

Lexicon and Grammar in Bilingual Individuals with Alzheimer's Disease and Parkinson's Disease: A Comparative Review

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Abstract

Given the number of bilingual individuals worldwide, many of patients with Alzheimer's disease (AD) or Parkinson's disease (PD) are bilinguals. Yet little is known about the consequences of the two neurodegenerative diseases on the language of bilingual patients. In this paper, we review the available data in the bilingual literature, specifically the decline of language in patients with AD and PD at the lexical and grammatical levels. Our literature search of three electronic databases identified nine articles on bilingual patients with AD and five on those with PD that analyzed the lexicon and grammar of these patients. The findings of these studies are inconsistent but suggest that AD and PD should affect both languages in bilingual patients. They also show a trend that AD results in greater difficulties with lexicon and L2 grammar, while PD affects L1 grammar to a greater extent. This pattern is as expected by the declarative/procedural model that each disease affects a distinct memory system.

Key words: *bilingual, language decline, Alzheimer's disease, Parkinson's disease, declarative/procedural model*

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1. Introduction

With an increase in the aging population, the number of people living with age-related diseases is growing. In particular, Alzheimer's disease (AD) and Parkinson's disease (PD), respectively, are the most and the second-most prevalent age-related neurodegenerative diseases (Ferri et al., 2005; Gibrat et al., 2009). It is estimated that there were around 55 million people worldwide living with dementia in 2020, most commonly with AD, and the number is expected to reach 78 million in 2030. Globally, there are over 10 million new patients with dementia each year, suggesting one new patient every 3.2 seconds (World Alzheimer Report, 2021). Moreover, the number of people living with PD worldwide has been reported at more than 10 million, with tens of thousands of undiagnosed cases. Similar to AD, the number of patients with PD is expected to rise, as PD is one of the world's fastest-growing neurological disorders (National Parkinson's Foundation, 2022).

AD and PD are both progressive neurological diseases that are associated with progressive cognitive deterioration, a decline in daily activities, and neuropsychiatric symptoms (Cazzato & Bava, 2003; Murray, 2000; Paradis, 2008). Importantly, both diseases are accompanied by language problems, albeit with different patterns from each other. Individuals with AD are often characterized as having lexical problems but with relatively intact grammatical abilities (Cummings et al., 1988; Hodges et al., 1992). By contrast, individuals with PD typically have grammatical deficits, with relatively intact lexical abilities (Saint-Cyr et al., 1988; Ullman et al., 1997). This selective pattern of linguistic problems seems to be caused by damage to different brain regions in AD and PD. AD is known to affect the cortical areas of the brain, including the hippocampus and temporal-lobe circuit, whereas PD particularly affects the basal ganglia and associated circuitry (McDowell, 1978). This neurological difference suggests that each disease may differently affect a distinct memory system that is evidently subserved by the damaged brain regions and neural circuits (Gabrieli, 1998). The declarative/procedural model of language (hereafter, D/P model) (Ullman, 2001a, 2001b) posits that the brain areas affected by AD modulate declarative memory, while those affected by PD subserve procedural memory. Declarative memory refers to the ability to learn and

use facts and event knowledge and supports explicit learning and conscious recall. In contrast, procedural memory refers to unconscious memory of skills and procedures, or "how-to" knowledge, and is engaged in the implicit acquisition, storage, and use of cognitive skills and rule-governed knowledge (Gabrieli, 1998; Ullman, 2001a, 2001b, 2004).

It is still not very clear how the memory system is connected to language functions. Yet, some empirical studies have reported a certain relationship between declarative memory and a mental lexicon of memorized words and between procedural memory and a mental grammar of rules. According to Paradis (1994) and Ullman (2001a, 2001b), metalinguistic knowledge and memorized mental lexicon are associated with declarative memory. Accordingly, individuals with AD are expected to have more difficulties with lexical processing than with grammatical processing. However, as the brain areas subserving procedural memory are relatively safe in AD, implicit linguistic competence or grammar that relies on procedural memory is predicted to be intact. As estimated, individuals with AD typically have lexical deficits, while their grammar is relatively intact. For example, patients with AD frequently scored low on picture-naming and word fluency tests, mostly due to the problems in retrieving words for a semantic category, even in the very early stage of the disease progression (Cummings et al., 1988; Kempler, 1995). However, these patients performed relatively well on grammatical tasks, generating adequate closed-class words and well-formed sentences (Bucks et al., 2000). Conversely, Ullman (2001a, 2001b) argues that procedural memory sustains implicit linguistic knowledge and a mental grammar of rules that combine lexical forms into sequential and hierarchical structures. In fact, individuals with PD are known to have greater difficulties with rule-based linguistic domains such as syntax, morphology, and phonology. For example, in a picture description task, PD patients tended to produce shorter phrases, fewer syntactically complex sentences, and fewer grammatical sentences (e.g., Cummings et al., 1988; Murray, 2000; Small et al., 1997). Yet, as the brain areas subserving declarative memory are spared in PD, lexical processing abilities, such as naming, were relatively intact in PD patients (e.g., Lewis et al., 1998).

While the differences between AD and PD in language impairments have been well documented for monolingual populations, language deterioration in bilingual individuals with AD and PD has been explored only recently. Although there is a very limited number of bilingual studies, selective impairments have also been found in the language of bilingual individuals with AD (BIAD) and PD (BIPD). That is, phonology, morphology, and syntax of the first-learned language (L1) are relatively impaired in BIPD, while the lexicon and semantics of the later-learned language (L2) are largely affected in BIAD. Moreover, there is another dissociation between the two languages of a bilingual patient: L2 is more vulnerable than L1 in BIAD, while L1 is more affected in BIPD than L2 (Mendez et al., 1999; 2004; Paradis, 2009; Ullman, 2001b).

These patterns of dissociation between language and linguistic levels add evidence to the D/P model of lexicon and grammar (Ullman, 2015). This model proposes that L1 is acquired implicitly and is dependent on procedural memory, whereas L2 is largely learned explicitly and depends to a great extent on declarative memory. The model further suggests that L1 grammar is linked to procedural memory, whereas L2 grammar is primarily linked to declarative memory (Paradis 1994, 2004; Ullman, 2001a, 2001b, 2004). The lexicon is assumed to be sustained by declarative memory in both L1 and L2. Accordingly, damage to the neural substrate for declarative memory in AD is expected to mainly affect the lexicon and L2 grammar, and damage to the neural circuits sustaining procedural memory in PD is expected to predominantly impact L1 grammar (Dick et al., 2018; Paradis, 2004, 2009; Ullman, 2001b).

Studies investigating language in BIAD and BIPD are rare, and they have reported mixed results regarding the pattern of language deterioration. Yet, as predicted by the D/P model, the empirical observations have shown a double dissociation in the two languages of these two populations. More specifically, AD primarily affects lexicon and L2, and PD mostly impacts grammar and L1. For example, Cameli et al. (2005) and Cameli (2006) demonstrated that BIAD made more errors generating irregular past tense verbs in both L1 and L2 and

regular past tense verbs only in L2.¹ By contrast, BIPD were selectively impaired in generating regular past tense verbs in L1.

In relation to the D/P model, the age of exposure to L2 is crucial in determining which memory system sustains the acquisition and processing of that language (Ullman, 2001a, 2001b). Given that the model proposes that languages learned after puberty in a formal setting rely heavily on declarative memory, late bilinguals are predicted to predominantly depend on declarative memory in learning L2. In contrast, it is expected that early bilinguals rely largely on procedural memory for the acquisition and processing of both L1 and L2. Thus, according to the D/P model, the double dissociation in language deterioration between BIAD and BIPD is expected only for late bilinguals (i.e., roughly defined as those learning L2 after puberty in an academic context).² However, it is worth noting that as bilingualism itself is a complex construct with various dimensions, factors other than the bilingual's age of L2 acquisition (AoA) may be more crucial determinants of language performance in bilinguals (Gollan et al., 2010; de Bot & Makoni, 2005). For example, it is possible that a bilingual's high proficiency or dominance in using L2 changes the memory system supporting L2 processing to employ more procedural memory (Gomez-Ruiz et al., 2011; Johari et al., 2013).

Exploring language in bilingual populations with AD and PD is of theoretical and practical importance. First, as AD and PD are neurodegenerative diseases that affect distinct memory systems, comparative research on language in BIAD and BIPD can offer an insight that helps better understand the relationship between memory and language. Second, the outcomes of the research can inform the design of more appropriate assessments and interventions for bilingual patients

¹ It has been argued that irregular past tense verbs are stored in the lexicon and are retrieved from declarative memory, which is a lexical function. By contrast, regular past tense verbs are generated through a procedure (e.g., "Verb + ed"), which is part of grammar and linked to procedural memory (Paradis, 1994; Pinker, 1999; Ullman, 2001).

² Although there is much debate on the definition of "late" bilinguals (e.g., Birdsong, 2005), we followed this criterion to classify the bilingual participants in this review.

with AD and PD in clinical practice and care. This practical consideration is based on the estimation that over half of the world's population use more than one language in their everyday lives (Grosjean, 2021), and accordingly, many individuals with AD and PD are also bilingual. Nonetheless, the study of language decline in BIAD and BIPD is at a very early stage. Moreover, apart from Cameli (2006), to our knowledge, no previous study has directly contrasted language in BIAD and that in BIPD. Under such circumstances, as a preliminary step toward a systematic comparative investigation, in this study, we review the available findings to date regarding language in BIAD and BIPD. More specifically, we aim to understand the effect of AD and PD across languages (L1 vs. L2) and linguistic levels (grammar vs. lexicon) drawing from the D/P model. Given the lack of research on a direct comparison of the two populations in terms of language decline, this comparative review is an attempt to provide an empirical base to understand the impact of AD and PD on the bilinguals' grammar and lexicon, verifying the theoretical validity of the D/P model.

2. Methods

The literature search was carried out in March 2022 using the keywords “bilingual*” and “Alzheimer* OR dement* OR Parkinson*” in three different electronic databases: Social Science Citation Index (Web of Science), PsycINFO, and Linguistics and Language Behaviour Abstracts (LLBA), following Stilwell et al. (2016). Then, the abstracts and reference lists of the extracted papers were manually searched, according to the following inclusion criteria: (1) at least one group of bilingual participants has a diagnosis of probable AD or PD (studies on other dementias such as semantic and vascular dementia, Huntington disease, etc. were not included); (2) the study reported analyses of grammatical and/or lexical aspects in each of the bilingual participants' languages; (3) the study included pre-morbidly proficient bilinguals and specified whether participants' L2 was learned late or early; and (4) the study was published and available in English. The following exclusion criteria were also applied: no language assessment was provided; the participants were polyglot speakers; it was not known how each of the

bilinguals' languages was affected; and language analyses were done only at a discourse or conversation level. Finally, 14 papers were included in this review. Nine of them were reviewed to examine BIAD's language deterioration. Besides the six studies included in Stilwell et al.'s (2016) review, our literature search identified only three additional papers on BIAD's language. We also found five papers on BIPD's language that met the inclusion and exclusion criteria.

3. Results

3.1 Findings of the studies on BIAD

Nine studies were identified as exploring AD's impact on bilinguals' grammar and lexicon. Five studies examined lexical aspects, one study looked at grammatical aspects, and the remaining three examined both lexicon and grammar. As summarized in Table 1, the participants were from various language backgrounds, including the age of L2 acquisition (AoA) and language dominance. Four studies reported empirical data from late bilinguals who had learned L2 after puberty, three from early bilinguals who learned both languages during childhood, and two from both late and early bilinguals. However, all participants were reported to be equally proficient in their two languages pre-morbidly, which is important in that a less proficient L2 could be a confounding factor for poor performance. Various methods were used to examine BIAD's comprehension and speech production. They were mostly productive tasks, and only three studies used receptive tasks. We summarized the findings on which language (L1 or L2) was more vulnerable to the disease for the examined linguistic level (grammar or lexicon).

Table 1. Summary of the studies on the lexicon and grammar in BLAD

Linguistic level	AoA (number of BLAD)	L1-L2 (equally proficient unless otherwise stated)	Task	More affected
Lexicon				
De Picciotto and Friedland (2001)*	Early (6)	English-Afrikaans	Productive	L2 (minor difference)
Salvatierra et al. (2007)*	Late (11)	Spanish-English (L1-dominant)	Productive	L2
Costa et al. (2012)*	Early (47)	Catalan-Spanish (36 L1-dominant and 11 L2-dominant)	Productive	No difference
Meguro et al. (2003)*	Late (2) Early (2)	Japanese-Portuguese (2 Japanese-dominant and 2 Portuguese-dominant)	Productive Receptive	No difference No difference
Gomez-Ruiz et al. (2011)*	Early (12)	Catalan-Spanish (L2-dominant)	Productive Receptive	L1 No difference
Cameli (2006)	Late (8)	7 French-English and 1 English-French	Productive	L1
Gollan et al. (2010)*	Early (16) Late (13)	Spanish-English (16 L2-dominant and 13 L1-dominant)	Productive	L2 L1
Manchon et al. (2015)	Late (13)	Italian/Spanish/German-French (L1-dominant)	Productive Receptive	No difference No difference
Grammar				
Gomez-Ruiz et al. (2011)*	Early (12)	Catalan-Spanish (L2-dominant)	Productive	L2
Cameli et al. (2005)	Late (2)	French-English	Productive	L2
Cameli (2006)	Late (8)	7 French-English and 1 English-French	Productive	L2
Manchon et al. (2015)	Late (13)	Italian/Spanish/German-French (L1-dominant)	Productive Receptive	No difference No difference

*Studies also reviewed in Stilwell et al. (2016)

All the nine studies, including the six reviewed in Stilwell et al. (2016), reported that AD affected all language skills in both the languages of bilingual patients. Yet, their findings of BIAD's grammar and lexicon showed mixed decline patterns. Some of them revealed that L2 was more impaired than L1, while some reported more affected L1. Still, some others demonstrated no significant difference between L1 and L2. Thus, it is difficult yet to conclude these studies whether a language was more affected than the other in AD, particularly for grammar or lexicon.

Nevertheless, there is a trend that L2 was more affected than L1 in BIAD's lexicon and/or grammar. De Picciotto and Friedland (2001) compared an early BIAD group and a group of bilinguals for control purpose (BC), who reported equal proficiency for their two languages, using a semantic fluency task. In the task, the participants were asked to generate as many words as they could from the "animals" category. The results showed that the bilingual patients generated more words in L1 than in L2 as compared to the BC group, although this between-language difference was not statistically significant. Using the same task, Salvatierra et al. (2007) reported a similar result for a late BIAD group who learned L2 in their twenties and whose L1 was dominant. That is, the BIAD produced more words in L1 than in L2 as compared to the BC group on a semantic fluency task. However, of note is that the L1–L2 difference was statistically significant, unlike in De Picciotto and Friedland (2001).

Gollan et al. (2010) compared a BC group and two unbalanced BIAD groups (i.e., L2-dominant early bilingual patients and L1-dominant late bilingual patients) on picture naming. They found that the BC group named more pictures than the BIAD groups, and both BIAD groups had greater difficulties producing words in their dominant language compared to their non-dominant language. The researchers interpreted these results as a greater decline in lexical accessibility in the BIAD's dominant language (either L1 or L2) than in the non-dominant language. However, of note is that the decline was significantly greater when L2 was the dominant language: that is, the difference between the dominant and the non-dominant languages in picture naming was larger in the L2-dominant group than in the L1-dominant group (17% and 5%,

respectively). This result suggests that late BIAD may have more lexical difficulties in their L2.

Cameli et al. (2005) and Cameli (2006) examined both lexical and grammatical abilities in late BIAD groups, comparing them to BC groups, who reported equal proficiency in their L1 and L2. They found a double dissociation between language and linguistic levels. At the lexical level, the BIAD groups were more impaired in L1 than in L2: the bilingual patients exhibited greater difficulty retrieving L1 words than L2 words in complex picture description tasks, and made more errors and took longer to generate irregular past tense verbs in their L1. At the grammar level, however, L2 was found to be more affected than L1: in the past tense generation task, reaction times were longer in L2 for inflecting regular verbs than in L1. Moreover, the latency data from the past tense generation task in L1 showed that it took longer to inflect irregular verbs (i.e., a lexical function) than regular verbs (i.e., a grammatical function), suggesting that lexicon was more affected than syntax in L1.

Gomez-Ruiz et al. (2011) reported rather complicated results in their comparison of a BC group and an early BIAD group using both productive and receptive tasks. They showed that both groups spontaneously produced more words and sentences in L1 than in L2, with the BC group performing better overall. At the lexical level, however, there was a dissociation between BIAD's speech production and comprehension: there was a between-language difference for productive abilities, but no such difference was found for receptive abilities (i.e., reading, word comprehension). In speech production, the BIAD group produced significantly more words in their dominant L2, and their word translation from L2 into L1 was more accurate. At the sentence level, the authors reported no significant difference with regard to accuracy or syntactic complexity between BIAD's two languages. However, they noted a significantly greater number of grammatically ill-formed sentences in L2 speech production.

Three studies showed a parallel impairment for L1 and L2 among BIAD, suggesting that AD may equally affect the two languages of a bilingual. Meguro et al. (2003) tested four Japanese-Portuguese BIAD, who seemed to be equally proficient in both languages. Two of them were Japanese-dominant, and the other two were Portuguese-dominant,

although their language backgrounds were not mentioned in the study in detail. The results from three lexical tasks (i.e., picture naming, vocabulary comprehension, and lexical decision) revealed that the bilingual patients had overall difficulties in both languages, but there was no significant difference between the two languages. However, notably, the patients were more impaired for irregularly spelled words than for regularly spelled words in both languages. This result suggests the possibility that these patients' lexicon was more affected than their grammar. Costa et al. (2012) also reported a parallel impairment. They compared three groups of early and highly proficient bilinguals diagnosed with mild cognitive impairment (as BC), mild AD, and moderate AD. The results of the picture naming, word translation, and word-picture matching tasks demonstrated that the BC group performed better than the two BIAD groups and that the lexicon in L1 and L2 has similarly deteriorated in BIAD. Most recently, Manchon et al. (2015) examined oral comprehension and production in a BC group and a late BIAD group, who were equally proficient in both their L1 and L2. The results demonstrated that the BIAD group performed worse than the BC group in all tasks (i.e., semantic and syntactic comprehension, naming, repetition, and fluency). The deterioration of BIAD's L1 and L2 was equal in all aspects of language, particularly at the lexical and grammatical levels, both in comprehension and production.

In summation, the overall pattern of language decline in BIAD reported in nine studies is not consistent with regard to whether AD selectively impairs L2 more than L1. This inconsistency renders drawing a conclusion difficult. In particular, the studies failed to provide conclusive evidence on whether the lexicon is more impaired than grammar, distinctively in one language than in the other. Yet, it is clear that BIAD performed much worse on all language tasks in their two languages than BC, indicating that AD affected both languages. More importantly, the studies provide preliminary evidence that BIAD had greater difficulties with the lexicon and/or L2 grammar. Notably, the difference was observed only in productive tasks but not in receptive tasks, which involve procedural memory. The three studies that conducted receptive tasks showed parallel impairment of both languages, on lexical and grammatical measures (Gomez-Ruiz et al., 2011; Meguro

et al., 2003; Manchon et al., 2015). This overall pattern of language impairments is in accordance with the D/P model that AD affects the lexicon and L2 grammar in bilingual patients.

3.2 Findings of the studies on BIPD

Our literature search identified only five studies that explored the lexicon and grammar in two languages of BIPD. Four studies examined grammatical aspects, and one study assessed both lexicon and grammar. Two studies included late bilinguals and three included early bilinguals, all of whom were reported to be equally proficient in both their languages. Similar to the studies on BIAD discussed above, these studies on BIPD also included patients from various language backgrounds and used various data collection methods. Table 2 summarizes their findings on which linguistic level (grammar or lexicon) was examined and which language (L1 or L2) was affected more in BIPD.

Table 2. A summary of the studies on grammar and lexicon in BPD

Linguistic level	AoA (number of BPD)	L1-L2 (equally proficient unless otherwise stated)	Task	More affected
Lexicon				
Cameli (2006)	Late (8)	6 French-English and 2 English-French	Productive	L2
Grammar				
Zanini et al. (2004)	Early (12)	Friulian-Italian	Receptive	L1
Cameli et al. (2005)	Late (9)	7 French-English and 2 English-French	Productive	L1
Cameli (2006)	Late (8)	6 French-English and 2 English-French	Productive	L1
Zanini et al. (2010)	Early (9)	Friulian-Italian	Productive	L1
Johari et al. (2013)	Early (13)	Azari-Farsi	Receptive	L1

Research on how PD affects language in bilinguals is relatively new. As seen in Table 2, to date, only a handful of studies have explored BIPD's linguistic performance. The findings of these studies are overall in agreement with the D/P model's predictions that PD impacts procedural memory and, thus, impairs grammar in L1 to a greater extent than in L2 (Paradis, 1994; Ullman, 2001a, 2001b).

Zanini et al. (2004) were the first to examine the grammatical abilities of BIPD. Using three receptive tasks (i.e., sentence comprehension, syntactic judgment, and syntactic judgment-plus-correction), they compared a BC group and an early BIPD group and found that BIPD exhibited a greater deficit of grammatical processing in their L1 (Friulian) than in their L2 (Italian). Zanini et al. (2010) investigated productive language abilities of the same BIPD group using a spontaneous speech production task, where participants had to tell a short story based on the template of six cards. The analysis of the speech revealed greater impairments in rule-based linguistic levels (i.e., phonology, morphology, and syntax) of L1 than L2. Using Zanini et al.'s (2004) three receptive tasks, Johari et al. (2013) replicated the pattern of decline in an early BIPD group who spoke different languages (L1–Azari and L2–Farsi). That is, on the three syntactic measures, the BIPD group had greater difficulties in L1 than in L2.

Cameli et al. (2005) and Cameli (2006) examined syntactic and lexical abilities in late BIPD and BC, using a past tense generation and a picture description task. The results showed that the BIPD groups performed significantly worse than the BC groups on the productive syntactic measures in both L1 and L2. Yet, in the past tense generation task, the BIPD groups made more syntactic errors than the BC groups only in L1, but not in L2. In addition to these between-language differences, Cameli (2006), as the only study comparing grammatical and lexical impairments in BIPD, suggested within-language differences between grammar and the lexicon. That is, in L1, the bilingual patients showed greater grammatical difficulties than lexical difficulties: they made more errors generating regular past tense verbs than irregular past tense verbs, but their lexical errors were comparable to the BC group. In L2, however, BIPD displayed both lexical and grammatical decline.

Collectively, the reviewed findings show that BIPD performed worse than BC groups on all linguistic measures. They further indicate dissociations between languages and between linguistic levels in BIPD. This means that BIPD exhibited greater impairments in L1 than in L2, and they also exhibited more difficulties with grammar than with the lexicon. These findings are consistent with the D/P model, according to which DP leads to procedural memory deficits, which cause greater impairments in implicit knowledge, such as L1 grammar.

4. Discussion

Studies of language deficits in monolinguals have shown that AD and DP affect different brain areas and, thus, lead to distinctive patterns of language impairments. These findings have raised the question of how AD and PD would affect the decline in lexicon and grammar in bilinguals' two languages. However, this question has not been investigated systematically yet. As an attempt to answer, this study reviewed the available data on language deterioration in bilingual individuals with AD and PD. Overall, the results from a small number of studies available in the literature are disparate and, thus, do not provide a clear picture of the consequence of these neurodegenerative diseases on bilinguals' language. Yet, they clearly showed that L1 and L2 deficits manifested in proficient BIAD and BIPD, as compared to BC. Another general pattern found in the majority of the studies was that AD and PD affect L1 and L2 differently, as predicted, specifically at the levels of lexicon and grammar. The performance of BIAD and BIPD revealed a trend of a double dissociation between language and linguistic levels: BIAD exhibited greater impairments in lexicon and L2 grammar in general, while BIPD displayed greater difficulties with L1 grammar. When looking at language impairments within L1, BIAD had more lexical than grammatical difficulties. In L1, the patients made more lexical errors and displayed greater difficulties retrieving words, although not significantly different from BC at the grammatical level. BIPD, in contrast, differed from BC primarily on grammatical measures, making more grammatical errors and producing fewer grammatical utterances in L1. Conversely, in L2, BIAD exhibited more difficulties with both

the lexicon and grammar as compared to BC. BIPD also seem to have difficulties with lexical and grammatical measures, but not as much as with L1 grammar. These patterns of language decline are consistent with the D/P model, which suggests that AD would primarily affect declarative memory supporting lexicon and/or L2, while PD would predominantly impair procedural memory sustaining grammar and/or L1 (Paradis, 1994; Ullman, 2001a, 2001b).

A further dissociation was noted between productive and receptive language modalities among BIAD: the between-language difference was found only in production, but not in comprehension (Gomez-Ruiz et al., 2011; Meguro et al., 2003; Manchon et al., 2015). This dissociation may be attributed to the nature of the tasks and can be explained by the D/P model. In comprehension tasks, access to linguistic information involves procedural memory, which is intact in AD. Accordingly, BIAD have better access to the lexicon and L2 grammar, which may depend on the intact memory system in receptive tasks. This stipulation may be supported by the findings that BIPD, who were impaired largely in procedural memory, did not show such between-modality dissociation: L1 grammar was more impaired in both productive and receptive tasks.

In contrast to the proposal of the D/P model, the reviewed studies did not provide evidence for the effect of AoA on language declines in bilingual patients. The D/P model argues that early bilinguals' L2 is implicitly learned through procedural memory, whereas late bilinguals' L2 is explicitly learned through declarative memory (Paradis, 1994; Ullman, 2001a, 2001b). Accordingly, when AD affects declarative memory, a difference is expected in L2 grammar between early and late bilinguals, with late BIAD being more impaired. By contrast, when PD affects procedural memory, L2 grammar is expected to be more impaired in early BIPD than in late BIPD. However, the above-reviewed studies indicate that BIPD consistently had greater grammatical deficits in L2 relative to BC, whether they learned L2 early or late. Further, early and late BIAD both tended to exhibit similar grammatical difficulties in L2. That is to say, it seems that AD affects L2 grammar and PD affects L1 grammar in both early and late bilinguals.

A possible explanation for this lack of the AoA effect is that the most frequently used or dominant language, whether it is learned early or late,

may depend more on procedural memory (Green, 1986). Then, it is expected that PD should affect the dominant language, while AD the non-dominant language. However, the reported patterns of decline do not follow this prediction. For BIAD, only two studies suggested that more difficulties were faced for the non-dominant language than the dominant language (Gomez-Ruiz et al., 2011 (at the lexical level); Salvatierra et al., 2007), but other studies demonstrated the opposite pattern (Gollan et al., 2010; Gomez-Ruiz et al., 2011 (at the grammatical level)) or a parallel impairment (Costa et al., 2012; Manchon et al., 2015; Meguro et al., 2003). For BIPD, it was not possible to determine the dominant language is more vulnerable to language decline than the non-dominant language because the reviewed studies only reported equal proficiency of L1 and L2 for their participants.

A more promising explanation for the lack of the AoA effect is that sequentially-learned L2 may rely on declarative memory, whether it is learned early or late. Since all the participants in the reviewed studies were sequential bilinguals and highly proficient in both of the languages, the later-learned language may never become fully automatized (Paradis, 1997) and, thus, requires declarative memory. Therefore, L2 is expected to be deteriorated or be preserved similarly both in early and late bilinguals. However, given the limited data, this possibility is only speculative, which merits further investigation.

In summation, the overall patterns of language decline demonstrated in the bilingual literature provide considerable evidence that AD affects the lexicon and L2 grammar to a greater extent, while PD primarily affects L1 grammar. The findings seem to support the D/P model's assumption that AD primarily affects declarative memory, which is linked to lexicon and L2, and PD predominantly affects procedural memory, which is linked to grammar and L1. However, it should be noted that language deterioration in BIAD and BIPD is only beginning to be explored in the literature and the existing data from the literature do not unambiguously agree on which linguistic level and to what extent AD and PD affect each language in bilinguals. Besides the limited number of studies, the studies also had different research questions and variables of interest, which could lead to the inconsistent findings. The variables include various sample sizes (i.e., 2 to 47), different language modalities

tested (e.g., production vs. comprehension), various tasks used (e.g., reading, picture naming, judgment), different AoA (i.e., early vs. late), different language dominance, various languages of participants, and different degrees of severity of AD and PD (e.g., the early stage vs. later stage of disease progression). For example, a parallel impairment in BIAD's L1 and L2, with no significant between-language differences, may be attributed to a severe degree of AD (e.g., Costa et al., 2012). Another example is that different task modalities require different memory pathways (e.g., more implicit procedural memory in a comprehension task but more meta-linguistic declarative memory in a judgment task) and, thus, may have a different effect for each linguistic level in each language (e.g., Zanini et al., 2004).

5. Conclusions

It is reasonably predicted that the impact of AD and PD is different for L1 and L2 and for lexicon and grammar, drawing on the D/P model. The findings from bilingual patients seem to preliminarily support the D/P model, in that AD leads to a greater decline in lexicon and L2 grammar, while PD leads to greater deficits in L1 grammar. However, much of the language decline in each language of bilingual patients remains unknown, and thus, the conclusion is tentative at this point, particularly regarding the dissociation between languages and between linguistic levels. This is mainly because there are only a limited number of studies, with only one study (i.e., Camel, 2006) directly comparing the language deterioration in BIAD and BIPD. Further research is needed to better understand the impact of the most common neurodegenerative diseases on bilingualism. Future studies should employ a design that systematically compares comparable groups of BIAD and BIPD in terms of the lexicon and grammar of each language, while controlling for the methodological factors that might influence language decline in bilinguals. Some examples of the factors include participants' characteristics (e.g., AoA, language dominance, degrees of severity, etc.) and assessments (e.g., tasks and language modalities). Such studies will provide robust evidence for the consequences of AD and PD on bilingualism and also for the D/P model.

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