The Contribution of Bilingualism to Cognitive Functioning and Biological Markers in the Progression of Normal and Abnormal Aging

by

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Abstract

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Controversy surrounds the idea that bilingualism leads to enhanced executive function (EF) and brain volume changes, potentially leading to delays in cognitive decline and dementia onset. The purpose of this research was to explore these claims in a sample of elderly monolinguals and bilinguals. This study explored gray matter volume (GMV) in 214 monolinguals and bilinguals (M_{age} = 71.21, SD = 7.53) who were cognitively normal (CN) or diagnosed with Mild Cognitive Impairment (MCI) or dementia. Neuropsychological performance was also examined between CN and MCI monolinguals and bilinguals (N = 153) across two visits. Scores from the Digit Span Backwards, Stroop interference, Trail Making Test A minus Trail Making Test B, and category fluency average scores were used. Magnetic Resonance Imaging (MRI) brain regions associated with memory, language, and EF were selected. Additionally, the study examined how a Bilingualism Index (BI) and the age of acquisition of English could predict GMV and EF in Spanish/English bilinguals whose native language was Spanish.

Lastly, the initial age of cognitive decline across language groups was compared. Results suggested higher GMV in language and EF regions in bilinguals, but differences were not found in memory regions. Furthermore, neuropsychological performance over time did not vary across language groups; however, bilinguals exhibited reduced Stroop interference as well as lower scores on Digit Span Backwards and category fluency. The age of acquisition of English did not predict GMV or EF scores, while the BI predicted category fluency, with lower scores associated with a higher degree of balanced bilingualism. Overall, the influence of bilingualism appears to be reflected in increased GMV in specific language and EF regions relative to neuropsychological performance.

Dedication

To my husband, family, and friends for their endless encouragement and love.

The Contribution of Bilingualism to Cognitive Functioning and Biological Markers in the Progression of Normal and Abnormal Aging

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Introduction

One of the most significant controversies within the field of bilingualism research surrounds the idea that this ability grants the speaker an advantage. In general, this advantage has been associated with enhanced executive function (EF; Bialystok, Craik, & Luk, 2008; Bialystok, Poarch, Luo, & Craik, 2014b; Costa, Hernández, & Sebastián-Gallés, 2008), potentially as a result of the manipulation of two languages and the need to continually inhibit one language and manage linguistic interference (Bialystok & Craik, 2010; Green, 1998). Another branch of research portrays bilingualism as a contributor to cognitive reserve (CR; Stern, 2009), allowing bilinguals to maintain healthy cognitive function in aging regardless of existing neuropathology (Perani et al., 2017). Not every researcher has found the bilingual advantage in the aging brain (REF) and this study aimed to build knowledge into this controversy.

Bilingualism and EF

The theory of bilingualism enhancing EF originates from the idea that the habitual use of two languages requires extensive use of cognitive control mechanisms. Because a bilingual individual must rely on these abilities for effective communication, the constant practice may serve to enhance inhibitory and switching mechanisms that are part of general EFs (Rosselli & Ardila, 2018). This idea implies that bilinguals need a superior inhibitory control mechanism (Green, 1998) to maintain the inhibition of the non-target language. If this mechanism is not language-specific, bilingualism may generate advantages in specific cognitive domains. These advantages have been described with

tasks that require attentional control (Costa et al., 2008), inhibition (Bialystok et al., 2008), and spatial tasks of working memory (Luo, Craik, Moreno, & Bialystok, 2013).

Despite positive findings, there is evidence that fails to support enhanced EF in bilinguals (e.g., Hilchey & Klein, 2011). A study by Paap and Greenberg (2013) tested the bilingual advantage in inhibitory control, monitoring, and switching with three studies in a sample of young adults. Their results suggest that there is little support for an executive processing advantage, and previous results could be misinterpreting information by only using one task to evaluate EF components. The authors also stressed the importance of adequately matching the study groups in terms of education and other demographic variables. In another study, Paap, Anders-Jefferson, Mikulinsky, Masuda, and Mason (2019) did not find a bilingual advantage in inhibitory control, and the authors highlighted the possibility that this ability is task-specific and is part of a language-processing system. Therefore, bilingual language control may be unrelated to inhibition in non-verbal tasks, thereby eliminating a potential link between these two mechanisms.

Von Bastian, Souza, and Gade (2016) suggested that bilingual benefits might be related to task-specific effects and are only reported in smaller samples. Antón, Carreiras, and Duñabeitia (2019) also failed to report a bilingual EF advantage in young adults using a large sample of monolingual and bilingual participants who underwent extensive EF testing. The study groups were matched for age, IQ, socioeconomic status, education, and immigrant status. Language competence was determined with a self-report questionnaire (age of acquisition, proficiency, and exposure), and an interview.

There is research focusing on different features pertinent to bilingualism to test the EF advantage. Sörman, Hansson, and Ljungberg (2019) included two different

bilingual language samples to explore the effect of linguistic distance (Swedish/Finnish and Swedish/English) and failed to identify a bilingual advantage in adults between the ages of 50-75. This research used bilingualism as a continuous measure as well as L2 proficiency and employed six executive tasks associated with cognitive control in a large sample. Furthermore, in a recent meta-analysis, Lehtonen et al. (2018) considered a wide range of moderating variables (e.g., task paradigm, testing language, group matching, among others) and concluded that publication bias is likely responsible for the positive associations between bilingualism and EF advantages.

Bilingualism has also been associated with disadvantages, specifically on verbal tests (e.g., fluency tests; Gollan, Montoya, & Werner, 2002; Lehtonen et al., 2018), perhaps as a result of the increased linguistic interference between languages (Rosselli et al., 2000) and reduced exposure for each language when both are used comparably (Lehtonen et al., 2018).

Bilingualism and Reserve

In addition to enhanced EF, bilingualism may contribute to reserve: cognitive (CR; Stern, 2009) or brain reserve (BR; Katzman, 1993). CR is considered an active and modifiable type of reserve by which the brain attempts to cope with existing damage by using preexisting cognitive processes. On the other hand, BR is a passive type of reserve derived from neuronal count or overall brain volume. BR differs across individuals; therefore, the functional capacity to deal with brain injury (e.g., neurodegenerative diseases) also varies. Accordingly, an individual with greater brain volume may sustain a higher degree of atrophy before demonstrating impairment.

Because of the demands on language control systems, bilingualism might alter the relationship between observed neuropathology and clinical performance by increasing bilinguals' reserve. Individuals with higher reserve could withstand greater neuropathology before showing cognitive impairment compared with individuals with lower reserve. This theory has garnered more attention due to the idea that increasing reserve might delay the onset of neurodegenerative diseases such as Alzheimer's disease (AD; Bialystok, Craik, Binns, Ossher, & Freedman, 2014a).

Researchers suggest that as a result of higher CR, bilinguals display symptoms of dementia at a later age than monolinguals (Fischer & Schweizer, 2014; Perani & Abutalebi, 2015; Perani et al., 2017). For example, Alladi et al. (2013) reported that in their sample of Indian bilinguals (some spoke more than two languages), there was a 4.5-year delay in the onset of AD, frontotemporal, and vascular dementia, after controlling for education. The bilingual group in this study reported speaking a wide range of languages, and, as emphasized by Paap, Johnson, and Sawi (2016), also included a higher proportion of men and individuals from an urban setting and had higher education. Bialystok, Craik, and Freedman (2007) also reported a four-year delay in dementia symptoms in bilinguals compared to monolinguals. Woumans et al.'s (2015) reported that bilinguals exhibited a delay of 4.6 years in symptom manifestation and 4.8 years in AD diagnosis compared to monolinguals. This research included AD monolingual and bilingual participants who reported Dutch as the native language and either Dutch or French as L2; however, individuals with other linguistic backgrounds were also included. Language status was determined based on proficiency and frequency of use of the second language (L2).

A delay in the onset of pathological conditions might occur because bilinguals have a higher capacity for withstanding neurological damage associated with neurodegenerative diseases, perhaps by more effectively using brain resources (Guzmán-Vélez & Tranel, 2015). As a result of this reserve, in a comparison of monolingual and bilingual groups matched by demographic variables, bilinguals would be expected to exhibit greater neurodegeneration, but comparable severity of clinical impairment compared to their monolingual counterparts. Besides delays in the onset of dementia, research by Kavé, Eyal, Shorek, and Cohen-Mansfield (2008) examined cognitive performance in older individuals and reported that the number of languages spoken was associated to performance, with multilingualism (speaking four or more languages) offsetting cognitive decline associated with aging. However, due to the lack of a monolingual control group in this study, the independent effects of language status cannot be definitively established.

Gold (2015) suggested that the mechanism underlying the delay in dementia diagnosis in bilinguals may result from a compensatory strengthening of executive control (EC) brain circuits, which in turn protects frontostriatal and frontoparietal networks. This explanation, therefore, lends support to both bilingualism theories, with the EF-bilingualism link acting as the underlying mechanism in the bilingualism-reserve link. The additional effort put forth by bilinguals to control their languages may be part of a general EC system, explaining the enhanced EF in bilinguals; consequently, these enhanced abilities compensate for the missing resources resulting from a neurodegenerative disease. García-Pentón, Pérez Fernández, Iturria-Medina, Gillon-Dowens, and Carreiras (2014) examined network connectivity and found two sub-

networks of regions with stronger connectivity in bilinguals compared to monolinguals, with the networks including left frontal parieto-temporal regions. The authors suggested that the sub-networks develop to support the complex linguistic demands in a bilingual individual.

Consistent with the theory of CR, aging bilinguals appear to exhibit increased damage in several brain regions. For instance, Schweizer, Ware, Fischer, Craik, and Bialystok (2012) found that bilinguals with AD had higher brain atrophy in the temporal horn (an area that is used to distinguish AD patients from healthy adults) than a group of monolinguals who were matched on the degree of clinical severity and the level of cognitive function. In this study, language status was determined by asking the participant (and, if applicable, a significant other) whether they were fluent in another language and whether this language had been consistently used. Perani et al. (2017) evaluated monolingual and bilingual AD patients and found that, despite the greater extent of cerebral hypometabolism in bilinguals, this group outperformed the monolinguals on verbal memory and visuospatial tasks but not language tasks. Additionally, the bilingual group exhibited enhanced connectivity in a network related to cognitive control, suggesting a compensatory mechanism to explain their increased cognitive performance. Participants completed a language background questionnaire assessing use and exposure, among other factors. A bilingual index ranging from zero (completely monolingual) to one (bilingual; using both languages daily for an equal amount of time) was used. Recently, Costumero et al. (2020) compared matched samples of monolingual (Spanish) and bilinguals (Spanish/Catalan) and found that MCI bilinguals exhibited higher brain atrophy despite performing similarly on cognitive tests. These

differences were found in the lingual and supramarginal gyrus, which are typically affected in AD (Schwindt & Black, 2009). Longitudinal analyses by Costumero et al. (2020) also demonstrated that monolinguals had higher brain atrophy and more cognitive decline than bilinguals in a follow-up visit.

Despite greater and sometimes more extensive damage, bilinguals (cognitively normal and those diagnosed with AD) in these studies had equivalent cognitive performance compared to matched monolinguals.

Luk, Bialystok, Craik, and Grady (2011a) suggested a possible mechanism for a delay in dementia onset. In their study, healthy older bilinguals had better maintenance of white matter (WM) integrity in the corpus callosum, bilateral superior longitudinal fasciculi, as well as right inferior frontal-occipital fasciculus and uncinate fasciculus. The monolingual participants reported only using English to communicate, while bilinguals reported the use of English and another language. The groups were matched by gender and age; however, the participants' languages varied. De Frutos-Lucas et al. (2019) used magnetoencephalography in a sample of late bilinguals and found increased functional connectivity (FC) in clusters related to language processing. The authors suggested that the enhanced FC of posterior regions in their bilingual sample could be the mechanism underlying the protective effects against AD, suggestive of higher BR, or greater flexibility in the face of aging because of higher CR. Participants in this study completed a questionnaire regarding the following: whether they spoke another language (besides Spanish), proficiency and frequency of use in L2, age of acquisition, and whether they had lived in a region where a language besides the native language was spoken. Individuals who rated their L2 proficiency as 'good' or 'very good' were included and

classified as bilinguals. The monolingual and bilingual groups were matched in cognitive status, age, and education. In general, it appears that through the maintenance of WM tracts, bilingualism might serve as a protective mechanism.

Gold, Johnson, and Powell (2013) also examined white matter (WM) integrity in cognitively normal groups of matched bilingual and monolingual participants. Unlike Luk et al.'s (2011a) findings, however, Gold et al. (2013) reported that bilinguals had lower WM integrity in the inferior longitudinal fasciculus/inferior fronto-occipital fasciculus, fornix, and in some corpus callosum regions. These pathways connect structures implicated in AD (e.g., the hippocampus), and some of the changes reported in these results are typically observed in MCI and AD. In this study, a questionnaire assessed language history (age and place of acquisition and proficiency). Lifelong bilinguals in this study included individuals who had been speaking English and another language daily since age 10 (or younger) and reported proficiency in both languages and a similar language proficiency compared to a monolingual. The bilinguals' L2 varied. Gold et al. (2013) suggested that the conflicting results from this study and Luk et al.'s (2011a) resulted from a higher incidence of preclinical AD in their sample, which could explain the reduced WM integrity. It is important to note, however, that the bilingual sample in Luk et al.'s (2011a) study had a mean age of 70.3 (*SD* = 3.8) and monolinguals were 70.6 years old (*SD* = 3.1), while Gold et al.'s (2013) sample was younger, with a mean age of 64.5 (*SD* = 5.1) and 63.9 (*SD* = 4.0) for monolinguals and bilinguals, respectively. Although, the reason for the discrepant results is unknown, the age of the participants could have been a contributing factor.

Besides higher connectivity, the inferior parietal lobule (IPL) and inferior frontal gyrus (IFG) also differ between monolinguals and bilinguals. Recently, Heim et al. (2019) examined GMV in IPL and IFG in a large sample of monolingual (n = 224) and bilingual (n = 175) participants. A language questionnaire was used, and participants who could speak, understand, read, or write in at least two languages were classified as bilingual. However, the L2 of the bilingual group varied. Their results suggested that bilinguals have higher GMV in the left IPL and left IFG than monolinguals only in younger ages, and the normal decline associated with age was faster in bilinguals but differed across regions; it occurred later in the IPL than the IFG. The authors concluded that the increased 'reserve' in linguistic areas diminished with age at a faster pace than the 'reserve' in nonlinguistic areas. Duncan et al. (2018) obtained similar findings when comparing multilingual (over half were bilinguals, the rest spoke three or more languages) and monolingual participants, diagnosed with MCI and AD. Multilingual AD patients had thinner cortex and lower tissue density in AD-related regions (implying higher CR), as well as more GMV in areas associated with language and cognitive control (e.g., bilateral IFG and right ventromedial prefrontal cortex, among others). Noteworthy, this study found similar results with a non-immigrant MCI sample; however, these researchers did not include a healthy control group for a more accurate comparison. The multilingual group reported using at least two languages (mostly English, French, and another third language) regularly; however, the specifics of proficiency and age of acquisition were not available. Monolinguals stated only speaking one language (English or French). Finally, Costumero et al. (2020) also reported lower GMV in MCI bilinguals compared to monolinguals in regions affected by AD (i.e.,

lingual and supramarginal gyrus). The monolingual sample included individuals who only spoke Spanish but who lived in a bilingual region and could, therefore, be considered passive bilinguals due to their likely ability to understand Catalan.

Despite these findings describing differences across language groups, several studies fail to support a bilingualism-reserve link. For example, Crane et al. (2009) found that L2 writing fluency did not protect against cognitive decline. Similarly, Yeung, St John, Menec, and Tyas (2014) did not find a link between bilingualism and dementia risk in a 5-year longitudinal study. Zahodne, Schofield, Farrell, Stern, and Manly (2014) also failed to find a protective effect of bilingualism on cognitive decline or conversion to dementia in a sample of bilingual immigrants who were born and raised in Spanish-speaking countries. However, bilinguals performed better at baseline on memory and EF tasks. Finally, Mungas, Early, Glymour, Zeki Al Hazzouri, and Haan (2018) did not report a relationship between bilingualism and the rate of cognitive decline in a large longitudinal study with a sample of monolinguals and bilinguals.

Delayed dementia onset in bilinguals may only appear in retrospective studies that rely on self-reported memory complaints (Mukadam, Sommerlad, & Livingston, 2017). Similarly, the mixed results behind the protective effect of bilingualism on aging were described in a recent review, which discussed relevant factors (e.g., immigration, education, profession) that influence the impact of bilingualism (Van den Noort et al., 2019). The authors emphasized the importance of using neuroimaging data and objective behavioral measures to strengthen this line of research.

Besides the contradictory results, additional challenges include the precise ways of assessing and quantifying CR, mainly because of the large overlap between other

factors that could increase CR (e.g., education). Gollan, Salmon, Montoya, and Galasko (2011) found that the degree of bilingualism was associated with the age of AD diagnosis, but only in Hispanics with low levels of education.

Research Aims and Hypotheses

In general, research appears to suggest that the beneficial effects of bilingualism in aging are associated with its protective and enhancing effects over brain networks and regions related to EF and language (García-Pentón et al., 2014; Luk et al., 2011a). Numerous studies do not support a delay in the onset of symptom or dementia diagnosis, and instead, emphasize the inconsistent findings and methodological concerns (Mukadam et al., 2017; Yeung et al., 2014).

The contentious association between bilingualism, its benefits, and the age of onset of dementia and cognitive decline might be partially attributed to different language assessments used across studies. Some of the commonly employed questionnaires include the Language Experience and Proficiency Questionnaire (Marian, Blumenfeld, & Kaushanskaya, 2007), the Acculturation Rating Scale for Mexican Americans (Cuellar, Arnold & Maldonado, 1995), the Language and Social Background Questionnaire (Anderson et al., 2018), or other scales inquiring "How well do you speak?', corroborated with achievement tests (e.g., Zahodne et al., 2014). Additionally, different criteria are often used to categorize samples into monolinguals and bilinguals. For instance, Heim et al. (2019) determined language status based on L2 proficiency and frequency of use, while Sörman et al. (2019) asked participants to rate the level of bilingualism on a scale from 0 (monolingual) to 10 (bilingual). Costumero et al. (2020) inquired about the age of acquisition of both languages, language proficiency ratings, and language use. It is

evident that there is not a straightforward standard for classifying participants into monolingual and bilingual groups.

Researchers emphasize the importance of the following criteria when conducting bilingualism research: a) the consideration of the age of acquisition of the L2; b) ensuring that all bilingual participants are proficient in the same languages; c) the inclusion of a monolingual control group; d) utilizing longitudinal data to explore changes associated with disease progression (Calvo, García, Manoiloff, & Ibáñez, 2016); e) the use of more than one EF measure derived from separate tasks to minimize the possibility that performance differences are task-specific (Paap, Johnson, & Sawi, 2015); and f) the inclusion of neuroimaging assessments (Van den Noort et al., 2019).

Furthermore, if different bilingualism assessment and classification methods partially underlie the discrepant results, it is essential to look beyond the dichotomy of monolingual-bilingual and examine variables associated with this ability to understand whether a specific aspect of the bilingual experience is responsible for the advantages and disadvantages. The benefits of bilingualism could be a result of the age of acquisition of L2 (Luk, de Sa, & Bialystok, 2011b) or language similarity (Bialystok, 2017). Another relevant factor is proficiency levels and language balance (Rosselli, Ardila, Lalwani, & Velez-Uribe, 2016; Yow & Li, 2015). However, a recent study failed to identify EF differences between low and high proficiency bilinguals (Mishra, Padmanabhuni, Bhandari, Viswambharan, & Prasad, 2019). It is worth noting, however, that this study did not include a monolingual control group.

Soveri, Rodriguez-Fornells, and Laine (2011) examined whether bilinguals' rate of language switching, age of acquisition of L2, or language use, was predictive of EF

performance. Their results suggested that language switching was the most relevant factor leading to performance changes in bilinguals between the ages of 30-75.

The present study analyzed differences between monolinguals and bilinguals in the GMV of memory-related regions and frontal regions associated with EF and language. Additionally, to explore the effects of bilingualism on neuropsychological performance, this study compared EF scores during two visits in a cognitively normal (CN) sample and in those diagnosed with Mild Cognitive Impairment (MCI). Four neuropsychological EF and language tasks were used: Digit Span Backwards (Wechsler, 2014a); Trail Making Test (Reitan & Wolfson, 1986, 1993); Stroop Color-Word Interference (Stroop, 1935; Trenerry, Crosson, DeBoe, & Leber, 1989), and category fluency average scores. These analyses were also conducted with a dementia subsample during the first visit. In addition to monolingual and bilingual comparisons, a Bilingualism Index and the age of acquisition of English (within the Spanish/English bilingual sample) were used to predict the neuropsychological performance and GMV regions that differed between the language groups.

Consistent with previous findings (Duncan et al., 2018), it was predicted that bilinguals would exhibit greater GMV in EF and language regions, but a higher degree of GMV loss in memory-related regions (in the MCI and dementia groups). Additionally, it was expected that bilinguals would outperform monolinguals on EF tasks except those with a strong verbal component (e.g., category fluency), as there is research suggesting that the interference resulting from bilingualism is associated with lower scores on verbal tasks (Rosselli et al., 2000). Additionally, the Bilingualism Index, indicating linguistic proficiency balance, was expected to be the most significant predictor of EF performance,

as previous findings support an association between these individual bilingual components and EF performance (Rosselli et al., 2019; Yow & Li, 2015). Lastly, bilinguals were expected to be older when cognitive symptoms were first observed.

Method

Participants

Participants were part of the 1Florida Alzheimer's Disease Research Center (ADRC), a 5-year longitudinal study that began in 2015 at the Mount Sinai Medical Center in Miami Beach, Florida. Three subsamples were included for the analyses: a) CN, MCI, and dementia participants with Magnetic Resonance Imaging (MRI) data; b) CN and MCI participants with longitudinal neuropsychological data; and c) dementia participants.

The first subsample included 214 participants with MRI data (M_{age} = 71.21, *SD* = 7.23), of which 75 were CN, 106 were diagnosed with MCI, and 33 with dementia. Within this sample, 124 participants were classified as bilinguals; 115 of these were Spanish/English bilinguals, 8 were English/Spanish bilinguals, and one was a simultaneous bilingual. Out of the 90 monolingual participants, 72 were English monolinguals, and 18 were Spanish monolinguals (see below for a description of the language groups). See Table 1.

The 72 English monolinguals and 13 bilinguals were born in the US. One hundred eleven bilinguals were immigrants from a Latin American country (including Puerto Rico). See Figure 1 for the country of origin distribution of the whole sample. The average age of immigration to the US for all participants was 25.51 (*SD* = 16.47), and these individuals had lived in the US for an average of 45.55 (*SD* = 15.83) years. For the Spanish monolingual group, the average age of immigration to the US was 36.28 (*SD* =

11.25), with an average of 35.44 years (*SD* = 11.97) living in the US. Lastly, for the bilingual group, the average age of immigration was 23.76 (*SD* = 16.55), and this group had lived in the US for an average of 47.19 years (*SD* = 15.82).

For the longitudinal analyses, 171 participants with Visit 1 (V1) and Visit 2 (V2) neuropsychological evaluations were included. This subsample included 66 CN, 87 MCI, and 18 dementia participants. Within the dementia group, there were six monolingual and 12 bilingual participants. Due to the limited number of available V2 data for the dementia sample and the uneven language group distribution, this diagnostic group was excluded from the longitudinal analyses. Separate cross-sectional analyses were done to examine this group's performance on V1 EF tests. The final sample used for the longitudinal analyses included 153 participants (64.7% female), 66 CN, and 87 MCI, with a mean age of 70.97 (*SD* = 6.93). This subsample included 63 monolinguals and 90 bilinguals. Within the bilingual sample, there were 83 Spanish/English bilinguals and 7 English/Spanish bilinguals. Within the monolingual sample, 50 were monolingual English speakers, and 13 were Spanish monolinguals. See Table 2.

The dementia subsample (*n* = 33) had a mean age of 72.18 (*SD* = 10.06) and included 19 bilinguals (18 of whom were Spanish/English bilinguals) and 14 monolinguals (11 English monolinguals). See Table 3.

Participants were assessed with a comprehensive neuropsychological battery, and for eligible participants, MRI scans were completed at the Mount Sinai Medical Center in Miami Beach, Florida, during V1.

The time between V1 and V2 ranged from 10 to 33 months (*M* = 14.04, *SD* = 3.34). This variable did not differ between diagnostic or language groups, $p > .05$.

Moreover, Spearman's correlations suggested that the visit interval was not associated with neuropsychological change scores from V2 and V1; therefore, it was excluded from the analyses.

Exclusion criteria. Participants who met the following criteria were excluded: a) presence of motor or sensory deficits and/or psychiatric disorders; b) born outside of the US or in a non-Spanish-speaking Latin American country; c) no Language Experience Acquisition Proficiency Questionnaire (LEAP-Q; Marian et al., 2007) data; and d) first and second languages besides English and/or Spanish.

Diagnosis

Participants were diagnosed according to the following criteria:

The CN group did not report memory deficits or impairment in daily function. This group had a Global Clinical Dementia Rating Scale (CDR; Morris, 1993) of 0, and did not show indications of cognitive decline upon clinical interview. The CN group had standard neuropsychological measures scores less than 1 SD below expected levels related to age, education, and culturally related norms on the following measures: a) Delayed Recall of the Hopkins Verbal Learning Test-Revised (HVLT-R; Brandt, 1991), b) Delayed Recall of the National Alzheimer's Coordinating Center (NACC) story passage (Beekly et al., 2007); c) category and letter fluency (Benton & Hamsher, 1976), d) Block Design of the Wechsler Adult Intelligence Scale (WAIS-IV; Wechsler, 2014a), and e) Trail-Making Test B (TMT-B; Reitan & Wolfson, 1993).

The MCI group had memory complaints confirmed by a reliable collateral informant, no impairment in their daily life activities, and had scores on the HVLT-R (Brandt, 1991) or NACC story delayed recall (Beekly et al., 2007) of 1.5 SD or greater

below what is expected using the same normative data listed for the CN group above. Other non-memory measures (such as the TMT-B and category fluency) could be 1.5 SD or greater above or below the mean, but a memory deficit had to be established. This group had a CDR of 0.5 and met the criteria for mild neurocognitive disorder according to the Diagnostics and Statistical Manual and Mental Disorders (DSM-5; American Psychiatric Association, 2013).

Individuals with dementia had a CDR of 1.0, scores more than 1.5 SD below the mean on memory and non-memory measures. This group also met the criteria for major neurocognitive disorder, and clinically, this group also met the criteria for probable AD (McKhann et al., 2011).

Materials

Language Experience and Proficiency Questionnaire (LEAP-Q)

The LEAP-Q (Marian et al., 2007) was used to create monolingual and bilingual groups for language group comparisons. If a participant reported an average English or Spanish proficiency of 3 (“fair”) or more in speaking, understanding, and reading, they were considered bilingual; otherwise, they were classified as monolinguals. The order of language acquisition was determined from participant responses.

Two bilingualism-related variables from the LEAP-Q within the Spanish/English bilingual sample were used: a Bilingualism Index (BI) and the age of acquisition of L2.

Bilingualism index (BI). The lower average LEAP-Q proficiency score (speaking, understanding, and reading, in one language, English or Spanish) was divided by the higher average LEAP-Q proficiency score (speaking, understanding, and reading, in the other language). Participants rated their proficiency on a 0 to 10 Likert scale (0 =

none, 1 = very low, 2 = low, 3 = fair, 4 = slightly less than adequate, 5 = adequate, 6 = slightly more than adequate, 7 = good, 8 = very good, 9 = excellent, 10 = perfect). The index resulted in scores ranging from zero (monolingual) to one (bilingual), providing information about the balance of an individuals' bilingual abilities.

Rosselli et al. (2019) used this measure in their study, and Gollan et al. (2011) originally developed a similar bilingualism index using scores from the Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1983), dividing the proportion of pictures named correctly in one language by the proportion of pictures named correctly in the other language.

Age of acquisition. Participants reported the age when they began acquiring the L2 (i.e., English).

Digit Span Backwards

Participants are read a sequence of one-digit numbers and asked to repeat the sequence in the reverse order. The Digit Span Backwards is considered a task of EF, specifically, working memory (WM; Hilbert, Nakagawa, Puci, Zech, & Bühner, 2015; Miyake et al., 2000).

Trail Making Test

The TMT consists of parts A and B. During Part A, participants are instructed to connect 25 circles numbered from 1 to 25 as quickly as possible. During Part B, participants are asked to connect circles with numbers and letters while alternating and maintaining numerical and alphabetic order (Reitan & Wolfson, 1986). Participants are allowed 150 s for part A and 300 s for part B. Errors are corrected by the experimenter as soon as they occur. The time to complete TMT B minus time to complete TMT A (TMT-

B-TMT-A) was used, as this difference score has been suggested to assesses cognitive flexibility and switching without considering dexterity (Corrigan & Hinkeldey, 1987; Kopp, 2011; Reitan, 1958).

Stroop Color-Word Interference Test

A measure of inhibitory control and interference, the Stroop test (Stroop, 1935; Trenerry et al., 1989), requires participants to inhibit reading a word (a color) while correctly identifying the ink color of the text. Participants completed color (C), word (W), and color-word conditions (CW), with 45 s given for each. Predicted CW scores were calculated with the following formula: (WxC)/(W+C). Subsequently, this value was subtracted from the CW score. Interference scores indicate the degree to which the participant can control interference.

Category Fluency

Participants are instructed to name as many animals, fruits, and vegetables in 60 s per category. Incorrect words include proper names, numbers, repetitions, or words sharing similar roots. The average score of the three categories was used. This fluency task involves language and EF, and lower scores are reported in AD compared to normal controls (Weakley & Schmitter-Edgecombe, 2014).

A similar index was derived to assess the validity of the BI. Scores on category fluency in one language (English or Spanish) were divided by the other, resulting in an objective measure (relative to the BI) regarding fluency balance in bilinguals' languages. This index resulted in scores ranging from 0 (monolingual) to 1 (bilingual), and positively correlated with the BI, $r = .50$, $p < .001$.

Procedure

Participants were evaluated in a one-day session with a lunch break. Monolingual European American participants were evaluated in English; monolingual Hispanic participants were tested in Spanish. Bilingual participants selected their preferred language of evaluation (English or Spanish). In these cases, neuropsychological tests were administered by fluent English/Spanish bilingual psychometricians. Out of 135 Hispanic participants, 71.9% were evaluated in Spanish.

Participants completed a comprehensive neuropsychological evaluation that assessed several cognitive domains. Verbal memory was measured using the Loewenstein Acevedo Scales of Semantic Interference and Learning (LASSI-L; Curiel et al., 2013), HVLT-R (Brandt, 1991), the Craft Story (Craft et al., 1996), and Logical Memory (Abikoff et al., 1987); confrontation naming was tested with the Multilingual Naming Test (Gollan, Weissberger, Runnqvist, Montoya, & Cera, 2012); visuospatial cognitive functioning was evaluated with the Benson Figure Drawing (Possin, Laluz, Alcantar, Miller, & Kramer, 2011) and WAIS-IV Block Design (Wechsler, 2014a); overall cognition was assessed using the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) and the Montreal Cognitive Aassessment (Nasreddine et al., 2005); EF was appraised using the Stroop Color-Word Interference test (Stroop, 1935; Trenerry et al., 1989), TMT-A and -B (Corrigan & Hinkeldey, 1987; Reitan & Wolfson, 1993), and Digit Span (Wechsler, 2014); and verbal fluency was assessed with category and letter fluency (Benton & Hamsher, 1976).

Spanish evaluations were completed with equivalent standardized neuropsychological tests and had appropriate age, education, and cultural/language

normative data for the translated versions (Arango-Lasprilla et al., 2015a; Arango-Lasprilla et al., 2015b; Benson, de Felipe, Xiaodong, & Sano, 2014; Golden, 1999; Gollan et al., 2012; Ostrosky-Solís, López-Arango, & Ardila, 2000; Peña-Casanova et al., 2009a; Peña-Casanova et al., 2009b; Peña-Casanova et al., 2009c; Wechsler, 2014b).

Imaging

MRI scanning was done using a Siemens Skyra 3T MRI scanner at the Mount Sinai Medical Center. Brain parcellation was obtained utilizing a 3D T1-weighted sequence (MPRAGE) with 1.0 mm isotropic resolution. FreeSurfer Version 5.3 software (http://surfer.nmr.mgh.harvard.edu) was used (Loewenstein et al., 2017).

Bilateral brain regions from MRI scans that are associated with memory (hippocampi and entorhinal cortex; Henneman et al., 2009; Leandrou et al., 2018), EF (orbitofrontal cortex [OFC]; Bryden & Roesch, 2015), and language (inferior frontal gyrus [IFG]; Duncan et al., 2018) were selected. For the OFC, the medial and lateral OFC were added. For the IFG, the pars opercularis, pars orbitalis, and pars triangularis were added. GMV measurements were corrected for total individual intracranial volume.

Statistical Analyses

Two one-way Welch's ANOVAs were used to compare English and Spanish proficiency between the language groups, as the Levene statistic indicated unequal variances. Within the bilingual group, a Repeated Measures (RM) General Linear Model (GLM) was used to compare English and Spanish proficiency.

Six 2X3 Univariate GLM analyses were used to compare the language and diagnostic groups on the GMV of bilateral regions associated with language (IFG; two), EF (OFC; two), and memory (hippocampi and entorhinal cortex; four). Age, education,

and sex were included as covariates. Similarly, six linear regressions were used to examine the predictive value of being bilingual over these regions, using age, education, sex, language group, and diagnostic group as predictors. The Bonferroni correction was used to adjust for multiple comparisons; this resulted in alpha values of .025 for the language and EF regions, and .013 for memory regions.

Four 2X2 RM GLM were used to compare the performance of the language (monolingual and bilingual) and diagnostic groups (CN and MCI) on the following EF tests over two visits: Digit Span Backwards (Wechsler, 2014a), TMT B-TMT-A (Reitan & Wolfson, 1993), Stroop interference (Stroop, 1935; Trenerry et al., 1989), and category fluency average scores. Age, education, and sex were included as covariates.

Spearman's rank correlations were used to explore the relationship between the EF scores during V1 and the GMV of regions related to memory, language, and EF. Due to unequal language group sizes, Fisher r-to-z transformations were conducted to test whether the correlation coefficients differed between the groups (VassarStats; Lowry, n.d.).

The predictive value of two variables related to bilingualism (Bilingualism Index [BI] and the English age of acquisition) was assessed with linear regressions in Spanish/English bilinguals. These analyses were conducted for EF tests and GMV in areas with language group differences from previous analyses. The bilingualism variables were used as predictors of the following: a) EF test performance (Digit Span Backwards, Stroop interference, and category fluency); b) GMV in left IFG; and d) GMV in bilateral OFC. These analyses included age, education, sex, language, and diagnostic group as

predictors. Using the Bonferroni correction, the alpha value was set at .008 for EF tests, .025 for the left IFG, and .013 for bilateral OFC.

Lastly, one 2X3 Univariate GLM compared the language groups in the age in which cognitive symptoms began. Age, education, and sex were included as covariates.

Results

Language Proficiency (LEAP-Q) of Monolinguals and Bilinguals

The average English and Spanish proficiency levels of the monolingual and bilingual groups did not differ. Within the bilingual group, Spanish proficiency was significantly higher (M = 9.16, SD = 1.21) than English proficiency (M = 8.32, SD = 1.66), $F(1,123)$ = 19.25, $p < .001$, η_p^2 =.135, with an average BI of .83 (SD = .16).

Language Group

Imaging

For the imaging analyses, the diagnostic groups differed in sex, χ^2 (2, N = 214) = 9.22, p = .010, with a greater number of females across the groups. Education also differed across the diagnostic groups, $F(2,11) = 3.87$, p = .022, with the CN group reporting the highest years of education, followed by the MCI group, and lastly, the dementia group. No differences were found in age, ethnicity, or language group. The language groups differed in age, $F(1,212) = 4.59$, p = .033, with the monolingual group (M_{age} = 72.49, SD = 7.91) older than the bilingual group (M_{age} = 70.27, SD = 7.12). Education, sex, or diagnosis did not differ.

Volumetric measures. The language groups were compared on the GMV of regions related to memory (hippocampi and entorhinal cortices), language (IFG), and EF (OFC). See Table 4.

IFG. Two 2X3 Univariate GLM were used to compare the language groups on the GMV of bilateral IFG. Significant differences on the left IFG, $F(1,205) = 11.88$, p =

.001, η_p^2 = .055 were found, with bilinguals exhibiting greater GMV than monolinguals. The right IFG was not significantly different between the language groups, with age as a significant covariate, $p < .001$.

Two linear regressions examined the influence of language group on the GMV of bilateral IFG (Tables 5 and 6). Age, education, sex, diagnosis, and language group (monolingual or bilingual) were included as predictors. A significant regression model for the left IFG emerged, predicting 15% of the variance. Language group and age were significant predictors. This suggested that bilingualism added significantly to prediction of the left IFG over and above other variables in the model.

A significant regression also emerged for the right IFG and the model predicted 14% of the variance. Age, education, and sex were significant predictors, while language group was nonsignificant.

OFC. Two 2X3 Univariate GLM were used to compare the GMV of bilateral OFC. Language group differences were found on the right and left OFC, $F(1,205) = 11.52$, $p = .001$, $\eta_p^2 = .053$, and $F(1, 205) = 8.56$, $p = .004$, , $\eta_p^2 = .040$, respectively. Bilinguals exhibited higher GMV in these regions compared to monolinguals.

Two linear regressions were used to examine the influence of bilingualism of bilateral OFC (Tables 7 and 8). Both models were significant, predicting 14% of the variance. Language group was not a significant predictor of either region, while age and diagnosis were significant predictors.

Memory. In addition to the language and EF areas, two 3X2 Multivariate GLM were used to compare the language and diagnostic groups in the GMV of bilateral hippocampi and entorhinal cortices. No significant language group effect was found for

either hemisphere. In the left and right hippocampi, age, sex, and diagnosis were significant covariates, $p < .001$. While bilaterally, age and diagnosis were the only significant covariates for the entorhinal cortices, $p < .001$.

Linear regressions were used to examine the predictive value of bilingualism over bilateral hippocampi and entorhinal cortices. The linear regression predicting the left hippocampal volume was significant, with the model predicting 33% of the variance; language group was not a significant predictor (Table 9). For the right hippocampus, a similar finding emerged, with a significant model predicting 32% of the variance, and language group as a nonsignificant predictor (Table 10). Bilaterally, age, sex, and diagnosis were significant predictors of hippocampal volume.

The model predicting the left entorhinal cortex was significant and predicted 11% of the variance (Table 11). For the right entorhinal cortex, the model was also significant, and predicted 6% of the variance (Table 12). Language group did not predict the GMV of the entorhinal cortices. Age and education were significant predictors of the left entorhinal cortex, while diagnosis was a significant predictor of the right entorhinal cortex.

Associations Between GMV and EF Performance

For validity purposes, Spearman correlations were used to examine the relationship of the ROIs and neuropsychological performance across the language groups. See Tables 13-16.

For the monolingual group, significant positive correlations emerged between the Digit Span Backwards and the left IFG, and between category fluency and bilateral hippocampi, entorhinal, IFG, and OFC. In the bilingual group, the TMT-B-TMT-A was

negatively correlated with bilateral hippocampi, entorhinal, and OFC, and there were positive correlations between fluency and bilateral hippocampi, entorhinal, and left OFC. Stroop interference scores were not correlated with these regions.

Fisher r-to-z transformations suggested that the TMT difference score correlation coefficients were not significantly different between the two language groups for the left hippocampus, right entorhinal cortex, or bilateral OFC. Differences were significant between the correlation coefficients from the right hippocampus, $p = .03$, and the left entorhinal cortex, $p = .04$.

Longitudinal Analyses

For the V1 and V2 analyses of neuropsychological performance, 153 participants (90 bilinguals) who were diagnosed as CN or MCI were included. The diagnostic groups were similar in age and education, but differences were found in sex, $\chi^2 (1, N = 153) = 4.62$, $p = .032$. The language groups did not differ in age, education, or sex. See Table 17 for EF scores across diagnostic and language groups.

A significant main effect emerged for Digit Span Backwards between language groups, $F(1,145) = 4.54$, $p = .035$, $\eta_p^2 = .030$. In general, the monolingual group outperformed the bilingual group. A significant interaction was not found. See Figure 2.

On Stroop interference scores, there was not a significant interaction of time and language group, $p > .05$. A main effect of language group was observed, $F(1,139) = 6.66$, $p = .011$, $\eta_p^2 = .046$. Overall, the bilingual group had reduced Stroop interference. See Figure 3.

Lastly, a main effect was also found for category fluency average scores, $F(1,127) = 4.36$, $p = .039$, $\eta_p^2 = .033$, with higher scores in the monolingual group. No interactions emerged. See Figure 4.

No significant language group effects or interactions were found on TMT-B-TMT-A.

Dementia and EF Performance

The EF performance during V1 of 33 participants (14 monolinguals) diagnosed with dementia was examined. There was no significant effect of language group on EF scores.

Bilingualism Characteristics

In addition to language group comparisons, the predictive value of the BI and the age of acquisition of English in CN or MCI participants who reported Spanish as their first language were examined.

Imaging

The initial analyses were performed with 115 Spanish/English bilinguals with MRI data and included CN, MCI, and dementia participants. Sex, diagnostic group, and variables associated with bilingualism were used as predictors, and the GMV of the left IFG and bilateral OFC were used as dependent variables. The BI and English age of acquisition did not predict the GMV in these regions.

EF Tests

These analyses were repeated with CN and MCI monolingual and bilingual participants ($n = 111$). The BI and English age of acquisition were used as predictors of V1 scores

from the Digit Span Backwards, Stroop interference, and category fluency average scores, as these measures exhibited language group differences.

There was a significant regression predicting category fluency average scores, $F(5,105) = 14.68$, $p < .001$, with the model predicting 38% of the variance. The BI was a significant predictor, $\beta = -3.42$, $t = -2.30$, $p = .023$, suggesting that the BI, indicating the balance between languages, added significantly to the prediction of category fluency over and above the other variables in the model.

The bilingualism variables did not predict Digit Span Backwards or Stroop interference after adjusting for multiple comparisons.

Age of Cognitive Decline

As previous research has reported delays in the onset of dementia symptoms in bilinguals, the estimated age in which participants began exhibiting cognitive symptoms was examined. The clinician answered the following question: “Based on the clinician's judgment, at what age did the cognitive decline begin?”. One hundred and fifty-seven participants with MCI or dementia (64 monolinguals and 93 bilinguals) were included. There were no differences in the estimated age of the onset of cognitive decline between the language groups.

Discussion

This study compared monolingual and bilingual participants undergoing normal and abnormal aging in GMV of regions associated with memory, language, and EF. Results suggested that bilinguals exhibit higher GMV in areas associated with language and EF; however, no volumetric differences were found in areas related to memory.

There was no evidence of a longitudinal bilingual advantage on EF performance across CN and MCI monolingual and bilingual participants. However, it appears that there were general language group differences on overall EF scores, with monolinguals outperforming bilinguals on Digit Span Backwards and category fluency average and bilinguals exhibiting reduced Stroop interference compared to monolinguals. No EF differences were found within the dementia group.

Within the Spanish/English bilingual sample, two additional characteristics relevant to bilingualism were explored: the Bilingualism Index (BI) and the age of acquisition of English. The predictive value of these variables was examined. The BI predicted category fluency scores, with greater language balance increasing the likelihood of lower scores on this task. Lastly, no differences in the age of cognitive decline onset between the language groups were found.

The following sections discuss the findings in detail.

Imaging

The bilingual group exhibited higher GMV in the left IFG and bilateral OFC, but no differences were found in regions related to memory. The hypotheses regarding

volumetric differences were partially supported; it was expected that due to the increased demand for language control, bilinguals would exhibit higher GMV in frontal regions associated with language and executive control. It was also expected that, consistent with the theory of CR, bilinguals would have reduced GMV in regions related to memory; this was not found in the present study.

Findings from the linear regression models suggested that bilingualism only predicted the GMV of the left IFG, with younger bilinguals more likely to exhibit higher GMV in this region. In the right IFG, younger female participants with fewer years of education were more likely to demonstrate higher GMV, while bilingualism was not a significant predictor for this region's volume.

Additionally, despite higher GMV in bilateral OFC in bilinguals compared with monolinguals, bilingualism was not a significant predictor of the GMV in these regions. Besides bilingualism, the regression models indicated that younger participants who were not diagnosed with MCI or dementia had a higher probability of exhibiting greater OFC GMV, bilaterally. These results indicate that when bilingualism is considered in combination with age and diagnosis, language experience does not contribute to the predictive value of the volume of these regions.

The findings related to frontal language and EF regions partially support previous research suggesting that increased language experience and manipulation leads to neuroplastic changes (García-Pentón et al., 2014). Duncan et al. (2018) also described that the bilingual experience might act as "exercise" for regions involved in control processes, ultimately leading to changes reflected in the increased GM density.

Additionally, our results also indicated that bilinguals had higher GMV in bilateral OFC, a region associated with EF, specifically response inhibition (Bryden & Roesch, 2015).

Results did not show significant GMV differences between monolinguals and bilinguals in bilateral hippocampi and entorhinal cortices. The current results contradict those from Duncan et al. (2018), who reported that bilinguals with AD had lower GMV in memory-related regions. It is important to note, however, that Duncan et al.'s (2018) sample was older than the present one, and the ROIs differed (these researchers selected the parahippocampal gyri and the rhinal sulci). Costumero et al. (2020) also reported lower volume in MCI bilinguals compared to monolinguals in regions related to brain atrophy in dementia. Besides ROI differences, our bilingual sample was mostly immigrants, while the sample from the Costumero et al.'s (2020) study were native-born bilinguals. Lastly, Schweizer et al. (2012) used computerized tomography (CT) scans and described increased atrophy in areas related to AD in a sample of monolingual and bilinguals with probable AD. The reason behind these discrepant results could be attributed to differential imaging techniques and age differences.

The linear regression analyses demonstrated that bilingualism was not a significant predictor of memory-related regions. However, bilaterally, younger female participants who were not diagnosed with MCI or dementia had a higher probability of exhibiting higher GMV in the hippocampi. Additionally, for the left entorhinal cortex, younger participants who were not diagnosed with MCI or dementia were more likely to display higher GMV. For the right entorhinal cortex, participants not diagnosed with MCI or dementia had a higher probability of exhibiting higher GMV.

Results suggested that there were differences between EF and memory regions and their associations with neuropsychological performance between the language groups. It appears that TMT-B-TMT-A scores were only negatively correlated to OFC and memory regions in the bilingual group, suggesting that the greater the time difference complete the TMT sections (indicating higher overall completion time), the smaller the GMV of hippocampi, entorhinal, and OFC. However, as the language groups differed in size, comparing the correlation coefficients suggested that the only relationships that significantly differed between groups were between the TMT difference scores and the right hippocampus and left entorhinal cortex. Nestor et al. (2015) reported associations with faster TMT B time and GMV of the left OFC and left middle orbital gyrus. TMT difference scores have been related to the left ventrolateral prefrontal cortex, dorsolateral prefrontal cortex, and frontopolar cortex, and the TMT, in general, is linked to networks encompassing prefrontal and parietal structures (Ruscheweyh et al., 2013; Varjacic, Mantini, Demeyere, & Gillebert, 2018).

The differential association between TMT-B-TMT-A scores across the language groups might indicate that for bilinguals, the ability to complete this task relies more strongly on memory regions. Somewhat paradoxically, no differences between the GMV of the hippocampi and entorhinal cortex, or the TMT-B-TMT-A scores between the language groups, were found. These results should be interpreted with caution.

Besides using TMT difference scores, other studies (Müller et al., 2014) have employed a ratio of TMT-B to TMT-A using the number of corrected circles, with this score also accounting for motor and cognitive decline, but greater control of participant variability (Corrigan & Hinkeldey, 1987). Also, the use of more than one TMT measure

might yield different findings; TMT-A reflects visuoperceptual abilities while TMT-B captures working memory and set switching (Sánchez-Cubillo et al., 2009). The positive correlations of TMT-B-TMT-A with the GMV temporal regions within the bilingual group only, despite the nonsignificant language group differences, indicate that future studies should consider the limits of using only one TMT assessment.

In general, scores from the other neuropsychological measures were similar between the language groups and suggested that the brain ROIs included in this study were suitable for assessing volumetric differences between the language groups.

Longitudinal Analyses

EF test performance during V1 and V2 in CN and MCI monolingual and bilingual participants was analyzed. Despite non-significant differences in performance between the language groups over time, differences emerged on Digit Span Backwards and category fluency, with monolinguals outperforming bilinguals on these tasks. The category fluency findings are consistent with previous research, typically reporting lower scores on verbal tasks in bilinguals, resulting from increased interference (Rosselli et al., 2000) and are in line with the hypotheses that monolinguals would have higher fluency scores than bilinguals. Performance in fluency tasks, particularly category fluency, is affected in AD (Weakley & Schmitter-Edgecombe, 2014). Findings from the current study contribute to the literature describing verbal disadvantages in bilingual CN and MCI individuals.

Findings from the Digit Span Backwards did not agree with the hypothesis, stating that as a result of the increased demands of bilingualism on executive control, bilinguals would outperform monolinguals. A study by Yang (2017) reported better

performance on Digit Span tasks in an intermediate bilingual group, while this finding was not replicated in a high bilingual group. Yang (2017) suggested that the intermediate bilingual group developed stronger WM abilities because of the WM demands of bilingualism, while the high bilingual group no longer experienced the demands of language monitoring and memorization. Therefore, it could be speculated that the Spanish/English bilinguals, with high English proficiency levels (M = 8.39, SD = 1.51, corresponding to a 'Very Good' on the LEAP-Q) do not experience such intense demands of the bilingual ability, and therefore, do not display WM advantages.

As predicted, Stroop interference scores followed a different trend from the other tasks; bilinguals exhibited reduced interference compared to monolinguals, supporting previous research (Bialystok et al., 2014b; Donnelly, Brooks, & Homer, 2019). It appears that the inhibitory requirements of bilingualism may not be confined to language control, and rather, may share a commonality with domain-general EF processes (Bialystok, 2017; Green, 1998). Previous studies have suggested that bilingualism influences results from the Stroop test (Rosselli et al. 2002), and Suarez et al. (2014) reported that higher L2 fluency was associated with inhibitory advantages on the Stroop even when administered in the native language.

No language group differences on TMT-B-TMT-A were found. Some research suggests a bilingual advantage on TMT (Suárez, 2013), while the opposite results are also reported (Kisser, Wendell, Spencer, and Waldstein, 2012). In the Kisser et al. (2012) study, the sample included undergraduate students (with ages between 18-44 years), while the Suárez (2013) study included participants aged 20-63. Furthermore, both studies used TMT-A and -B separately as opposed to TMT difference scores, which is

considered a better estimator of switching abilities (Kopp, 2011). Further research needs to examine the influence of aging in TMT completion times and related indices.

Because this study did not perform cross-sectional neuropsychological analyses, it is not possible to determine whether the differences in scores were driven by one of the visits, possibly resulting from practice effects on V2. Furthermore, because the current analyses only included CN and MCI participants, changes in scores from V1 to V2 could be minimal and undetectable. As data collection continues, it will be possible to explore whether considering subsequent visit data can capture neuropsychological differences between the language groups. However, previous studies, such as Zahodne et al.'s (2014), did not find different rates of decline or dementia conversion between the language groups. Likewise, Mungas et al. (2018) did not find evidence of a bilingualism effect in cognitive decline.

Dementia EF Performance

These results suggested that during dementia, being monolingual or bilingual does not influence EF performance. Although most bilingualism research is conducted with young and normally aging samples, Schweizer et al. (2012) also failed to report differences between monolinguals and bilinguals on neuropsychological assessments. As discussed above, different imaging methods were used relative to the present study, and the participants in Schweizer et al.'s (2012) study were older than the ones used in this research.

Bilingualism Variables

In addition to the language group comparisons, further aims of this study involved the identification of factors within the bilingual sample (Spanish/English) that were

predictive of GMV and EF differences. To this end, the influence of the BI (reflecting the language proficiency balance) and the age of English acquisition was explored. These variables did not predict GMV, and the BI only predicted category fluency scores, with greater linguistic balance increasing the probability of lower scores. It appears that higher proficiency balance is accompanied by increased interference, and this resulted in reduced category fluency scores. Rosselli et al. (2016) reported that proficiency, more so than balance, was associated with EF advantages.

The BI was expected to be a strong predictor of neuropsychological test performance and GMV. However, it appears that language proficiency balance was only related to the task with the strongest verbal component. Likewise, the age of acquisition of L2 was not a significant predictor of neuropsychological scores or GMV. Sörman et al. (2019) included L2 proficiency in their language group comparisons and did not report its significant influence on executive control systems in 50-75-year-old adults. An earlier age of L2 acquisition is associated with reduced processing costs in bilinguals, and language balance is also suggested to play a significant role in EF advantages (Soveri et al., 2011; Yow & Li, 2015). Findings from this study do not support a substantial influence of L2 age of acquisition, and the BI only influenced category fluency scores. Therefore, it is likely that if there are EF advantages to be found in bilinguals, these results suggest that they do not stem from these characteristics of the bilingual experience.

Age of Cognitive Decline

The age in which cognitive decline began was not different between language groups. While this partly disagrees with several studies that report that bilinguals are

older at the onset of dementia (Alladi et al., 2013; Woumans et al., 2015), these findings in line with results from other researchers (Mungas et al., 2018; Zahodne et al., 2014) who used prospective assessments to establish this age. The present findings, like those reported by Alladi et al. (2013) and Woumans et al. (2015), used retrospective analyses for the age of symptom onset, while Mungas et al. (2018) and Zahodne et al. (2014) followed participants over time. Furthermore, the current sample included Hispanic American individuals, and therefore, had a greater degree of cultural and linguistic similarity with participants from the Mungas et al. (2018) and Zahodne et al. (2014) study compared to Alladi et al.'s (2013) participants from India and Woumans et al.'s (2015) European participants.

Limitations and Future Directions

Females and participants with an MCI diagnosis were overrepresented in the present sample. Furthermore, the dementia sample was limited, and due to insufficient V2 data, longitudinal EF performance was not assessed in this group. The cross-sectional dementia analyses should be generalized with caution and be replicated in a larger sample.

In the current study, the time between the two visits was highly variable, and it is possible that the 10-33 month interval influenced the longitudinal findings; however, the number of months between visits did not differ across our groups and was not associated with neuropsychological change scores. Zahodne et al.'s (2014) visit interval was 18-24 months, while Mungas et al.'s (2018) sample was evaluated every 12-15 months; therefore, in the present study, the broader range might partially explain the disparity of findings between these previous studies and the current one.

Our language groups were formed based on subjective self-assessments of language proficiency in speaking, understanding, and reading; the use of objective measures of linguistic abilities might be more accurate. Several studies use similar methods of classification (e.g., Mungas et al., 2018 and Woumans et al., 2015). Additionally, while steps were taken to achieve a relatively homogenous bilingual sample (e.g., excluding participants who reported a second language besides English or Spanish), this group included individuals from 10 Spanish-speaking countries (excluding Puerto Rico), with the majority being immigrants. The influence of immigration continues to be a significant confound in bilingualism research (Fuller-Thomson & Kuh, 2014).

Another important limitation was the retrospective nature of the variable used to determine the age of cognitive decline, as well as the limited number of participants with this information available. Alladi et al. (2013) and Bialystok (2007) used a similar methodology to establish the age of symptom onset. However, as noted in Mukadam et al. (2017), these types of assessments are more likely to lead to confounding by other factors (e.g., education).

Despite these limitations, the strengths of the current study included a large sample size for the imaging and longitudinal analyses (n = 214 and n = 153, respectively), the use of four tasks to assess the construct of EF, and the exclusion individuals who were not US-born or Hispanics who did not have the shared experience of immigrating to the US. The bilingual sample in this study included individuals with high Spanish and English proficiency; therefore, these results can be generalized to highly fluent Spanish/English bilinguals who are immigrants to the US and who have resided in the US for a large portion of their lives. Furthermore, the use of longitudinal

data in bilingual research remains scarce. As the 1Florida ADRC study is ongoing, the cognitive and imaging trajectories of these samples will be examined.

Conclusion

In general, results suggest that bilingualism is accompanied by volumetric changes in frontal regions related to language and EF. No support was found for the theory that bilingualism increases CR; bilinguals were not older at the time when cognitive decline first appeared, and there was no evidence of reduced GMV in regions related to memory. Additionally, the effect of bilingualism on longitudinal EF changes was not significant; however, the bilingual group exhibited reduced interference on the Stroop test, while the monolingual group had higher scores on Digit Span Backwards and category fluency. Besides the BI predicting category fluency, individual characteristics within the bilingual sample were generally not predictive of GMV or neuropsychological performance. Overall, it appears that the influence of bilingualism on EF performance is modest and most apparent in brain changes rather than on traditional neuropsychological assessments.

Appendices

Appendix A: List of Tables

Table 1

Imaging Subsample Demographic Characteristics

		Diagnosis											
		CN				MCI				Dementia			
		Mono		Bi		Mono		Bi		Mono		Bi	
		M(SD)	*n*	*M(SD)*	*n*	*M(SD)*	*n*	*M(SD)*	*n*	*M(SD)*	*n*	*M(SD)*	*n*
Age		71.38 (6.09)	34	69.37 (6.44)	41	72.55 (7.95)	42	70.91 (7.02)	64	75 (11.18)	14	70.11 (8.88)	19
Education		16.03 (3.66)	34	16.02 (2.74)	41	14.74 (3.41)	42	15.14 (3.28)	64	14.57 (3.65)	14	13.89 (4.59)	19
Ethnicity													
	EA		29		4		32		3		11		-
	Hispanic		5		37		10		61		3		19
Sex													
	Male		11		8		21		29		5		6
	Female		23		33		21		35		9		13
Eval. Lang.													
	English		29		17		32		22		11		6
	Spanish		5		24		10		42		3		13
Lang. Order													
	Eng/Spa.		-		4		-		4		-		-
	Spa/Eng.		-		37		-		60		-		18
	Simultaneous		-		-		-		-		-		1
	Mono Eng.		29		-		32		-		11		-
	Mono Spa.		5		-		10		-		3		-

Note. CN = Cognitively normal; MCI = Mild Cognitive Impairment; Mono = Monolingual; Bi = Bilingual; EA = European American; Eval Lang = Evaluation language; Lang. Order = Language order; Eng/Spa. = English/Spanish; Spa/Eng. = Spanish/English; Mono Eng. = Monolingual English; Mono Spa. = Monolingual Spanish.

Table 2

Demographic Characteristics of the Longitudinal Subsample

		Diagnosis							
		CN				MCI			
		Mono		Bi		Mono		Bi	
		M(SD)	*n*	*M(SD)*	*n*	*M(SD)*	*n*	*M(SD)*	*n*
Age		70.93 (6.30)	30	69.97 (6.3)	36	72.36 (7.61)	33	70.81 (7.27)	54
Education		15.83 (3.71)	30	15.72 (2.78)	36	14.48 (2.99)	33	15.07 (3.58)	54
Ethnicity									
	EA		24	-	3	-	26	-	4
	Hispanic		6	-	33	-	7	-	50
Sex									
	Male		10	-	7	-	12	-	25
	Female		20	-	29	-	21	-	29
Eval. Lang.									
	English		24		14		26		20
	Spanish		6		22		7		34
Lang. Order									
	Eng/Spa.		-		3		-		4
	Spa/Eng.		-		33		0		50
	Mono Eng.		24		-		26		-
	Mono Spa.		6		-		7		-

Note. CN = Cognitively normal; MCI = Mild Cognitive Impairment; Mono = Monolingual; Bi = Bilingual; EA = European American; Eval Lang = Evaluation language; Lang. Order = Language order; Eng/Spa. = English/Spanish; Spa/Eng. = Spanish/English; Mono Eng. = Monolingual English ; Mono Spa. = Monolingual Spanish.

Table 3

Demographic Characteristics of the Dementia Subsample

		Language Group			
		Mono		Bi	
		M (SD)	*n*	*M (SD)*	*n*
Age		75 (11.18)	14	70.11 (8.88)	19
Education		14.57 (3.65)	14	13.89 (4.59)	19
Ethnicity					
	EA	-	11	-	-
	Hispanic	-	3	-	19
Sex					
	Male	-	5	-	6
	Female	-	9	-	13

Note. Mono = Monolingual; Bi = Bilingual; EA = European American.

Table 4

Gray Matter Volume Across Diagnostic and Language Groups

	Diagnosis											
	CN				MCI				Dementia			
	Mono		Bi		Mono		Bi		Mono		Bi	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Left Hipp.	0.0024	0.0003	0.0025	0.0003	0.0023	0.0004	0.0024	0.0003	0.0021	0.0003	0.0021	0.0003
Right Hipp.	0.0025	0.0003	0.0027	0.0003	0.0024	0.0003	0.0024	0.0003	0.0022	0.0003	0.0022	0.0003
Left Ento.	0.0012	0.0002	0.0013	0.0002	0.0012	0.0003	0.0012	0.0003	0.001	0.0003	0.001	0.0002
Right Ento.	0.0012	0.0002	0.0012	0.0002	0.0012	0.0003	0.0011	0.0003	0.0009	0.0003	0.001	0.0003
Left IFG	0.0062	0.0008	0.0064	0.0007	0.006	0.0007	0.0063	0.0009	0.0054	0.0011	0.0065	0.0007
Right IFG	0.0063	0.0009	0.0064	0.0007	0.0062	0.0007	0.0064	0.0008	0.0055	0.001	0.0063	0.001
Left OFC	0.0079	0.001	0.0082	0.0007	0.0078	0.0007	0.0078	0.0009	0.0066	0.0014	0.0078	0.0009
Right OFC	0.0079	0.0008	0.0082	0.0007	0.0079	0.0007	0.0078	0.0008	0.0066	0.0013	0.0079	0.0009

Note. CN = Cognitively normal; MCI = Mild Cognitive Impairment; Mono = Monolingual; Bi = Bilingual; Left = Left Hemisphere; Right = Right Hemisphere; Hipp = Hippocampus; Ento = Entorhinal cortex; IFG = Inferior frontal gyrus ; OFC = Orbitofrontal cortex.

Values presented as a percentage of intracranial volume.

Table 5

Linear Regression Analyses Predicting GMV of Left IFG

Predictors	*B*	*SE B*	*β*	*t*	*p*
Age	-3.481E-5	.00	-.31	-4.76	< .001
Education	-2.838E-5	.00	-.12	-1.74	.083
Sex	.00	.00	.06	.90	.369
Diagnosis	.00	.00	-.12	-1.85	.066
Bilingual	.00	.00	.18	2.74	.007
Adjusted R^2	.15				
F	8.67				
p	< .001				

Note. *N* = 214; GMV = gray matter volume; IFG = Inferior frontal gyrus. Male = 0; cognitively normal = 0, Mild Cognitive Impairment = 1, dementia = 2; Monolingual = 0.

Table 6

Linear Regression Analyses Predicting GMV of Right IFG

Predictors	*B*	*SE B*	*β*	*t*	*p*
Age	-3.085E-5	.00	-.28	-4.32	< .001
Education	-3.467E-5	.00	-.14	-2.18	.030
Sex	.00	.00	.15	2.34	.020
Diagnosis	.00	.00	-.10	-1.56	.121
Bilingual	.00	.00	.11	1.68	.095
Adjusted R^2	.14				
F	8.14				
p	< .001				

Note. *N* = 214; GMV = gray matter volume; IFG = Inferior frontal gyrus. Male = 0; cognitively normal = 0, Mild Cognitive Impairment = 1, dementia = 2; Monolingual = 0.

Table 7

Linear Regression Analyses Predicting GMV of Left OFC

Predictors	*B*	*SE B*	*β*	*t*	*p*
Age	-2.983E-5	.00	-.24	-3.73	<.001
Education	-1.185E-5	.00	-.04	-.67	.506
Sex	.00	.00	.09	1.35	.179
Diagnosis	.00	.00	-.24	-3.71	< .001
Bilingual	.00	.00	.11	1.63	.105
Adjusted R^2	.14				
F	7.87				
p	< .001				

Note. *N* = 214; GMV = gray matter volume; OFC = Orbitofrontal cortex. Male = 0; cognitively normal = 0, Mild Cognitive Impairment = 1, dementia = 2; Monolingual = 0.

Table 8

Linear Regression Analyses Predicting GMV of Right OFC

Predictors	*B*	*SE B*	*β*	*t*	*p*
Age	-2.745E-5	.00	-.23	-3.58	< .001
Education	-2.621E-5	.00	-.10	-1.54	.126
Sex	.00	.00	.09	1.39	.166
Diagnosis	.00	.00	-.24	-3.65	< .001
Bilingual	.00	.00	.12	1.91	.058
Adjusted R^2	.14				
F	7.95				
p	< .001				

Note. *N* = 214; GMV = gray matter volume; OFC = Orbitofrontal cortex. Male = 0; cognitively normal = 0, Mild Cognitive Impairment = 1, dementia = 2; Monolingual = 0.

Table 9

Linear Regression Analyses Predicting GMV of Left Hippocampus

Predictors	*B*	*SE B*	*β*	*t*	*p*
Age	-1.342E-5	.00	-.31	-5.47	< .001
Education	-1.060E-5	.00	-.11	-1.94	.054
Sex	.00	.00	.22	3.73	< .001
Diagnosis	.00	.00	-.39	-6.73	< .001
Bilingual	2.602E-5	.00	.04	.70	.484
Adjusted R^2	.33				
F	22.23				
p	< .001				

Note. *N* = 214; GMV = gray matter volume. Male = 0; cognitively normal = 0, Mild Cognitive Impairment = 1, dementia = 2; Monolingual = 0.

Table 10

Linear Regression Analyses Predicting GMV of Right Hippocampus

Predictors	*B*	*SE B*	*β*	*t*	*p*
Age	-1.349E-5	.00	-.29	-5.11	< .001
Education	-9.640E-6	.00	-.10	-1.64	.103
Sex	.00	.00	.23	3.85	< .001
Diagnosis	.00	.00	-.37	-6.35	< .001
Bilingual	5.543E-5	.00	.08	1.39	.167
Adjusted R^2	.32				
F	20.86				
p	< .001				

Note. *N* = 214; GMV = gray matter volume. Male = 0; cognitively normal = 0, Mild Cognitive Impairment = 1, dementia = 2; Monolingual = 0.

Table 11

Linear Regression Analyses Predicting GMV of Left Entorhinal Cortex

Predictors	*B*	*SE B*	*β*	*t*	*p*
Age	-4.887E-6	.00	-.14	-2.12	.035
Education	-6.871E-6	.00	-.09	-1.34	.181
Sex	2.762E-6	.00	.01	.08	.939
Diagnosis	.00	.00	-.32	-4.78	< .001
Bilingual	3.223E-5	.00	.06	.93	.356
Adjusted R^2	.11				
F	6.25				
p	< .001				

Note. *N* = 214; GMV = gray matter volume. Male = 0; cognitively normal = 0, Mild Cognitive Impairment = 1, dementia = 2; Monolingual = 0.

Table 12

Linear Regression Analyses Predicting GMV of Right Entorhinal Cortex

Predictors	*B*	*SE B*	*β*	*t*	*p*
Age	-2.882E-6	.00	-.08	-1.24	.215
Education	-2.651E-6	.00	-.04	-.51	.608
Sex	2.082E-5	.00	.04	.57	.568
Diagnosis	-9.957E-5	.00	-.26	-3.85	< .001
Bilingual	-1.137E-5	.00	-.02	-.32	.746
Adjusted R^2	.6				
F	3.77				
p	.003				

Note. *N* = 214; GMV = gray matter volume. Male = 0; cognitively normal = 0, Mild Cognitive Impairment = 1, dementia = 2; Monolingual = 0.

Table 13

Correlations Between EF Scores and Memory Regions in Monolinguals

	DSB	Stroop	TMT	Fluency	Left Hipp.	Right Hipp.	Left Ento.	Right Ento.
DSB	-							
Stroop	0.178	-						
TMT	-.450**	-.307**	-					
Fluency	.391**	0.09	-.408**	-				
Left Hipp.	0.187	0.068	-0.109	.376**	-			
Right Hipp.	0.12	0.077	-0.051	.344**	.833**	-		
Left Ento.	0.173	0.074	0.025	.216*	.497**	.470**	-	
Right Ento.	0.04	0.14	-0.126	.237*	.393**	.459**	.564**	-

Note. DSB = Digit Span Backwards; Stroop = Stroop Interference; Fluency = Category fluency; TMT = Trail Making Test B minus Trail Making Test A; Left = Left Hemisphere; Right = Right Hemisphere; Hipp. = Hippocampus; Ento. = Entorhinal cortex.

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Table 14

Correlations Between EF Scores and Frontal Regions in Monolinguals

	DSB	Stroop	TMT	Fluency	Left IFG	Right IFG	Left OFC	Right OFC
DSB	-							
Stroop	0.178	-						
TMT	-.450**	-.307**	-					
Fluency	.391**	0.09	-.408**	-				
Left IFG	.256*	0.075	-0.187	.332**	-			
Right IFG	0.143	0.053	-0.181	.208*	.738**	-		
Left OFC	0.109	0.128	-0.171	.395**	.668**	.669**	-	
Right OFC	0.15	0.138	-0.16	.342**	.709**	.662**	.865**	-

Note. DSB = Digit Span Backwards; Stroop = Stroop Interference; Fluency = Category fluency; TMT = Trail Making Test B minus Trail Making Test A; Left = Left Hemisphere; Right = Right Hemisphere; IFG = Inferior frontal gyrus; OFC = Orbitofrontal cortex.

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Table 15

Correlations Between EF Scores and Memory Regions in Bilinguals

	DSB	Stroop	TMT	Fluency	Left Hipp.	Right Hipp.	Left Ento.	Right Ento.
DSB	-							
Stroop	.199*	-						
TMT	-.370**	-.298**	-					
Fluency	.348**	0.178	-.504**	-				
Left Hipp.	0.055	-0.06	-.344**	.328**	-			
Right Hipp.	0.033	0.117	-.341**	.301**	.791**	-		
Left Ento.	0.141	-0.007	-.259**	.283**	.455**	.430**	-	
Right Ento.	0.025	0.124	-.236**	.264**	.344**	.472**	.673**	-

Note. DSB = Digit Span Backwards; Stroop = Stroop Interference; Fluency = Category fluency; TMT = Trail Making Test B minus Trail Making Test A; Left = Left Hemisphere; Right = Right Hemisphere; Hipp. = Hippocampus; Ento. = Entorhinal cortex.

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Table 16

Correlations Between EF Scores and Frontal Regions in Bilinguals

	DSB	Stroop	TMT	Fluency	Left IFG	Right IFG	Left OFC	Right OFC
DSB	-							
Stroop	.199*	-						
TMT	-.370**	-.298**	-					
Fluency	.348**	0.178	-.504**	-				
Left IFG	0.114	-0.057	-0.082	-0.042	-			
Right IFG	0.023	-0.029	-0.097	0.028	.620**	-		
Left OFC	0.112	0.124	-.318**	.211*	.424**	.407**	-	
Right OFC	0.049	0.111	-.181*	0.01	.521**	.457**	.742**	-

Note. DSB = Digit Span Backwards; Stroop = Stroop Interference; Fluency = Category fluency; TMT = Trail Making Test B minus Trail Making Test A; L = Left Hemisphere; R = Right Hemisphere; IFG = Inferior frontal gyrus; OFC = Orbitofrontal cortex.

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Table 17

EF Scores During V1 and V2 Across Diagnostic and Language Groups

	Diagnosis			
	CN		MCI	
	Mono	Bi	Mono	Bi
	M(SD)	*M(SD)*	*M(SD)*	*M(SD)*
DSB V1	7.30 (1.93)	6.25 (2.29)	5.50 (1.78)	5.59 (2.49)
DSB V2	7.00 (2.10)	6.25 (1.79)	5.33 (1.49)	5.00 (2.14)
TMT V1	51.83 (30.42)	56.19 (35.24)	90.81 (64.38)	99.15 (79.13)
TMT V2	62.27 (55.57)	55.94 (41.88)	98.62 (58.80)	88.51 (61.81)
Stroop V1	-3.74 (4.95)	-1.33 (6.70)	-5.25 (6.40)	-4.41 (6.15)
Stroop V2	-4.87 (5.73)	-0.47 (6.27)	-6.41 (7.05)	-4.16 (6.22)
Fluency V1	16 (3.24)	15.54 (3.21)	13.54 (3.57)	12.32 (2.85)
Fluency V2	16.46 (4.07)	15.19 (3.36)	12.62 (3.86)	11.84 (3.45)

Note. CN = Cognitively normal; MCI = Mild Cognitive Impairment; Mono = Monolingual; Bi = Bilingual; V1 = Visit 1; V2 = Visit 2; DSB = Digit Span Backwards; TMT = Trail Making Test B minus Trail Making Test A; Stroop = Stroop Interference; Fluency = Category fluency.

Appendix B: List of Figures

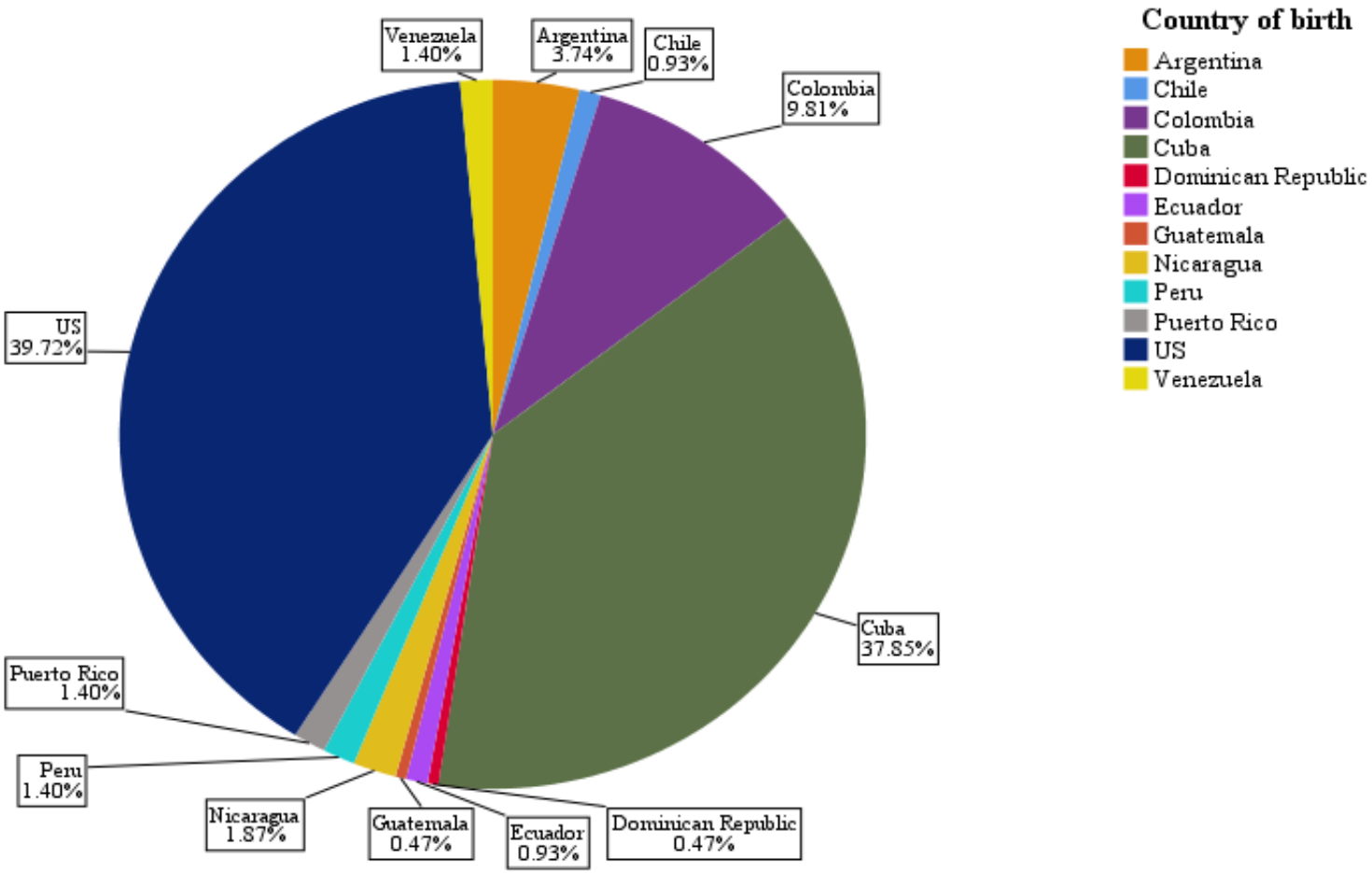

Figure 1. Country of Birth.

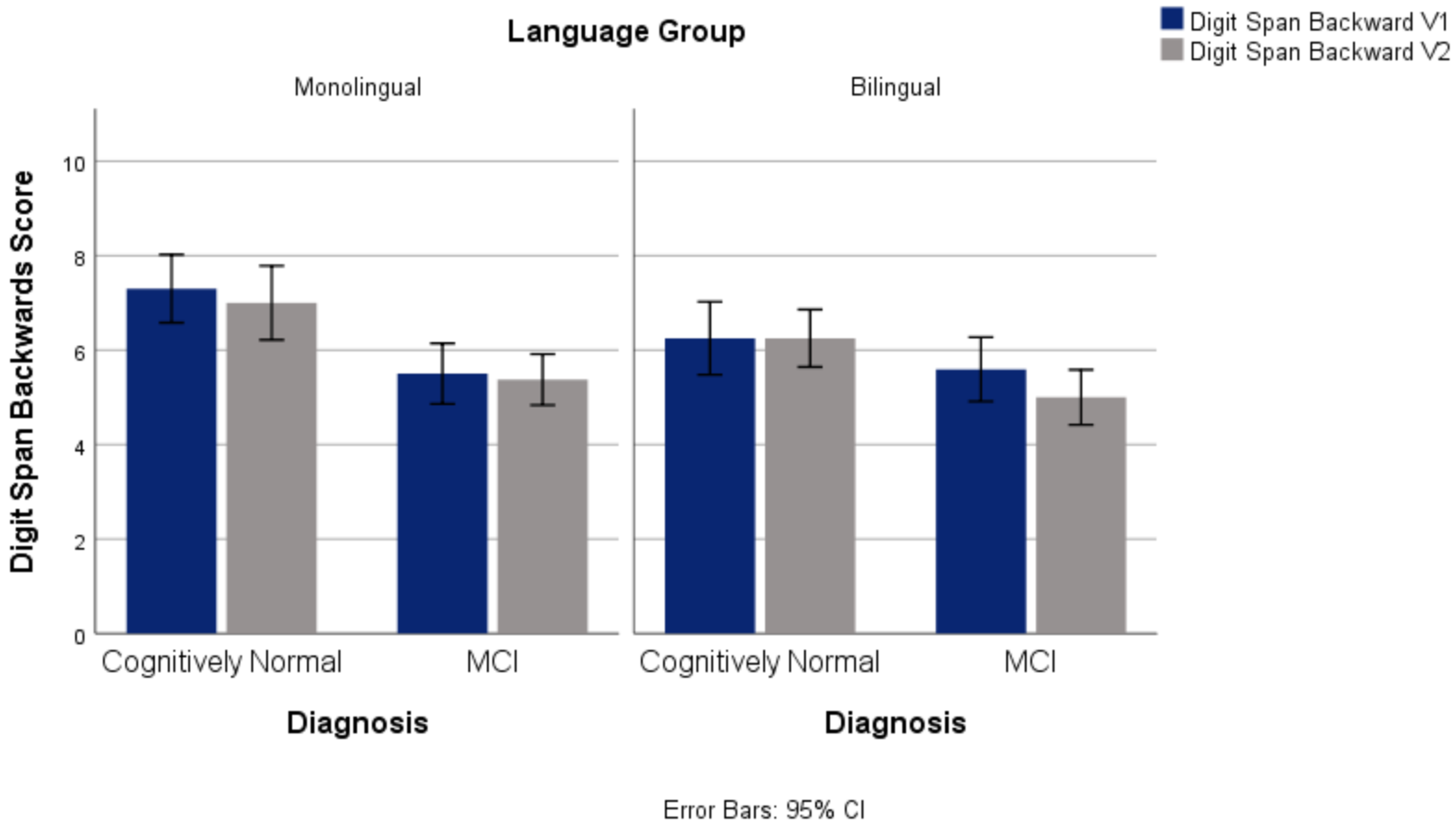

Figure 2. Digit Span Backwards Scores on V1 and V2 Across Diagnostic and Language Groups.

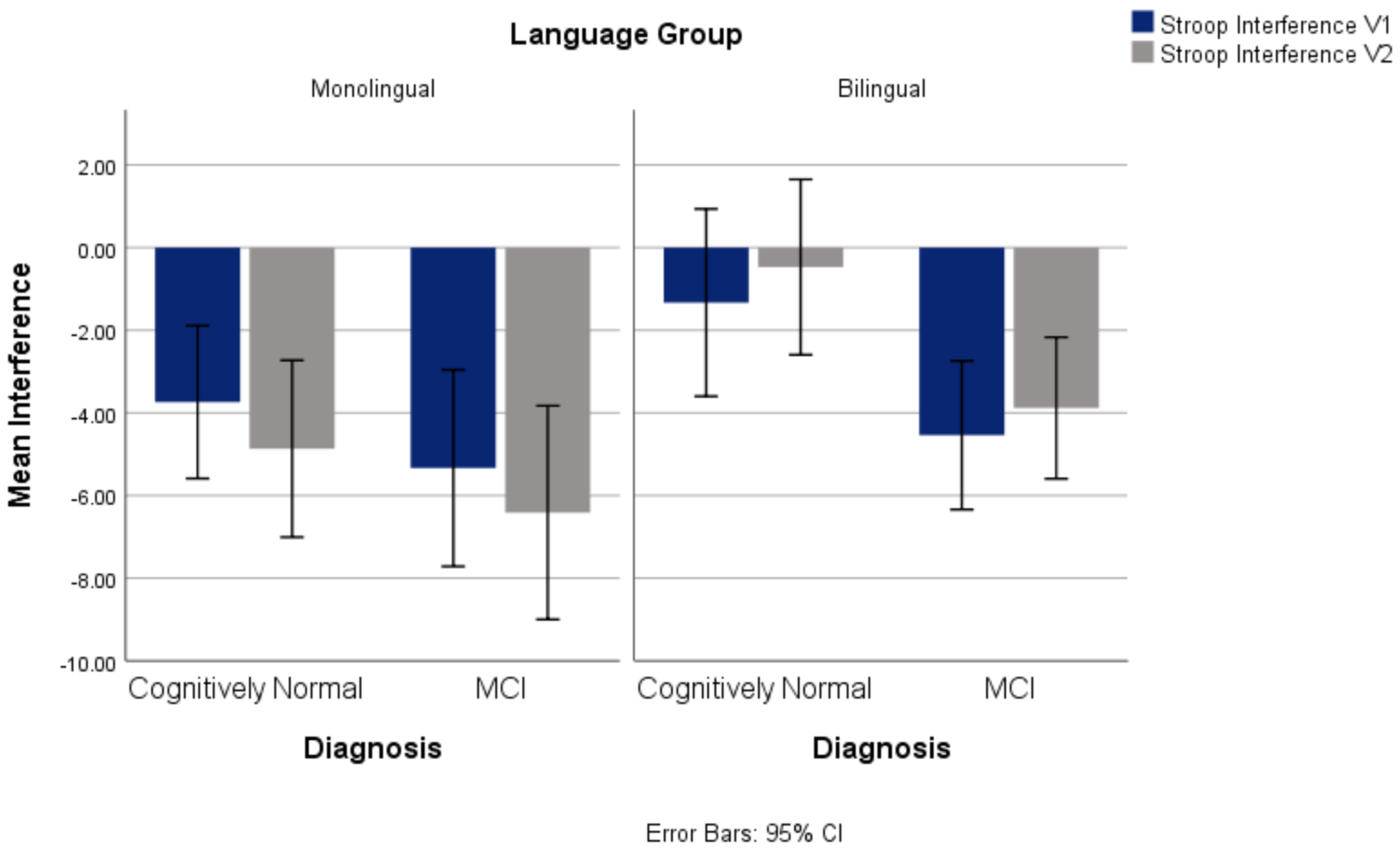

Figure 3. Stroop Interference on V1 and V2 Across Diagnostic and Language Groups.

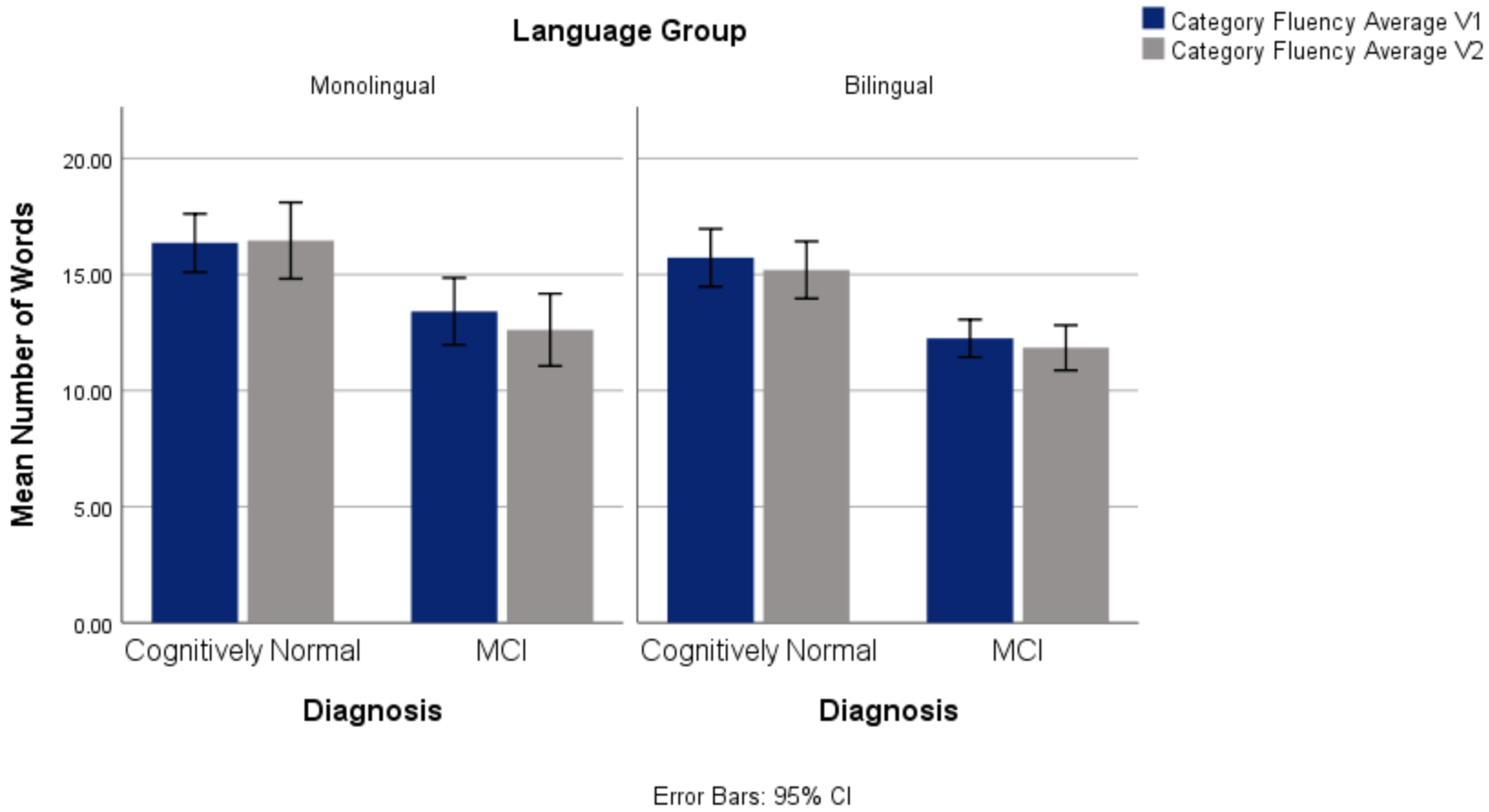

Figure 4. Category Fluency Average Scores on V1 and V2 Across Diagnostic and Language Groups.

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