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Review

What Can Aphasia Tell Us about How the First-Acquired Language Is Instantiated in the Brain?

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Abstract: Recent neurolinguistic theories converge on the hypothesis that the languages of multilingual people are processed as one system in the brain. One system for the multiple languages is also at the core of a translanguaging framework of multilingualism—a framework that focuses on each speaker's complete linguistic repertoire rather than on the separate languages they know. However, evidence from neuroimaging studies suggests at least some nonoverlapping activations of the first-acquired language (L1) and other (non-L1) languages of multilingual people, especially when the age of acquisition and/or levels of proficiency differ across the languages. Neurolinguistic studies of acquired language disorders have demonstrated that in multilingual people who experience language impairments due to brain lesion, L1 may be less impaired or better recovered than non-L1. This paper explores the evidence available to date from the study of acquired language impairment regarding this potential primacy of the first-acquired language. Findings suggest that L1 may be better preserved in many instances of language impairment, challenging the theory of a single system for multiple languages.

Keywords: first-acquired language; L1; non-L1; aphasia; primary progressive aphasia; dementia; neuroimaging; bilingual; multilingual; adults

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1. Introduction

Two main sources of neurolinguistic evidence have informed our understanding of language processing in the brain: lesion studies and neuroimaging studies. The complexity of the human language system, combined with great interindividual variability, has made the mapping of those neuronal networks responsible for language challenging. Despite these challenges, researchers have put forward models of language processing in the brain, implicating extensive neuronal networks in both cerebral hemispheres (e.g., Fridriksson et al. 2018; Price 2010), though such models are still debated. Further complicating matters is the even greater interindividual variabilities associated with multilingualism. Multilingual people, who comprise the majority of the world's population, are those who use more than one language (e.g., Grosjean 2022). Indeed, one of the questions that has preoccupied many researchers and that has remained unresolved is whether people who know and use multiple languages engage the same neuronal system for all their languages. Scholars have hypothesized that the system subserving language adapts to manage all languages as they are learned and mastered. Thus, the same neuronal networks are engaged for (any) language processing, rather than that separate systems subserve different languages of the same individual (Abutalebi and Green 2007, 2016).

This idea may challenge the notion that the first-acquired language, sometimes termed the mother tongue, has a special status in the brains of multilingual people, especially when other languages are learned later in life or do not reach the highest levels of proficiency. A special status of the first-acquired language has been hypothesized and examined in both sets of literature: lesion studies and neuroimaging studies. The following sections explore what the literature tells us about processing differences of the first-acquired language (L1) and other languages (non-L1) of multilingual people. I first briefly review evidence from neuroimaging studies with neurotypical multilingual people.

2. Functional Neuroimaging Studies of L1 vs. Non-L1

Since the early studies of functional neuroimaging, and with renewed interest in neuroplasticity, a large number of neurolinguistic studies set out to examine similarities and differences in brain activation of the first language (L1) and second language (L2) of bilingual people (e.g., Abutalebi et al. 2001; Cao et al. 2014; Golestani et al. 2006; Illes et al. 1999; Jeong et al. 2007; Liu et al. 2007, 2021; Nakada et al. 2001; Nelson et al. 2009; Oh et al. 2019; Perani et al. 2003; Saur et al. 2009; Tan et al. 2003; Vingerhoets et al. 2003, to name a few).

In such studies, brain activation is measured—using functional magnetic resonance imaging (fMRI) or positron emission tomography (PET)—while the participants are performing a language task in each of their languages, to compare activation patterns associated with each language. Activation patterns are also compared across different groups of bilingual participants while performing a language task in their non-L1 to examine the effects of the age of language appropriation and degrees of proficiency on activation patterns. The following two examples illustrate this approach.

In one study, while in the scanner, participants were presented with verbs in the present tense in their second language and were asked to first covertly conjugate the verbs in the past tense, and then to say the verbs in their past tense forms (Oh et al. 2019). The authors were interested in comparing regular and irregular verbs in English, the participants' L2. Group results for the regions activated during the overt conjugation of the two verb types were computed and contrasted to examine differences between the two conditions and across three participant groups: early bilingualism with high proficiency in both languages, late bilingualism with high proficiency in both languages, and late bilingualism with low proficiency in L2 (Oh et al. 2019).

In Wartenburger et al. (2003), for instance, bilingual participants completed a grammaticality judgement task in each of their two languages (German and Italian), and the performance of three bilingual groups (early bilingualism with high proficiency in both languages, late bilingualism with high proficiency in both languages, late bilingualism with low proficiency in L2) was compared across the two languages. Other studies have employed a variety of language processing and production tasks, such as verbal fluency (e.g., Perani et al. 2003), listening to sentences (e.g., Saur et al. 2009), silent narrative production (e.g., Tu et al. 2015), and word rhyming judgment (e.g., Cao et al. 2014).

This large literature, studying speakers of different language combinations (e.g., English–Mandarin, Cantonese–Mandarin, Catalan–Spanish, English–Spanish, German–Italian), evinced an inconclusive answer to the question of whether the two languages engage completely overlapping or somewhat differential neuronal networks. Individual studies revealed that processing in non-L1 activates the same language areas found to be active during L1 processing (e.g., Illes et al. 1999; Tan et al. 2003), but a number of studies have found also significant (albeit often small) differences in activation patterns emerging for each of the languages (e.g., Liu et al. 2007; Perani et al. 2003). Differences in the results obtained from individual studies may be attributed to variation in structural differences between the language pairs examined, variation in the language components engaged by the tasks used (e.g., semantics, syntax, phonology), and heterogeneity in the bilingual profiles of the participants (e.g., age of L2 learning, degree of L2 proficiency). Several recent systematic reviews and meta-analyses of neuroimaging studies with bilingual people attempt to extract findings that traverse the individual studies and their methodological variation. These review studies converge on the finding of wider brain activation patterns in the participants' non-L1 compared with their L1, although this finding is qualified by the levels of proficiency and the age of language appropriation of the participants studied and the linguistic components examined.

The most recent of these reviews is a meta-analysis study published by Cargnelutti et al. (2019) of 57 papers that reported fMRI (53) and PET (4) studies of L1 and L2 processing in bilingual participants. The results demonstrated that for participants who learned their second language after age 3 and before age 5 (the early bilingual group), performing language tasks in both L1 and L2 activated primarily left frontal regions, with no significant differences between the activation patterns of L1 and L2. Specifically, activation associated with L1 included the left precentral gyrus, left inferior frontal gyrus, left posterior medial frontal gyrus, left inferior temporal gyrus, and left middle temporal gyrus. Similarly, L2 activated the left precentral gyrus, left inferior frontal gyrus, left posterior medial frontal gyrus, and also left superior parietal lobule. For the late bilingual group (those who learned their L2 after age 6), the meta-analysis revealed that both languages activated the expected regions associated with language, namely, left frontal and left temporal regions (including the precentral gyrus, posterior medial frontal gyrus, and inferior frontal gyrus), as well as regions associated with executive functioning, such as the dorsolateral prefrontal cortex. Within-group comparisons revealed no activation clusters associated exclusively with L1. L2, however, was associated with greater activation than L1 in the left inferior frontal gyrus and left posterior medial frontal gyrus. In their review, Cargnelutti et al. aimed to examine the role of the age of L2 acquisition on L1 and non-L1 neuronal processing and selected the papers accordingly; they did not address which language tasks were performed by the participants included in the studies or the specific language pairs represented in the sample.

Interestingly, evidence for greater dissimilarities between the two languages in early rather than in later bilingual participants, when controlling for proficiency levels, was reported in at least one study, published after the 2019 review, although overall similar regions were activated for both L1 and L2 (including left inferior and middle frontal cortex, left superior temporal gyrus, and bilateral occipital cortices) (Ou et al. 2020).

The greater activation during L2 processing reported in Cargnelutti et al. (2019) was also found in a previous meta-analysis study (Liu and Cao 2016). One of the questions Liu and Cao (2016) set out to answer was, again, whether the age of L2 appropriation affects the degree of similarities in brain activations associated with L1 and L2. To answer this question, they examined 13 studies with early bilingual participants and 27 studies with late bilingual participants, all highly proficient in both languages. Their results revealed greater areas of activation associated with L2 than with L1 for both early and late bilingual participants, with greater differences between L1 and L2 processing for the late bilingual group. The regions associated with greater L2 than L1 activation included the left insula, left precentral gyrus, left middle frontal gyrus, and left inferior frontal gyrus in both the early and late groups, plus the left superior frontal gyrus and left medial frontal gyrus in the late group only. The additional regions included areas associated with both language processing and executive functioning (e.g., left inferior frontal gyrus) or primarily with executive functioning (e.g., left medial frontal gyrus). Liu and Cao attempted to match the language tasks the studies used for the comparisons between L1 and L2 activation. Moreover, they were interested in the role of orthographic similarities in L1 and L2 and found differences in L2 activation depending on the degree of orthographic transparency (e.g., greater bilateral temporal and precentral gyri activation for L2 that was more transparent than L1 vs. greater left frontal gyri activation for L2 that was less transparent than L1).

Language-specific activation has been consistently found in studies that used cortical stimulation as their method. Direct cortical stimulation involves applying direct current to an exposed cortical surface during neurosurgery. Cortical stimulations allow for a perhaps more refined localization of language processing in the brain than do neuroimaging studies, such as fMRI, although the language tasks are typically limited in scope (as they are performed immediately pre-op). Giussani et al. (2007) reviewed studies that used cortical stimulation to map language-related brain regions prior to neurosurgical operations in multilingual patients. They included in their review seven studies, reporting on 70 patients, mostly using naming tasks. All studies reported common but also language-specific sites; language-specific performance was associated with left posterior temporoparietal regions and left frontal regions.

The greater activation associated with L2 compared with L1 revealed in the review papers can point to the differential engagement of neuronal networks by each language, providing the answer "not completely" to the question of the overlapping neuronal involvement of L1 and non-L1. Indeed, the finding of greater activation in L2 is consistent with findings from skill learning. It has been shown that performing a new task activates larger regions compared with performing the same task after becoming skilled in it (e.g., Gobel et al. 2011; Patel et al. 2013). Thus, performing a task in an L2 may be associated with greater activation than performing a similar task more proficiently in L1.

Moreover, the greater activation found for L2 can be interpreted, as Abutalebi and Green argue (Abutalebi and Green 2007; Green and Abutalebi 2013), as associated with activation and inhibition mechanisms, rather than with differences in language processing per se. Abutalebi and Green identified a control network involving cortical and subcortical areas, likely responsible for the mechanisms that allow bilingual people to select one language or more during their communication with speakers who do or do not share all their languages. In papers published in 2007 and 2008 (Green and Abutalebi 2008), these authors reviewed neuroimaging studies of L1 and L2 processing and demonstrated the association between cognitive control processes and activation in regions including the left prefrontal cortex, the left caudate, and the inferior parietal lobules bilaterally. In a 2016 paper, the authors focused on control processes as fundamental to language use, and updated their model of the neural basis for the control mechanism to include the dorsal anterior cingulate cortex/pre-supplementary motor area, the left prefrontal cortex, the left caudate, the inferior parietal lobules bilaterally, the right prefrontal cortex, the thalamus and the putamen of the basal ganglia, and the cerebellum (Abutalebi and Green 2016). The regions that have evinced greater activation during L2 processing in the systematic reviews, such as the left inferior frontal gyrus, including the dorsolateral prefrontal cortex and left posterior medial frontal gyrus, and the left superior parietal lobule, are all part of the control network proposed by Abutalebi and Green. However note that there is some overlap in the regions that are included in the control network and in the language network, such as the left inferior frontal gyrus.

The conviction that language, any language, is processed in one system of neuronal networks whether the person speaks one language or multiple languages (e.g., Abutalebi and Green 2016; Marangolo et al. 2009) is consistent with the framework of translanguaging (Otheguy et al. 2015). A translanguaging theory of multilingualism reminds us that individuals who know multiple languages use components from one or more of their languages at any given moment according to the communication situation and their interlocutors, appropriately selecting those, typically without awareness or explicit decisions. These individual idiolects, the complete linguistic repertoire of each person, are likely represented as a single system in the individual's brain. These ideas are also consistent with evidence from psycholinguistic studies for nonselective lexical access in multilingual people. That is, experimental studies have repeatedly shown cross-language influences even when the language context and task at hand were designed to elicit processing in only one language. (The large body of literature on nonselective lexical activation is beyond the scope of this paper, but see, for example, Kroll et al. 2012, 2014).

Taken together, many researchers agree that the complete linguistic system of each person is instantiated in one, albeit complex, network system in the brain (e.g., Green and Abutalebi 2013; Perani and Abutalebi 2005) and that named languages are sociopolitical constructs rather than (neuro)linguistic ones (e.g., Vogel and Garcia 2017). However, neurolinguistic evidence for a potential special status of the first-acquired language persists (e.g., Cargnelutti et al. 2022). Similarly, psycholinguistic evidence for the need to inhibit a dominant (often the first-acquired) language while processing non-L1 (or a less-proficient language) (e.g., Green 1998; Misra et al. 2012) is consistent with the possibility of a unique status for that first-acquired language. The notion of L1 inhibition has been examined in a variety of studies in relation to nonselective lexical activation (e.g., Kroll et al. 2012), language switching processing cost (e.g., Costa and Santesteban 2004), and the extra activation during L2 processing (Abutalebi and Green 2007).

Nevertheless, within the framework of a single system subserving multiple languages, one might predict that an acquired lesion in the brain will affect all languages—indeed, the single language system—of a multilingual person. I turn next to evidence from studies of acquired language disorders in multilingual adults.

3. Brain Lesion Studies of L1 vs. Non-L1

The promise that the manifestation of acquired language disorders resulting from brain lesion in bilingual people can shed light on the underlying brain organization in bilingualism has intrigued the neurolinguistic community for quite some time. Comparable impairment of all the languages of a multilingual person is consistent with the assumption of a single neuronal network subserving all languages: even a single focal lesion to the system will affect all languages. Moreover, lesion in the networks hypothesized to be responsible for language control may manifest in impairment in language selection. I turn next to review the evidence from two types of acquired language impairments: stroke related and dementia related.

3.1. Stroke-Induced Aphasia

Aphasia is an acquired language disorder resulting from brain lesion, most commonly a stroke. The language impairments among people with aphasia vary in degree of severity and in scope. Typically, all language modalities are impaired (spoken, written, signed), and most people with aphasia experience word-finding difficulties that interfere with their ability to communicate. In severe aphasia, all linguistic systems appear impaired and communication is greatly affected, such that people with severe aphasia have compromised capability to understand spoken or written language and to contribute meaningfully to a communicative situation. On the other end of the severity continuum, people with mild aphasia retain much of their communicative abilities but experience difficulty retrieving words during language production (anomia) and may have difficulty comprehending and contributing meaningfully to a fast, multi-interlocutor conversation. The degree of severity and the profile of the impairment are associated with the size and the site of the stroke-induced lesion (e.g., McNeil and Pratt 2001; Papathanasiou and Coppens 2021; Turkeltaub 2019).

Early reports of stroke-induced aphasia in multilingual people highlighted cases with differential impairment across languages (Paradis 1983, 2004). In such reported cases, one language was markedly more impaired than another, or the person was able to communicate in only one of their previously used languages. The focus on differential impairment, possibly a result of a publication bias, led to a discussion of factors that can account for the patterns observed. Ribot (1881) suggested that the first-acquired language would have greater resilience compared with all other languages. In contrast, Pitres (1895) observed that the language most used at the time of the aphasia onset may be the more accessible to the patients. Nevertheless, early reviews seem to agree that the majority of multilingual people with aphasia show comparable impairment in their languages, or relative impairments that are consistent with their relative levels of proficiency prior to the aphasia onset (Albert and Obler 1978; Fabbro 2001; Paradis 2004).

A recent systematic review and meta-analysis that included 65 studies with 130 cases found a small but significant advantage to the first language of multilingual people with aphasia (Kuzmina et al. 2019). That is, L1 tended to be less impaired than L2, for both language comprehension and language production tasks. This was especially true for late bilingual participants, those who learned their L2 after age 7. (Note that to answer the question and compare the degree of impairments in L1 vs. L2, the authors excluded from the analyses six cases of simultaneous bilingualism, for whom there were two L1s rather than L1 and an L2.) A recent meta-analysis of language intervention effects in multilingual people with aphasia also revealed that treatment in L1 yielded stronger within-language benefits than treatment in non-L1, regardless of the linguistic modality targeted or tested (Lehtonen et al. 2022). (In their analyses, Lehtonen et al. included both later and early bilingual participants, including those who had two L1s.) These results are consistent with those of a previous review of treatment efficacy in bilingual people with aphasia (Faroqi-Shah et al. 2010) and with the better recovery of L1 reported in Kuzmina et al. (2019).

Despite these findings, multiple reports have also demonstrated the less expected pattern, that is, cases for whom the first language is not better preserved than other non-L1 languages. Cases illustrating this outcome include those reported in Filiputti et al. (2002), Goral et al. (2013), and Kiran and Roberts (2010). For example, one of the four participants described in Kiran and Roberts (2010), P1, demonstrated greater difficulty communicating in her L1, Spanish, than her L2, English, in all language modalities, after her stroke. Growing up in the U.S., she was exposed first to Spanish and then to English, has used both languages daily, and rated her proficiency higher in English than in Spanish. The higher proficiency in L2 prior to the stroke may have influenced the better recovery of that language after the stroke. In the case reported in Goral et al. (2013), the first-acquired language of the participant was the least recovered of her three languages. Lower abilities in L1 were observed in all language modalities and tasks. That first-acquired language was arguably the least used in the years following her aphasia onset. The participant's greatest recovery of English, the language of the environment and the one spoken in her immediate family, is consistent with Pitres' law. Therefore, we find an interaction between the laws of Ribot and Pitres: For many bilingual people, the first-acquired language also remains their most proficient and dominant language, and, in aphasia, often the most resilient. However, given the dynamic nature of language proficiency (e.g., Lerman et al. 2020; Navarro and Rossi 2022), some people develop higher proficiency in their non-L1, and when the first-acquired language is not used much for years around the aphasia onset, a more used non-L1 may be the more recovered one.

In the literature on another type of acquired language impairments, dementia, we find reports that corroborate Ribot's law even when language use would have predicted Pitres'. I turn now to the literature on language impairment and language preference in multilingual people with dementia. I address two sets of studies: those that examine language impairment in primary progressive aphasia and those that study dementia of the Alzheimer's type.

3.2. Dementia-Related Aphasia

3.2.1. Primary Progressive Aphasia Studies

Primary progressive aphasia (PPA) is a type of dementia that primarily affects language abilities before affecting other cognitive abilities. Although the etiology of PPA is not well understood, a variety of etiologies have been suggested, including genetic mutation (e.g., Premi et al. 2013). People with PPA vary in the manifestation of the acquired impairment. Language difficulties include anomia, slowed rate of language production, semantic deficits, and reading impairment, among others. Variability in these impairments is associated with three main variants: nonfluent, semantic, and logopenic (Gorno-Tempini et al. 2011). A growing number of studies have been published on individuals who are multilingual and manifest language difficulties due to PPA (e.g., Costa et al. 2019; Ellajosyula et al. 2020; Kambanaros and Grohmann 2012; Lind et al. 2018; Malcolm et al. 2019; Zanini et al. 2011). Several case reports converge on the finding of greater resilience of the first-acquired language in bilingual individuals with PPA.

For example, Lind et al. (2018) collected data in two time points from a bilingual English–Norwegian speaker with PPA. At the first testing time, 12 months after diagnosis, there was a clear advantage to the first-acquired language, with better word retrieval performance in L1 in naming tasks and in conversation. However, at the second testing time, 30 months after diagnosis, both languages appeared to be impaired, with marked word-finding difficulties in single-word retrieval tasks and in a conversation context in both.

Similarly, Zanini et al. (2011) reported greater impairments—in all linguistic components—in the L2 (Italian) of their Friulian–Italian bilingual participant who was highly proficient in both her languages. A similar pattern was also observed for an English–Hebrew bilingual woman who was highly proficient in both her languages prior to her diagnosis (Lerman et al. Forthcoming), for a Portuguese–French bilingual with PPA (Machado et al. 2010), and for two multilingual patients with PPA who demonstrated greater impairment in their non-L1 as their symptoms worsened (Mendez et al. 2004). In three cases of Spanish–English bilingual people with PPA, all of whom reported using English regularly at work and in other domains and two of whom endorsed better skills in and greater use of their English than their Spanish at the time before the diagnosis, better performance was observed in their Spanish, L1, than in English, their L2, on tasks including object and action naming and recognition and elicited language production (Goral Forthcoming).

Largely comparable impairments were documented in one case of a Chinese–English bilingual person (Filley et al. 2006) at a later stage of the PPA progression (the authors reported that the participant had noted language decline for 6 years prior to participation in their study). Similarly, comparable deterioration over a 1-year period was reported in Druks and Weekes (2013) for a Hungarian–English late bilingual person with PPA, despite greater impairment in L2 at the start of the study. The time after diagnosis may play a crucial role in the finding of comparable vs. differential impairments in L1 and non-L1 in PPA (Lind et al. 2018).

Two recent review papers of language impairment in bilingual people with PPA support the potential better preservation of L1. A review of 13 published cases with PPA (Malcolm et al. 2019) confirmed that in no case was L1 more impaired than non-L1. Of the 13 individuals, 8 were highly proficient in both (or all) their languages, 3 were L2 dominant, and 1 was dominant in L1 (for 1 individual, this information was not available). Another review paper reporting on 33 bilingual/multilingual participants with PPA found largely comparable impairments in the languages of the participants, although the authors highlight the great interindividual variability in the sample (Costa et al. 2019). The authors reported the dominant language for the participants, which was almost evenly divided between L1 (n = 15) and L2 (n = 14), with 3 individuals reporting equal dominance and 1 for whom no information was available. Interestingly, in over 50% of the sample, language impairment was noted in L2 first; from the data the authors present, it is difficult to say whether this finding was driven primarily by the individuals reporting L1 dominance. Moreover, greater impairment in naming in L2 was observed for the patients with the agrammatic variant of PPA (n = 14), not all of whom reported L1 dominance, whereas parallel naming impairments were evident for the other two variants. Overall impairment was largely comparable across the languages of all the participants. A recent group study of 16 bilingual people with PPA that examined the question of comparable versus differential levels of impairments reported greater resilience of L1 in both word comprehension and word retrieval (Ellajosyula et al. 2020). However, Ellajosyula et al. determined L1 to be the language of greater proficiency, as rated by the participants or their caregivers; this was the first-acquired language of 14 of the 16 participants.

Taken together, the studies of multilingual people with PPA suggest largely comparable impairment across the languages, as language abilities deteriorate with the progression of the dementia. In some cases, greater impairment may be experienced in non-L1, even for individuals who have achieved high proficiency levels and have used their non-L1 languages extensively throughout their lives.

3.2.2. Alzheimer's Disease Dementia Studies

Dementia of the Alzheimer's type is the most common type of dementia, affecting multiple cognitive abilities, including language. Early language difficulties associated with Alzheimer's disease (AD) include word-retrieval difficulties and impaired discourse production and comprehension (e.g., Mendez and Cummings 2003; Vonk et al. 2020). The anomia observed in people with AD manifests in empty speech (use of light words, such as "this" and "that one"), circumlocutions, and neologisms (nonwords) (e.g., Kavé and Goral 2016; Nicholas et al. 1985).

Evidence supporting the idea that L1 may be more resilient in bilingual individuals with dementia has been reported in the literature, but only in a few case reports (e.g., McMurtray et al. 2009). McMurtray et al. (2009) reported on two Japanese–English highly proficient bilingual individuals who had used both their languages regularly. Both individuals started preferring using their L1, Japanese, while gradually stopping the use of their L2, English, prior to the time of the evaluation when they were diagnosed with dementia. The study did not report their language performance in their two languages, but the authors proposed the idea that the language preference shift may be taken as an early marker for the onset of dementia. Brice et al. (2014) examined the performance of a Spanish–English bilingual person with AD at multiple testing times and demonstrated that his performance was, over time, better in his L1, Spanish, than in his highly proficient English, as measured by general language and cognition assessment tools (the Global Deterioration Scale and the Mini-Mental Status Examination). In four Japanese–Portuguese individuals with AD, language performance did not seem to differ in L1 and L2 (Meguro et al. 2003), but language specific characteristics affected the participants' reading performance in the two languages.

Three group studies, reporting on highly proficient bilingual people with dementia, lend minimal support to a greater resilience of a first-acquired language. Salvatierra et al. (2007) examined verbal fluency performance in a group of 11 Spanish–English bilingual people with mild to moderate AD. As a group, the participants retrieved more words in Spanish, their L1. Differences in performance between the AD group and a cognitively healthy control group were found for semantic (but not phonemic) fluency, and for both Spanish and English. In contrast, Manchon et al. (2014) found comparable impairments in the two languages of their 13 highly proficient bilingual individuals (L1 German, Spanish, or Italian; L2 French) with probable AD, who were tested on a variety of language tests. Veenstra et al. (2014) examined object naming in 26 highly proficient Frisian–Dutch bilingual participants with mild to moderate dementia associated with probable AD and found comparable levels of accuracy performance for both languages. They did, however, find a significant correlation between the age of acquisition of the words and naming accuracy, consistent with the idea that earlier-acquired words would be more resilient to dementia-related deterioration.

Gollan et al. (2010) compared Spanish–English bilingual participants (all native speakers of Spanish) with and without AD-related dementia on an object picture naming test. English-dominant participants with AD (n = 16) named fewer pictures than a matched group of participants without AD. The difference was more pronounced in English than in Spanish. The Spanish-dominant participants with AD (n = 13) in the study also named fewer pictures than their matched control group, but there was no interaction between group and language such that the participants with AD named fewer items in both their L1 and L2 compared with the participants without dementia. The authors interpreted their results to suggest that testing in the dominant language of bilingual people with dementia is more revealing than testing in their nondominant language.

However, the results of Gollan et al. (2010) may be specific to the population they enrolled, namely, native speakers of Spanish who have been immersed in English and may have become more proficient in their early-acquired L2, English, than in their first-acquired Spanish. Moreover, as the authors acknowledge, the test they used was designed in English, and the two versions, the English and Spanish ones, may not have been comparable. It is possible that the Spanish-dominant participants in the Gollan et al. (2010) study would have demonstrated better performance in their L1, Spanish, but because of the test characteristics, an equal degree of impairment was found for both their L1 and L2 compared with the participants without dementia. In a later study, Ivanova et al. (2014) observed that their 18 participants with probable AD, all childhood bilingual individuals with high proficiency in both their languages, also demonstrated greater decline in picture-naming performance in their nondominant language than in their dominant language, suggesting again that the degree of language use interacts with the age of language appropriation in the process of decline.

I hypothesize that the different patterns of results emerging for PPA vs. AD dementia may be related to the underlying impairment in the two types of dementia. In PPA, language is primarily impaired, at least in the early stages of neurodegeneration, while other cognitive abilities remain preserved to a great extent. If there is a differential linguistic impairment of L1 and non-L1 with acquired brain lesion, we may expect this difference to emerge in multilingual people with PPA. An exception here would be the presence of semantic degradation, which would affect all languages. Semantic degradation is evident in the semantic variant of PPA and in later stages of dementia of the AD type, and appears to affect all languages. This is consistent with the assumption that the underlying semantic network is shared for all languages of multilingual people, supported by a large body of literature (see, for example, Francis 2020; Kroll and Tokowicz 2005; Kroll et al. 2010).

In AD, declining cognitive abilities, such as executive functioning and cognitive control (Baudic et al. 2006; Bondi et al. 2009), may underlie the observed language impairment, at least at the early stages of the acquired language impairments (e.g., Kempler and Goral 2008; Rogers and Friedman 2008). Such cognitive impairment is likely to affect task performance, regardless of the language examined, and thus, we may expect no differences in the decline patterns observed for L1 and non-L1. Evidence from caregiver reports supports reversion to the first-acquired language in later stages of AD-related dementia (e.g., Mendez et al. 1999), presumably when the language system itself is impaired due to further deterioration in brain integrity.

Finally, consistent with the prediction of impaired language control following lesions affecting the control network is the finding that some multilingual individuals with an acquired brain lesion mix their languages unintentionally (e.g., Fabbro et al. 2000; Svennevig et al. 2019). In some instances, atypical language switching behavior is observed, such as switching to a language that the interlocutor does not understand. Such language selection errors have been interpreted as the result of faulty language control mechanisms (Fabbro et al. 2000; Fyndanis and Lehtonen 2021). In other cases, mixing words and phrases from two (or more) languages or switching midutterance from one language to another—often but not always to L1—can be attributed to attempts to resolve word-finding difficulties (Goral et al. 2019).

4. Concluding Remarks

In search of an answer to the question of whether the processing of the first-acquired language is unique as compared with later-learned languages, I have reviewed research evidence from neuroimaging studies of neurotypical multilingual adults and from studies of multilingual adults with acquired brain lesion. Evidence from cases of acquired language impairment is consistent with a more robust instantiation of the first-acquired language in the brain of multilingual people. This was evident in the better preservation and recovery of the first-acquired language in people who experience a stroke and consequently acquire aphasia. Similarly, evidence from primary progressive aphasia, a progressive acquired language impairment due to neurodegeneration, suggests that the first-acquired language deteriorates less or after non-L1 languages do. In dementia associated with Alzheimer's disease, in which cognitive impairment is prevalent, language impairment appears to progress in parallel in both languages of bilingual people, although in this case too, a reverting to the use of the first-acquired language in later stages of brain deterioration may be evident.

This evidence from lesion studies aligns, albeit only partially, with evidence from neuroimaging studies with neurotypical bilingual people. Whereas many researchers converge on the idea that the same neuronal system is engaged in the processing of all languages of multilingual people, neuroimaging studies have consistently found differential brain activation during the performance of a variety of language tasks in the first-acquired language vs. non-L1 languages. The activation differences between L1 and L2 have been found across studies that used different language tasks and included participants with varying degrees of language proficiency and varying ages of language acquisition. Differences between languages appear more consistently in studies that used more refined methods, such as cortical stimulation, than the broader activation captured in fMRI and PET studies, which may point to the shortcomings of the latter methods. In current neuroimaging studies, interpretation of the association between the signals measured and the language activities used can be affected by the regions analyzed, the tasks and subtractions used, among other variables (e.g., Fedorenko and Kanwisher 2009; Hayes and Huxtable 2012; Indefrey 2006).

The activation differences for L1 and non-L1 found in the neuroimaging studies have been interpreted primarily as indicating the engagement of control mechanisms necessary for the appropriate activation and inhibition of a language while using another, a skill that bilingual people develop as they adapt to using one or more of their languages in different communicative situations. Indeed, much of the additional activation observed for L2 over L1 centered in regions associated with the hypothesized control mechanisms. Almost all of the extra activation associated with non-L1 could be attributed to control mechanisms, supporting the argument that multiple languages share their underlying neuronal networks. We would expect greater prevalence of unintentional language switching and mixing following acquired brain lesion that affects the control network, a phenomenon that has been reported but is not highly prevalent. A control deficit explanation of all differential impairments is also less consistent with the systematically better preservation of L1, rather than any one of the languages, evident in the literature. The data reviewed here suggest that regardless of whether the first-acquired and later-learned languages may share overlapping or not completely overlapping neuronal networks, L1 may be instantiated in the brain in a manner that affords it greater resilience in the presence of brain damage.

It takes a shift in language dominance to change the expected pattern of better recovery in L1; language is dynamic, and patterns of language use clearly affect language processing in the brain (Green and Abutalebi 2013; Libben and Schwieter 2019). However, evidence suggests that even when non-L1 becomes highly proficient and predominantly used, L1 may be more resilient against brain-related deterioration. The special status of the first-acquired language evident in the lesion studies is consistent with findings from other disciplines, including, for example, the differential patterns found for emotional processing in the first-acquired language (e.g., Hadden et al. 2020; Liu et al. 2022; Sulpizio et al. 2019).

The greater resilience of a first-acquired language may be related to the notion of automaticity. It is possible that processing in a first-acquired language is automatic in a way that later-learned languages, even when achieving high levels of proficiency, never reach (e.g., McLeod and McLaughlin 1986; Segalowitz 2008). High proficiency in a language is associated with faster processing and more accurate performance than that measured for lower levels of proficiency in non-L1, but performance in non-L1, even at high proficiency, still retains a degree of variability that can indicate nonautomatic processing (Segalowitz 2010). The additional demands associated with the nonautomatic processing can be the source of differential activation patterns documented in neuroimaging studies of bilingualism and with differential effects of acquired brain damage. I attempted to bring together evidence from these two types of neurolinguistic studies to explore the potential special status of a first-acquired language. Whereas the two sets of data converge, to a degree, the review highlights a number of ways in which the discipline can move forward.

Avenues for future directions include investigations of the relationship between underlying brain impairment and the manifestation of the language deficits in each language, especially with respect to the patterns of language proficiency and use across the individual's lifespan and in the period prior to the acquired brain changes. This has been explored in the literature on stroke-related aphasia and, to a lesser extent, in dementia among multilingual people, but the heterogeneity inherent in this population makes drawing conclusions difficult. In this respect, dissociating the effects of specific cognitive and linguistic deficits and their influence on each language can help resolve inconsistent results for differing types of dementias and aphasias. The implications of such dissociations for models of bilingual processing and control mechanisms could then be interrogated. For example, the role of language inhibition in the manifestation of selective impairment in the languages of bilingual people with varying types of acquired brain lesions warrants further investigation. As well, the implication of shared neuronal networks for applied theories of translanguaging could strengthen the evidence supporting the shift toward translanguaging instruction and assessment in typical and atypical multilingual individuals. Furthermore, as our detection tools improve, a more fine-grained understanding of brain activation patterns as they relate to language processing should help refine our conclusions about multiple language processing in the brain. Triangulating results from a variety of measures and disciplines will help us understand the potential primacy of the first-acquired language and its implications.

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References

Abutalebi, Jubin, and David W. Green. 2007. Bilingual language production: The neurocognition of language representation and control. *Journal of Neurolinguistics* 20: 242–75. [CrossRef]

Abutalebi, Jubin, and David W. Green. 2016. Neuroimaging of language control in bilinguals: Neural adaptation and reserve. *Bilingualism: Language and Cognition* 19: 689–98. [CrossRef]

Abutalebi, Jubin, Stefano F. Cappa, and Daniela Perani. 2001. The bilingual brain as revealed by functional neuroimaging. *Bilingualism: Language and Cognition* 4: 179–90. [CrossRef]

Albert, Martin L., and Loraine K. Obler. 1978. *The Bilingual Brain: Neuropsychological and Neurolinguistic Aspects of Bilingualism*. New York: Academic Press.

Baudic, Sophie, Gianfranco D. Barba, Marie C. Thibaudet, Alain Smagghe, Philippe Remy, and Latchezar Traykov. 2006. Executive function deficits in early Alzheimer's disease and their relations with episodic memory. *Archives of Clinical Neuropsychology* 21: 15–21. [CrossRef]

Bondi, Mark W., David P. Salmon, and Alfred W. Kaszniak. 2009. The neuropsychology of dementia. In *Neuropsychological Assessment of Neuropsychiatric and Neuromedical Disorders*. Edited by Igor Grant and Kenneth M. Adams. Oxford: Oxford University Press, pp. 159–98.

Brice, Alejandro E., Sarah E. Wallace, and Roanne G. Brice. 2014. Alzheimer's dementia from a bilingual/bicultural perspective: A case study. *Communication Disorders Quarterly* 36: 55–64. [CrossRef]

Cao, Fan, Say Y. Kim, Yanni Liu, and Lin Liu. 2014. Similarities and differences in brain activation and functional connectivity in first and second language reading: Evidence from Chinese learners of English. *Neuropsychologia* 63: 275–84. [CrossRef]

Cargnelutti, Elisa, Barbara Tomasino, and Franco Fabbro. 2019. Language brain representation in bilinguals with different age of appropriation and proficiency of the second language: A meta-analysis of functional imaging studies. *Forntiers in Human Neuroscience* 13: 154. [CrossRef]

Cargnelutti, Elisa, Barbara Tomasino, and Franco Fabbro. 2022. Effects of linguistic distance on second language brain activations in bilinguals: An exploratory coordinate-based meta-analysis. *Frontiers in Human Neuroscience* 15: 744489. [CrossRef]

Costa, Albert, and Mikel Santesteban. 2004. Lexical access in bilingual speech production: Evidence from language switching in highly proficient bilinguals and L2 learners. *Journal of Memory and Language* 50: 491–511. [CrossRef]

Costa, Ana S., Regina Jokel, Alberto Villarejo, Sara Llamas-Velasco, Kimiko Domoto-Reilley, Jennifer Wojtala, Kathrine Reetz, and Álvaro Machado. 2019. Bilingualism in primary progressive aphasia: A retrospective study on clinical and language characteristics. *Alzheimer Disease and Associated Disorders* 33: 47–53. [CrossRef]

Druks, Judit, and Brendan S. Weekes. 2013. Parallel deterioration to language processing in a bilingual speaker. *Cognitive Neuropsychology* 30: 578–96. [CrossRef] [PubMed]

Ellajosyula, Ratnavalli, Jwala Narayanan, and Karalyn Patterson. 2020. Striking loss of second language in bilingual patients with semantic dementia. *Journal of Neurology* 267: 551–60. [CrossRef] [PubMed]

Fabbro, Franco. 2001. The bilingual brain: Bilingual aphasia. *Brain and Language* 79: 201–10. [CrossRef] [PubMed]

Fabbro, Franco, Miran Skrap, and Salvatore Aglioti. 2000. Pathological switching between languages after frontal lesions in a bilingual patient. *Journal of Neurology Neurosurgery and Psychiatry* 68: 650–52. [CrossRef] [PubMed]

Faroqi-Shah, Yasmeen, Tobi Frymark, Robert Mullen, and Beverly Wang. 2010. Effect of treatment for bilingual individuals with aphasia: A systematic review of the evidence. *Journal of Neurolinguistics* 23: 319–41. [CrossRef]

Fedorenko, Evelina, and Nancy Kanwisher. 2009. Neuroimaging of language: Why hasn't a clearer picture emerged? *Language and Linguistics Compass* 3: 839–65. [CrossRef]

Filiputti, Dario, Alessandro Tavano, Lorenza Vorano, Guido De Luca, and Franco Fabbro. 2002. Nonparellel recovery of languages in a quadrilingual aphasic patient. *International Journal of Bilingualism* 6: 395–410. [CrossRef]

Filley, Christopher M., Gail Ramsberger, Lise Menn, Jiang Wu, Bessie Y. Reid, and Allan L. Reid. 2006. Primary progressive aphasia in a bilingual woman. *Neurocase* 12: 296–99. [CrossRef]

Francis, Wendy S. 2020. Shared core meanings and shared associations in bilingual semantic memory: Evidence from research on implicit memory. *International Journal of Bilingualism* 24: 464–77. [CrossRef]

Fridriksson, Julius, Dirk-Bart den Ouden, Argye E. Hillis, Gregory Hickok, Chris Rorden, Alexandra Basilakos, Grigori Yourganov, and Leonardo Bonilha. 2018. Anatomy of aphasia revisited. *Brain* 141: 848–62. [CrossRef]

Fyndanis, Valantis, and Minna Lehtonen. 2021. Cognitive control and pathological language mixing in aphasia. In *Multilingualism Across the Lifespan*. Edited by Robert Blackwood and Unn Røyneland. London: Routledge, pp. 209–30.

Giussani, Carlo, Franck-Emmanuel Roux, Vincent Lubrano, Sergio M. Gaini, and Lorenzo Bello. 2007. Review of language organisation in bilingual patients: What can we learn from direct brain mapping? *Acta Neurochirurgica* 149: 1109–16. [CrossRef] [PubMed]

Gobel, Eric W., Todd B. Parrish, and Paul J. Reber. 2011. Neural correlates of skill acquisition: Decreased cortical activity during a serial interception sequence learning task. *Neuroimage* 58: 1150–57. [CrossRef] [PubMed]

Golestani, Narly, François Xavier Alario, Sébastien Meriaux, Denis Le Bihan, Stanislas Dehaene, and Christophe Pallier. 2006. Syntax production in bilinguals. *Neuropsychologia* 44: 1029–40. [CrossRef] [PubMed]

Gollan, Tamar H., David P. Salmon, Rosa I. Montoya, and Eileen Da Pena. 2010. Accessibility of the nondominant language in picture naming: A counterintuitive effect of dementia on bilingual language production. *Neuropsychologia* 48: 1356–66. [CrossRef] [PubMed]

Goral, Mira. Forthcoming. Language shift in bilingual people with primary progressive aphasia.

Goral, Mira, Maryam Naghibolhosseini, and Peggy S. Conner. 2013. Asymmetric inhibitory treatment effects in multilingual aphasia. *Cognitive Neuropsychology* 30: 564–77. [CrossRef]

Goral, Mira, Monica Norvik, and Bård U. Jensen. 2019. Variation in code-switching in multilingual aphasia. *Journal of Clinical Linguistics and Phonetics* 33: 915–29. [CrossRef]

Gorno-Tempini, Maria L., Argye E. Hillis, Sandra Weintraub, Andew Kertesz, Mario Mendez, Stefano E. E. Cappa, Jennifer Ogar, Jonathan D. Rohrer, Stuart Black, Bradley F. Boeve, and et al. 2011. Classification of primary progressive aphasia and its variants. *Neurology* 76: 1006–14. [CrossRef]

Green, David W. 1998. Mental control of the bilingual lexico- semantic system. *Bilingualism: Language and Cognition* 1: 67–81. [CrossRef]

Green, David W., and Jubin Abutalebi. 2008. Understanding the link between bilingual aphasia and language control. *Journal of Neurolinguistics* 21: 558–76. [CrossRef]

Green, David W., and Jubin Abutalebi. 2013. Language control in bilinguals: The adaptive control hypothesis. *Journal of Cognitive Psychology* 25: 515–30. [CrossRef]

Grosjean, François. 2022. *The Mysteries of Bilingualism: Unresolved Issues*. Hoboken: Wiley.

Hadden, Lowri M., Ben Alderson-Day, Mike Jackson, Charles Fernyhough, and Richard P. Bentall. 2020. The auditory-verbal hallucinations of Welsh-English bilingual people. *Psychology and Psychotherapy: Theory, Research and Practice* 93: 122–33. [CrossRef] [PubMed]

Hayes, Dave J., and Adrianne G. Huxtable. 2012. Interpreting deactivations in neuroimaging. *Frontiers in Psychology* 3: 27. [CrossRef] [PubMed]

Illes, Judy, Wendy S. Francis, John E. Desmond, John D. Gabrieli, Gary H. Glover, Russell Poldrack, Anthony D. Christine J. Lee, and Anthony D. Wagner. 1999. Convergent cortical representation of semantic processing in bilinguals. *Brain and Language* 70: 347–63. [CrossRef]

Indefrey, Peter. 2006. A meta-analysis of hemodynamic studies on first and second language processing: Which suggested differences can we trust and what do they mean? *Language Learning* 56: 279–304. [CrossRef]

Ivanova, Iva, David P. Salmon, and Tamar H. Gollan. 2014. Which Language Declines More? Longitudinal versus Cross-Sectional Decline of Picture Naming in Bilinguals with Alzheimer's Disease. *Journal of the International Neuropsychological Society* 20: 534–46. [CrossRef] [PubMed]

Jeong, Hyeonjeong, Motoaki Sugiura, Yuko Sassa, Tomoki Haji, Nobuo Usui, Masatoi Taira, Kaoru Horie, Shigeru Sato, and Ryuta Kawashima. 2007. Effect of syntactic similarity on cortical activation during second language processing: A comparison of English and Japanese among native Korean trilinguals. *Human Brain Mapping* 28: 194–204. [CrossRef] [PubMed]

Kambanaros, Maria, and Kleanthes K. Grohmann. 2012. BATting multilingual primary progressive aphasia for Greek, English, and Czech. *Journal of Neurolinguistics* 25: 520–37. [CrossRef]

Kavé, Gitit, and Mira Goral. 2016. Word retrieval on structured tests and in connected speech in healthy older adults and in individuals with Alzheimer's disease. *Journal of Clinical and Experimental Neuropsychology* 38: 958–66. [CrossRef]

Kempler, Daniel, and Mira Goral. 2008. Language and Dementia: Neuropsychological aspects. *Annual Review of Applied Linguistics* 28: 1–18. [CrossRef]

Kiran, Swathi, and Patricia M. Roberts. 2010. Semantic feature analysis treatment in Spanish–English and French–English bilingual aphasia. *Aphasiology* 24: 231–61. [CrossRef]

Kroll, Judith F., and Natasha Tokowicz. 2005. Models of bilingual representation and processing: Looking back and to the future. In *Handbook of Bilingualism: Psycholinguistic Approaches*. Edited by Judith F. Kroll and Annette M. B. de Groot. Oxford: Oxford University Press, pp. 531–54.

Kroll, Judith F., Janet G. Van Hell, Natasha Tokowicz, and David W. Green. 2010. The Revised Hierarchical Model: A critical review and assessment. *Bilingualism: Language and Cognition* 13: 373–81. [CrossRef]

Kroll, Judith F., Paula E. Dussias, Cari A. Bogulski, and Jorge R. V. Kroff. 2012. Juggling two languages in one mind: What bilinguals tell us about language processing and its consequences for cognition. In *The Psychology of Learning and Motivation*. Edited by Brian H. Ross. Cambridge: Elsevier Academic Press, pp. 229–62. [CrossRef]

Kroll, Judith F., Susan C. Bobb, and Noriko Hoshino. 2014. Two languages in mind: Bilingualism as a tool to investigate language, cognition, and the brain. *Current Directions in Psychological Science* 23: 159–63. [CrossRef]

Kuzmina, Ekaterina, Mira Goral, Monica Norvik, and Brendan Weekes. 2019. What influences language impairment in bilingual aphasia? A meta-analytic review. *Frontiers in Psychology* 10: 445. [CrossRef] [PubMed]

Lehtonen, Minna, Monica Norvik, Jan Antfolk, and Mira Goral. 2022. Cross-language generalization in treatment of multilingual aphasia: A meta-analysis. Poster presented at the Learning and Neuroplasticity Meeting, Äkäslompolo, Finland, April 2–5.

Lerman, Aviva, Dorit Mais, Yael Nissani, and Taryn Malcolm. Forthcoming. Preserving lexical retrieval skills across languages in a bilingual person with logopenic primary progressive aphasia. *Aphasiology*. [CrossRef]

Lerman, Aviva, Mira Goral, and Loraine K. Obler. 2020. The complex relationship between pre-stroke and post-stroke language abilities in multilingual aphasia. *Aphasiology* 34: 1319–40. [CrossRef]

Libben, Gary, and John W. Schwieter. 2019. Lexical organization and reorganization in the multilingual mind. In *The Handbook of the Neuroscience of Multilingualism*. Edited by John W. Schwieter. Malden and Oxford: Wiley-Blackwell, pp. 297–313.

Lind, Marianne, Hanne G. Simonsen, Ingeborg S. B. Ribu, Bente A. Svendsen, Jan Svennevig, and Kees de Bot. 2018. Lexical access in a bilingual speaker with dementia: Changes over time. *Clinical Linguistics & Phonetics* 32: 353–77. [CrossRef]

Liu, Hengshuang, and Fan Cao. 2016. L1 and L2 processing in the bilingual brain: A meta-analysis of neuroimaging studies. *Brain and Language* 159: 60–73. [CrossRef]

Liu, Linyan, John W. Schwieter, Fenqi Wang, and Huanhuan Liu. 2022. First and second languages differentially affect rationality when making decisions: An ERP study. *Biological Psychology* 169: 108265. [CrossRef] [PubMed]

Liu, Xiaojin, Liu Tu, Xiaoxi Cheng, Junjing Wang, Meng Li, Zhi Lu, and Ruiwang Huang. 2021. Effect of AoA-L2 on L1 and L2 networks in early and late bilinguals. *International Journal of Bilingualism* 25: 1616–34. [CrossRef]

Liu, Ying, Susan Dunlap, Julie Fiez, and Charles Perfetti. 2007. Evidence for neural accommodation to a writing system following learning. *Human Brain Mapping* 28: 1223–34. [CrossRef]

Machado, Alvaro, Margarida Rodrigues, Sonia Simoes, Isabel Santana, and Joao Soares-Fernandes. 2010. The Portuguese who could no longer speak French: Primary progressive aphasia in a bilingual man. *Journal of Neuropsychiatry and Clinical Neurosciences* 22: E31–E32. [CrossRef] [PubMed]

Malcolm, Taryn, Aviva Lerman, Marta Korytkowska, Jet M. J. Vonk, and Loraine K. Obler. 2019. Primary Progressive Aphasias in Bilinguals and Multilinguals. In *The Handbook of the Neuroscience of Multilingualism*. Edited by J. Schwieter. Hoboken: Wiley.

Manchon, Mélanie, Karin Buetler, Françoise Colombo, Lucas Spierer, Frédéric Assal, and Jean-marie M. Annoni. 2014. Impairment of both languages in late bilinguals with dementia of Alzheimer type. *Bilingualism: Language and Cognition* 18: 90–100. [CrossRef]

Marangolo, Paula, Christina Rizzi, Patrice Peran, Fabrizio Piras, and Umberto Sabatini. 2009. Parallel recovery in a bilingual aphasic: A neurolinguistic and fMRI study. *Neuropsychology* 23: 405–09. [CrossRef] [PubMed]

McLeod, Beverly, and Barry McLaughlin. 1986. Restructuring or automaticity? Reading in a second language. *Language Learning* 36: 109–23. [CrossRef]

McMurtray, Aaron, Erin Saito, and Beau Nakamoto. 2009. Language preference and development of dementia among bilingual individuals. *Hawaii Medical Journal* 68: 223–26. [PubMed]

McNeil, Malcolm R., and Shiela R. Pratt. 2001. Defining aphasia: Some theoretical and clinical implications of operating from a formal definition. *Aphasiology* 15: 901–11. [CrossRef]

Meguro, Kenichi, Mirna L. H. Senaha, Paulo Caramelli, Junichi Ishizaki, Rosa Y. S. Chubacci, Mitsue Meguro, Hideo Ambo, Ricardo Nitrini, and Atsushi Yamadori. 2003. Language deterioration in four Japanese–Portuguese bilingual patients with Alzheimer's disease: A trans-cultural study of Japanese elderly immigrants in Brazil. *Psychogeriatrics* 3: 63–68. [CrossRef]

Mendez, Mario F., and Jeffry L. Cummings. 2003. *Dementia: A Clinical Approach*, 3rd ed. Amsterdam and New York: Butterworth-Heinemann Medical.

Mendez, Mario F., Kent M. Perryman, Marcel O. Pontón, and Jeffry L. Cummings. 1999. Bilingualism and dementia. *The Journal of Neuropsychiatry and Clinical Neurosciences* 11: 411–12. [CrossRef]

Mendez, Mario F., Samira Saghafi, and David G. Clark. 2004. Semantic dementia in multilingual patients. *The Journal of Neuropsychiatry and Clinical Neurosciences* 16: 381–81. [CrossRef]

Misra, Maya, Taomei Guo, Susan C. Bobb, and Judith F. Kroll. 2012. When bilinguals choose a single word to speak: Electrophysiological evidence for global inhibition in bilingual word production. *Journal of Memory and Language* 67: 224–37. [CrossRef]

Nakada, Tsutomu, Yukihiko Fujii, and Ingrid L. Kwee. 2001. Brain strategies for reading in the second language are determined by the first language. *Neuroscience Research* 40: 351–58. [CrossRef]

Navarro, Ester, and Eleonora Rossi. 2022. Using latent variable analysis to capture variability in bilingual language experience. *PsyArXiv*. [CrossRef]

Nelson, Jessica R., Ying Liu, Julie Fiez, and Charles A. Perfetti. 2009. Assimilation and accommodation patterns in ventral occipitotemporal cortex in learning a second writing system. *Human Brain Mapping* 30: 810–20. [CrossRef] [PubMed]

Nicholas, Marjorie, Loraine K. Obler, Martin L. Albert, and Nancy Helm-Estabrooks. 1985. Empty speech in Alzheimer's disease and fluent aphasia. *Journal of Speech, Language, and Hearing Research* 28: 405–10. [CrossRef] [PubMed]

Oh, Tomasina M., Steven Graham, Philina Ng, Ing B. Yeh, Bernard P. L. Chan, and Andrew M. Edwards. 2019. Age and Proficiency in the bilingual brain revisited: Activation patterns across different L2-learner types. *Frontiers in Communication* 4: 39. [CrossRef]

Otheguy, Ricardo, Ofelia García, and Wallis Reid. 2015. Clarifying translanguaging and deconstructing named languages: A perspective from linguistics. *Applied Linguistics Review* 6: 281–307. [CrossRef]

Ou, Jian, Wenlong Li, Yang Yang, Nizhuan Wang, and Min Xu. 2020. Earlier second language acquisition is associated with greater neural pattern dissimilarity between the first and second languages. *Brain and Language* 203: 104740. [CrossRef]

Papathanasiou, Ilias, and Patrick Coppens. 2021. *Aphasia and Related Neurogenic Communication Disorders*, 3rd ed. Burlington: Jones & Bartlett Learning.

Paradis, Michel. 1983. *Readings in Aphasia in Bilinguals and Polyglots*. Montreal: Didier.

Paradis, Michel. 2004. *A Neurolinguistic Theory of Bilingualism*. Amsterdam: John Benjamins.

Patel, Ronak, R. Nathan Spreng, and Gary R. Turner. 2013. Functional brain changes following cognitive and motor skills training: A quantitative meta-analysis. *Neurorehabilitation and Neural Repair* 27: 187–99. [CrossRef]

Perani, Daniela, and Jubin Abutalebi. 2005. The neural basis of first and second language processing. *Current Opinion in Neurobiology* 15: 202–6. [CrossRef]

Perani, Daniela, Jubin Abutalebi, Eraldo Paulesu, Simona Brambati, Paula Scifo, Stefano F. Cappa, and Ferruccio Fazio. 2003. The role of age of acquisition and language usage in early, high-proficient bilinguals: An fMRI study during verbal fluency. *Human Brain Mapping* 19: 170–82. [CrossRef]

Pitres, Albert. 1895. Etude sur l'aphasie chez les polyglottes. *Revue de Medecine* 15: 873–99, [Translated by M. Paradis. *Readings on Aphasia in Bilinguals and Polyglots*. Montreal: Marcel Didier, pp. 26–48].

Premi, Enrico, Stefano Gazzina, Marco Bozzali, Silvana Archetti, Antonella Alberici, Mara Cercignani, Angelo Bianchetti, Roberto Gasparotti, Marinella Turla, Carlo Caltagirone, and et al. 2013. Cognitive reserve in *Granulin*-related frontotemporal dementia: From preclinical to clinical stages. *PLoS ONE* 8: e74762. [CrossRef] [PubMed]

Price, Cathy J. 2010. The anatomy of language: A review of 100 fMRI studies published in 2009. *Annals of The New York Academy of Sciences* 1191: 62–88. [CrossRef] [PubMed]

Ribot, Théodule. 1881. *Les Maladies de la Mémoire*, 2nd ed. Paris: Baillère.

Rogers, Sean L., and Rhonda B. Friedman. 2008. The underlying mechanisms of semantic memory loss in Alzheimer's disease and semantic dementia. *Neuropsychologia* 46: 12–21. [CrossRef] [PubMed]

Salvatierra, Judy, Monica Rosselli, Amarillis Acevedo, and Ranjan Duara. 2007. Verbal fluency in bilingual Spanish/English Alzheimer's disease patients. *American Journal of Alzheimer's Disease & Other Dementias* 22: 190–201.

Saur, Dorothee, Annette Baumgaertner, Anja Moehring, Christian Büchel, Matthias Bonnesen, Michael Rose, Mariachristina Musso, and Jürgen M. Meisel. 2009. Word order processing in the bilingual brain. *Neuropsychologia* 47: 158–68. [CrossRef]

Segalowitz, Norman. 2008. Automaticity and second languages. In *The Handbook of Second Language Acquisition*. Edited by Catherine J. Doughty and Michael H. Long. Hoboken: Wiley, pp. 382–408.

Segalowitz, Norman. 2010. *Cognitive Bases of Second Language Fluency*. London: Routledge.

Sulpizio, Simone, Michelle Toti, Nicola Del Maschio, Albert Costa, Davide Fedeli, Remo Job, and Jubin Abutalebi. 2019. Are you really cursing? Neural processing of taboo words in native and foreign language. *Brain and Language* 194: 84–92. [CrossRef]

Svennevig, Jan, Pernille Hansen, Hanne G. Simonsen, and Anne M. D. Landmark. 2019. Code-switching in multilinguals with dementia: Patterns across speech contexts. *Clinical Linguistic and Phonetics* 33: 1009–30. [CrossRef]

Tan, Li H., John A. Spinks, Ching M. Feng, Wai T. Siok, Charles A. Perfetti, Jinhu Xiong, Peter T. Fox, and Jia-Hong Gao. 2003. Neural systems of second language reading are shaped by native language. *Human Brain Mapping* 18: 158–66. [CrossRef]

Tu, Liu, Junjing Wang, Jubin Abutalebi, Bo Jiang, Ximin Pan, Meng Li, Wei Gao, Yuchen Yang, Bishan Liang, Zhi Lum, and et al. 2015. Language exposure induced neuroplasticity in the bilingual brain: A follow-up fMRI study. *Cortex* 64: 8–19. [CrossRef]

Turkeltaub, Peter E. 2019. A taxonomy of brain–behavior relationships after stroke. *Journal of Speech, Language, and Hearing Research* 62: 3907–22. [CrossRef]

Veenstra, Wencke S., Mark Huisman, and Nick Miller. 2014. Age of acquisition and naming performance in Frisian-Dutch bilingual speakers with dementia. *Dementia & Neuropsychologia* 8: 249–59. [CrossRef]

Vingerhoets, Guy, John Van Borsel, Cathelijne Tesink, Maurits van den Noort, Karel Deblaere, Ruth Seurinck, Pieter Vandemaele, and Eric Achten. 2003. Multilingualism: An fMRI study. *NeuroImage* 20: 2181–96. [CrossRef] [PubMed]

Vogel, Sara, and Ofelia Garcia. 2017. *Translaguaging. Oxford Research Encyclopedia of Education*. Oxford: Oxford University Press.

Vonk, Jet M. J., Vincent Bouteloup, Jean F. Mangin, Bruno Dubois, Frédéric Blanc, Audrey Gabelle, Mathieu Ceccaldi, Cédric Annweiler, Pierre Krolak-Salmon, Catherine Belin, and et al. 2020. Semantic loss marks early Alzheimer's disease-related neurodegeneration in older adults without dementia. *Alzheimer's & Dementia: Diagnosis, Assessment & Disease Monitoring* 12: e12066.

Wartenburger, Isabell, Hauke R. Heekeren, Jubin Abutalebi, Stefano F. Cappa, Arno Villringer, and Daniela Perani. 2003. Early setting of grammatical processing in the bilingual brain. *Neuron* 37: 159–70. [CrossRef]

Zanini, Sergio, Valentina Angeli, and Alessandro Tavano. 2011. Primary progressive aphasia in a bilingual speaker: A single-case study. *Clinical Linguistics & Phonetics* 25: 553–64.