these studies, only the latter found significant differences in measures between monolinguals and bilinguals, thus supporting the hypothesis of the protective effects of bilingualism against AD. This study also reported that among bilinguals the onset of AD (reported by a family member or caregiver) occurred at a significantly older age than among monolinguals. Lawton et al[110] reported no association between bilingualism and age at diagnosis of dementia whereas the other two studies found small effect sizes and in different directions. Chertkow et al[29] reported a trend for older age of AD diagnosis in the monolingual group whereas Clare et al[111] identified a non-significant finding in the opposite direction, i.e., later age of diagnosis in bilinguals. In addition, Clare et al[111] reported that bilinguals were significantly more cognitively impaired at time of diagnosis. Overall, the findings of these four studies do not help to test hypotheses of a potential impact of LD as a moderator for delaying functional and cognitive decline in dementia. Studies with similar language-pairs (Cantonese-Mandarin and French-English) found opposite results and the results of the study with the most distant language-pair (English-Welsh) tended to be similar to the findings from the study with the closest pair (Cantonese-Mandarin). Overall, the lack of suitable previous studies prevented a more thorough analysis of the influence of LD on age of dementia diagnosis, leading to qualitative results that are not conclusive and do not allow us to reject the hypothesis stated in the Introduction.

Discussion

Bilingualism induces neuroplasticity[10,44] as does education, literacy, musical training, and other lifestyle factors that contribute to cognitive reserve.[5] Some studies also support the hypothesis that bilingualism confers a cognitive advantage[44] although null findings have been reported.[40,50,52,54,131] Differences in LD may contribute to mixed results motivating the present review.

The present systematic review and meta-regression reports limited evidence that LD modulates the influence of bilingualism on executive function with consequences for the generalization of reported results across different populations.[42] Two sources of published evidence were reviewed: 1) studies with neurologically healthy seniors comparing monolinguals and bilinguals on measures of executive function and; 2) studies in which the age at diagnosis of dementia was reported comparing monolinguals and bilinguals. To test the influence of LD, only studies reporting bilingual samples that were homogeneous in terms of language-pairs were included. Results suggest LD has a modulatory influence on measures of executive function in seniors. Specifically, speaking linguistically distant language-pairs positively influences monitoring performance on cognitive tasks. Monitoring is generally not considered a separate domain of executive function but is viewed as a subcomponent of shifting and updating.[102] Given it is not agreed that bilingualism provides an advantage for any specific domains of cognition, the present results are illustrative rather than definitive in terms of addressing theoretical models. However, they do have implications for some recent conceptualizations of executive function.

Recent conceptualizations of executive function view monitoring as contributing to a broader factor.[22] Hitherto, studies of the bilingual advantage have considered monitoring as "the ability to monitor conflict in information processing and evaluate the need for cognitive control".[50] Given this approach, reported differences between monolingual and bilingual samples in mixing costs or global reaction times from tasks that present conflict were used as a proxy measure of monitoring. Since Costa and colleagues' seminal findings,[132] a range of studies have reported an influence of bilingualism on monitoring. However, a recent synthesis found this effect is weak, even when focusing only on studies in adult samples.[50] When considering our finding in light of these null results, possible explanations can be found in our exclusion of samples of bilinguals speaking different pairs of languages, and our operationalization of LD as a continuous variable. It is possible that any influence of bilingualism on monitoring is modulated by LD, and these effects only emerge in samples of bilinguals speaking the same pair of distant languages. This resonates with Lehtonen and colleagues'[50] review as they found English-Chinese bilinguals showed significantly better monitoring compared to most other language pairs. Future work comparing samples of bilinguals who are homogenous in their spoken language pair is needed to better understand the influence of LD on executive function. Furthermore, future studies should consider applying more robust statistical analyses such as mixed-effects models in order to better account for nontrivial individual differences across samples of bilinguals.[133]

One goal of this review was to investigate whether LD modulates possible delays in the onset of dementia. Only four studies fulfilled our inclusion criteria and all but one reported age of diagnosis, not the age of onset. This measure is not very robust as it can be influenced by access to medical professionals and/or subjective perception of cognitive changes. Another limitation is that retrospective and prospective studies have reached opposite findings regarding the protective effects of bilingualism against dementia. The small number of included studies along with their different design precluded a quantitative analysis. The narrative synthesis showed mixed results without any clear pattern regarding the possible influence of LD on the reported outcomes. Nevertheless, it indicated that linguistic features have been neglected as possible moderators of the protective effects of bilingualism in dementia onset or diagnosis, with current conclusions derived from studies conducted in samples speaking multiple combinations of language-pairs. This research gap questions the cross-linguistic and cross-cultural generalizability of data.[42,71,126] Our results therefore do not alter the conclusion from extant[134] studies that bilingualism does not delay the onset of dementia.[41,110,134–136] However, this does not preclude the possibility that extant findings result from a modulatory influence of LD since this is rarely considered.

Results of our meta-regression corroborate findings of previous studies with younger adults as more distant languages exert higher influence on executive function[78,90] although in our analyses any significant effects for seniors were restricted to the monitoring domain. However, the limited amount of included studies and diversity of language- pairs, along with poor descriptions of the bilingual sample profiles requires a cautious interpretation along with confirmation by future studies. A lack of reporting of individual differences across samples is a common limitation that is consistently identified in reviews of bilingual effects.[36,39,48,126]

Additional limitations of the present review relate to decisions made during the search and screening phase. Only published studies in English were included, missing relevant work in the grey literature or published in other languages. Studies that included bilingual samples speaking heterogeneous pairs of languages were also excluded. While this was a necessary step considering research questions of the review, it limited the number of included studies. In addition, our research questions were explored using a single measure of LD based on comparisons of consonants between words in two languages and does not reflect other differences between languages such as syntax or script. With these reservations in mind, our results provide some preliminary evidence that LD plays a role in bilingual effects and support the conclusions of recent meta-analyses.

Finally, the review is limited by our reliance on previous studies that adopted binary classifications of bilingualism and between-subjects designs. Recently, this view has been replaced by broad spectrum accounts that consider several dimensions of the bilingual experience and language use, so this phenomenon is currently acknowledged as dynamic and multifaceted.[130,137–140] There is growing evidence that additional differences in language experience and the features of these languages should be considered when investigating the influence of LD. Połczyńska & Bookheimer[64] proposed a set of global principles to explain how different moderators account for the neuroanatomical overlap of languages in bilinguals, with variable impacts on the efficiency for language control and cognitive effort. Linguistic features (LD and language modality) along with variables related to language acquisition (age, proficiency, exposure, and manner) are considered *primary modifiers* (i.e., affect the language neural substrate directly) whereas factors such as language switching demands of the context are proposed to exert an indirect influence on the neural substrate (*secondary modifiers)* by modulating language attainment. Some recent meta-analyses support this model by identifying influences on neural substrates related to LD. Carlegnutti et al.[62] investigated how L2-related networks change in response to LD from L1, by comparing groups of participants with English as L2 and either a European language or Chinese as L1. Irrespective of L1-L2 distance—and to an extent—irrespective of L2 proficiency, L2 recruited brain areas supporting cognitive control, although there were group-specific differences (the insula region in the European group and the frontal cortex in the Chinese group). A previous study addressed the role of using different writing systems on L2 brain representation[60] revealing that, when L2 is orthographically shallower than L1, the primary sensorimotor cortex and phonological processing areas are primarily activated, reflecting regularity in grapheme-phoneme conversion. On the contrary, when L2 is orthographically deeper, higher-order frontal regions are recruited to meet additional cognitive demands. These findings suggest that bilinguals may rely on different cognitive processes when using L2, depending also on LD. The findings of these studies point to the need to further explore how the brain is shaped by the complex interactions between primary and secondary modifiers during language development. This is a necessary step to understand the contribution of bilingualism to cognitive reserve.

The results of the current review suggest that characterization of the bilingual profile should include measures of LD between a bilingual's pair of languages. Most studies focus on speech but with advances in technology and global communications, multiliteracy needs to be addressed as a potential source of cognitive reserve and as a modulating factor of bilingual effects.[71] With a few exceptions,[90] the potential impacts of using different reading and writing systems have not been addressed. This approach requires refinement of measures of LD and can open new avenues for research in bilingualism and cognitive reserve.

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Supplemental Material

All supplementary materials including data and code used in the present review can be access on Open Science Framework (https://osf.io/vprbu/).

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