On the parallel deterioration of lexico-semantic processes in the bilinguals' two languages: Evidence from Alzheimer's disease

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Abstract

In this article we aimed to assess how a neurodegenerative disease, such as Alzheimer's disease (AD), affects the linguistic performance in the two languages of early and high-proficient bilinguals. To this end, we compared the picture naming and word-translation performance of two groups (Mild and Moderate) of AD patients with that of bilingual individuals diagnosed with Mild Cognitive Impairment (MCI). The results revealed that the linguistic deterioration caused by AD affected the two languages similarly. Also, we found that cognate status and word frequency are two major determinants of language performance and deterioration. These results are consistent with the notion of a common neural substrate recruited to represent and process the two languages of high-proficient bilinguals.

Keywords: Bilingualism, Alzheimer's disease, language breakdown

1. Introduction

The issue of how bilingual individuals learn, process and represent their two languages has been of interest for many different sorts of scholars, from linguists to neurologists, including social psychologists and clinicians. This interest has led to the study of a wide range of issues such as: What are the neural circuits involved in the representation of two languages? What are the effects of age of acquisition and proficiency level in the way the circuits are set? How are bilinguals able to control their two languages? What are the collateral effects of bilingualism for other cognitive domains beyond language? All these questions have been addressed by using different experimental strategies, both in terms of the populations studied (children, young adults, brain damaged individuals, etc.) and the techniques used (e.g., classical experimental psychology, neuropsychology, or neuroimaging approaches). As a result of this effort, there is no doubt that our knowledge of the questions put forward above has experienced major growth (see for reviews, Abutalebi & Green, 2007; Bialystok, Craik, Green, & Gollan, 2010; Costa & Santesteban, 2006; Hartsuiker, Costa, & Finkbeiner, 2008; Hernandez, Dapretto, Mazziotta, & Bookheimer, 2001; Indefrey, 2006; Kroll, Bobb, Misra, & Guo, 2008; Kroll & Hermans, 2011; Rodriguez-Fornells, Rotte, Heinze, Nosselt, & Munte, 2002; Rodriguez-Fornells et al., 2005).

However, in the context of this bilingual research there is an important gap: little is known about the effects of neurodegenerative disorders on the processing of the two languages of a bilingual. The available experimental evidence about how (and to what extent) a bilingual's two languages are affected by the cognitive deterioration produced by neurodegenerative diseases is very slim, and comes mostly from a few single case studies (see below). The present research aims at contributing to fill this gap by exploring how one particular neurodegenerative disorder, Alzheimer's disease (AD), affects the linguistic performance of early and high-proficient bilinguals. In particular, we focus on how AD affects the lexico-semantic processes involved in language processing. The relatively small number of studies devoted to this issue is surprising given that both bilingualism and dementia are becoming increasingly prevalent in modern society. The number of bilingual speakers around the world is increasing dramatically as a consequence of globalization and migration (e.g., European Commission, 2006). Also, and as a result of an increase in life expectancy, the incidence of neurodegenerative diseases associated with aging is also on the rise (Alzheimer's disease International, 2010). The combination of these two factors reveals that in future years the number of bilingual speakers suffering from dementia will increase considerably. In this context, and from a sociolinguistic perspective, it is important that we advance in our knowledge about how degenerative brain diseases affect the two languages of bilinguals. Furthermore, this information may also have important theoretical implications for constraining hypotheses regarding the brain basis of bilingualism.

As a first approximation to the issue of how degenerative diseases affect the two languages of a bilingual, we could consider the research conducted with healthy older bilinguals. Most of this research has focused on exploring how different variables such as proficiency and age of acquisition impact the deterioration of the two languages, sometimes even comparing such effects to monolingual performance (e.g., Gollan, Fennema-Notestine, Montoya, & Jernigan, 2007; Rosselli et al., 2000; for reviews see Ardila & Ramos, 2008; Obler, Albert, & Lozowick, 1986; Schrauf, 2008). Unfortunately, as interesting as these studies can be, they are relatively silent regarding the changes in language performance that results from modification of the cognitive system as a result of aging. This is because in order to identify age-related changes in function one needs to compare the performance of older bilinguals with that of a young control group, or to test older bilinguals across different time intervals in a longitudinal fashion.

One exception is the study by Juncos-Rabadan (1994) in which the continuous aging effects associated to bilingual language processing were explored. This author tested bilingual adults of three different ages (30-40, 50-59 and 70-90 years old) through the Battery Aphasia

Test (Paradis & Libben, 1987) in several domains of language (morphology, phonology, syntax, comprehension and production). The results revealed a similar decrease in performance for the two languages with aging. Juncos-Rabadan (1994) also highlights the hypothesis that the decrease in efficiency of attentional abilities could account for this age-related decrease in language performance.

More in general, age-related changes in the efficiency of language processing have been explained in different ways. An early hypothesis is the regression hypothesis, which suggested that languages might be lost in the reverse order in which they were acquired (Jakobson, 1970). Consequently, to the extent that the dominant language is acquired before the non-dominant language, the former would be more protected against cognitive decline. A similar proposal comes from Ribot's observations on memory sparing in retrograde amnesia (Pearce 2005; Lorch, 2009). Ribot's law refers to the observation that in amnesic patients recently learnt events are disproportionally impaired compared to older memories. Following this principle, Ribot proposed that bilingual aphasic patients should recover their mother tongue first.

Other hypotheses are based on the evidence that older adults have reduced cognitive resources including a decrease in cognitive control (e.g., Hasher & Zacks, 1988; Salthouse, 1988; Zied et al., 2004). The age-related decrease in efficiency of cognitive control could be reflected in a decrease also in bilingual language control, as these two systems overlap to some extent (Abutalebi & Green, 2007). As a consequence, the impairment of the two languages could be the result of a lack of cognitive control associated with aging (see Juncos-Rabadan, 1994; Juncos-Rabadan & Iglesias, 1994; Gollan et al., 2011).

The information regarding how the two languages are affected by brain damage as a consequence of stroke is also informative to some extent. The main problem with these studies is the fact that it is sometimes difficult to know pre-injury proficiency levels. Nevertheless, we briefly discuss some of theses studies.

Although, various patterns of impairment and recovery have been reported, the most frequent observation is the parallel impairment of the two languages (e.g., Filley et al., 2006; Green et al., 2011; Marangolo, Rizzi, Peran, Piras, & Sabatini, 2009; van Lieshout, Renier, Eling, de Bot, & Slis, 1990; see for reviews: Green, 2005; Paradis, 1999; Paradis, 2001). However, observations of disproportionate impairment in one language (or differential recovering) have also been reported (for L1 e.g., Aladdin, Snyder, & Ahmed, 2008; Ku, Lachmann, & Nagler, 1996; Machado, Rodrigues, Simoes, Santana, & Soares-Fernandes, 2010; Vajramani, Akrawi, McCarthy, & Gray, 2008; Weekes & Raman, 2008; for L2 e.g., Adrover-Roig et al., 2011; Aglioti, Beltramello, Girardi, & Fabbro, 1996; Garcia-Caballero et al., 2007; Gomez-Tortosa, Martin, Gaviria, Charbel, & Ausman, 1995; Leemann, Laganaro, Schwitter, & Schnider, 2007; Moretti et al., 2001; Paradis & Goldblum, 1989; Tschirren et al., 2011).

This scenario becomes even more complex when examining the effects of language rehabilitation. Some authors have reported that the benefits are transferred from the trained to the untrained language to some extent (e.g., Fabbro, 2001; Filiputti, Tavano, Vorano, de Luca, & Fabbro, 2002; Gil, & Goral, 2004; Watamori, & Sasanuma, 1978), while in other cases no transfer benefits are present (e.g., Abutalebi, Rosa, Tettamanti, Green, & Cappa, 2009; Galvez, & Hinckley, 2003; Meinzer, Obleser, Flaisch, Eulitz, & Rockstroh, 2007), and some studies only found this transfer for certain type of bilingual aphasics (e.g., balanced bilinguals – Edmonds, & Kiran, 2006). In this context, the issue of how rehabilitation impacts the language control network is relevant. For example, Abutalebi et al. (2009) studied the neural pattern following the rehabilitation in a bilingual (Spanish-Italian) aphasic patient. The patient was treated in Italian and after the full recovery of Italian, extensive activations of frontal areas were observed when naming in Italian but not when naming in Spanish. Also brain areas for language control were activated (anterior cingulated cortex and left caudate) when naming in Italian but not when naming in Spanish. The authors concluded that the rehabilitation functionally reorganize the areas both for language production and language control.

In sum, highly variable patterns of language breakdown and subsequent recovery have been reported in bilingual cases of aphasia. Factors like age of acquisition, proficiency or frequency of language use before and after brain damage are believed to be crucial in determining each specific pattern of bilingual aphasia (e.g., Marrero, Golden, & Espe-Pfeifer, 2002). The specific contribution of each of these factors, however, still has to be disentangled.

1.1. Neurodegenerative Diseases and Bilingual Language Processing

More relevant for our purposes here are those few group studies that have addressed bilingual language deterioration in the context of degenerative diseases (for a review see Paradis, 2008). As in the previous studies, the results of these studies are mixed.

Of specific interest for the present project are the studies that have assessed how AD affects the language deterioration of bilingual patients (De Santi, Obler, Sabo-Abramson, & Goldberger, 1990; Friedland & Miller, 1999; Gollan, Salmon, Montoya, & da Pena, 2010; Hyltenstam & Stroud, 1989; Mendez, Perryman, Pontón, & Cummings, 1999).

Although some of the linguistic abilities of AD patients, such as phonological and morphological processing, are relatively well-preserved until advanced stages of the disease (Murdoch, Chenery, Wilks, & Boyle, 1987), the lexical/semantic processing of AD patients seem to be compromised already in relatively early stages (e.g., Adlam, Bozeat, Arnold, Watson, & Hodges, 2006; Hodges, Salmon, & Butters, 1992; Hodges & Patterson, 1995). Hence, AD patients offer the possibility of assessing how damage to the semantic (and/or lexical system) system impacts lexical processing in the two languages of a bilingual, which is the main goal of the present study.

Although most of the studies in this domain report small groups of participants, there seems to be a broad common pattern (de Picciotto & Friedland, 2001; De Santi et al., 1990; Friedland & Miller, 1999; McMurtray, Saito, & Nakamoto, 2009; Meguro et al., 2003; Mendez et al., 1999; Salvatierra, Rosselli, Acevedo, & Duara, 2007). In three out of four group studies the general conclusion is that the non-dominant language is more impaired than the dominant one. For example, Mendez et al. (1999) conducted a study of 51 bilingual patients with different types of dementia (31 of those with AD) by asking caregivers to report the patient's use of the two languages. All caregivers reported decreased use of the non-dominant (English) language and word intrusions from the dominant to the non-dominant language. De Picciotto & Friedland (2001) tested 6 highly proficient English-Afrikaans bilinguals in a verbal fluency task. As expected, AD patients retrieved fewer words compared to older controls in both languages. However, this was specially so when performing the task in the non-dominant language. Meguro et al. (2003) reported similar results in four Japanese-Portuguese bilingual patients with AD. The four patients scored marginally better in picture naming in the dominant languages. That is, the two Japanese-dominant bilinguals scored better in Japanese than in Portuguese whereas the two Portuguese-dominant bilinguals scored better in Portuguese than in Japanese. However, given the lack of a control group, it cannot be determined whether these differential scores were due to the cognitive decline associated with the disease. Finally, one study reported parallel deterioration of the two languages (Salvatierra et al., 2007). These authors tested 11 older bilinguals and 11 AD bilingual patients in a fluency task. They found that, in the AD patients, performances in their dominant language (Spanish) and in their non-dominant language (English) were similarly affected by the disease. Other single-case studies or studies with few participants have described deficits of language control abilities in bilingual patients with dementia (De Santi et al. 1990; De Vreese, Motta, and Toschi, 1988; Friedland & Miller, 1999). The general conclusion from these studies is that AD patients: a) in the later stages of the disease, make errors in the choice of the appropriate language to speak with an interlocutor (De Santi et al., 1990); b) language mixing in AD patients is characterized by utterances from the dominant language intruding into the non-dominant language (Friedland & Miller, 1999).

Perhaps the most complete study on how AD affects the bilinguals' two languages, revealed a surprising and puzzling result. Gollan et al. (2010) tested Spanish-English unbalanced bilinguals on the Boston Naming Test. Crucially and always compared to healthy controls, AD appeared to affect picture naming in the dominant language to a larger extent than in the non-dominant language, a result inconsistent with the notion that first-memories are better protected against neurodegenerative diseases. Let us describe this study a bit more in detail. English dominant bilinguals with AD (N = 16) were able to name 60% of the pictures in English and about 30% in Spanish (the percentages reported here are approximations taken from Figure 2 of Gollan et al's article: the authors did not report the exact percentage of errors in their manuscript). This performance as compared to controls (N = 22; 80% in English and 40% in Spanish) reveals that the dominant language was more affected by the disease (20% difference between groups) than the non-dominant language (7% difference between groups). All in all, these results suggest that the impact of AD on the lexico-semantic system involved in word retrieval is larger in the dominant than in the non-dominant language, and that first-acquired memories are not always more protected against dementia. Seeking an explanation of this counterintuitive pattern of results the authors put forward the following tentative hypothesis. Lexical items from the dominant language may have richer (or more) associations with semantic representations than lexical items from the non-dominant language. Therefore, a disease affecting the integrity of semantic representations, such as AD, would have a larger impact on the dominant than on the non-dominant language. We defer further discussion of this explanation to the general discussion.

As it can be appreciated in this review, the issue of how cognitive decline associated to aging or to brain-damage (cause by strokes or by neurodegenerative disease) affects the two languages of a bilingual is a complex issue, and it is far from being resolved. The pattern of linguistic deterioration often (but not always) seems to depend on certain variables such as the age of L2 acquisition and the relative linguistic dominance of the participants. In this context, we deem particularly important to bring new experimental data including a large sample of a homogeneous population.

1.2. The present study

The main goal of the present study is to explore how AD affects the deterioration of the two languages, and in particular lexico-semantic processing, of early and high-proficient bilingual speakers. Several aspects of our study are worth discussing before presenting the results.

First, to gather more complete information about how AD affects the linguistic performance of bilinguals, we included two groups of AD patients that differed in their cognitive deterioration according to the Mini Mental Score Examination (MMSE). Thus, we tested mild (N=23) and moderate (N=24) AD patients. The performance of these patients will be compared against that of Mild Cognitive Impairment (MCI) patients (N=24), which will serve as controls.

Second, the linguistic profile of the 71 participants in our study was relatively homogeneous. They all were early and high-proficient Catalan-Spanish bilinguals with a life-long experience with the two languages (i.e., continuous exposure to and use of the two languages for at least 60 years), and living in a rather bilingual community where the two languages are used regularly. A description of the sociolinguistic environment of the participants can be found in Appendix A.

Third, we tested participants in three different tasks that involve lexico-semantic processing: a picture naming task, a word translation task, and a picture-word matching task. The use of these three tasks should help us to obtain more detailed information about how the two languages of a bilingual deteriorate.

Fourth, we analyzed the effect of two variables that are known to affect the performance of individuals in lexico-semantic tasks, namely word frequency and cognate status. This analysis helped us to determine to what extent similarities between the two languages aid the lexical system to cope with neurological degeneration.

Although our study is exploratory, we do have some tentative predictions. Given the early acquisition of the two languages, the high level of second language proficiency attained by the bilinguals, the similarities between the two languages, and the fact that the bilinguals are immersed in a bilingual sociological context, it is reasonable to expect that the two languages deteriorate similarly as a consequence of AD. However, note that according to previous observations we cannot exclude the possibility of observing differences between the two languages, especially for those patients in relatively advanced stages of the disease. That is, if one of the languages is more affected by cognitive decline than the other, one should expect that the larger the decline the larger the difference in performance between the two languages.

These hypotheses were assessed by looking at whether the performances in the dominant and non-dominant languages and the severity of the disease (MCI, Mild AD and Moderate AD) interact. An interaction of this sort might indicate that AD differentially affects the two languages of a bilingual. This interaction was to be assessed by means of an ANOVA in which the degree of cognitive decline was treated as a categorical variable with three levels (MCI, Mild and Moderate), and also by means of a regression analysis in which the degree of cognitive impairment was treated as a continuous variable using the values of the MMSE for each subject as an index of this decline.

2. Method

2.1. Participants

Seventy-one bilingual speakers were recruited for participating in the study from three different hospitals: Hospital Universitari de Bellvitge, Hospital de la Santa Creu i Sant Pau, and Hospital General de Granollers. All these hospitals are situated in metropolitan areas of Barcelona, where Spanish and Catalan are used regularly.

Clinical Profile: Patients with potentially confounding neurological and psychiatric disorders, clinically known hearing or vision impairment, a past history of alcohol abuse, psychosis, or major depression, were excluded from the study. Participants were either diagnosed with probable AD (n= 47) or were considered to suffer from Mild Cognitive Impairment (MCI, n = 24). This first assessment was conducted by neurologists and the diagnostics were based on neurological, neuropsychological evaluations (see Table 1 for a description of the neuropsychological scores) and the clinical criteria from the National Institute of Neurological and Communication Disorders and Stroke Alzheimer disease and Related Disorders Association (McKhann et al., 1984) or MCI (Petersen, 1999).

Table 1

Participants diagnosed with AD were assigned to the mild or moderate groups according to their scores in the Mini Mental Score Examination (MMSE; Folstein, Folstein, & McHugh, 1975). Participants with a score lower than 21 were assigned to the moderate group (n = 24), those with a score between 21 and 24 to the mild group (n= 23). The group of patients diagnosed with a MCI (Petersen et al., 1999) had a score above 25 out of 30. As a result, all three groups had significant differences in their scores of the MMSE. All the three groups also had significant differences in the rating of the Global Deterioration Scale (GDS). The age of the participants in the two AD groups was not significantly different (p= 0.24). However, the participants in the MCI group were slightly younger (4 years) than the participants in the Moderate group (p = 0.06). The educational level between groups was matched (p= 0.26).

Within the MCI group, 17 participants were single-domain, having deficits only of the long-term memory, and 7 participants were multi-domain MCI (four patients with episodic memory impairment associated to working memory impairment and three patients having deficits of long-term memory, working memory and fluency).

All the AD patients received Acetylcholinesterase inhibitor (AChEI) as drug treatment whereas the MCI participants did not receive any drug treatment.

Linguistic Profile: Language history and dominance were determined by means of a questionnaire administered to the participants and an interview with the patient and some relatives. As it can be appreciated in Table 2, all participants scored quite high in their self-assessed knowledge of the two languages, and reported to have been using them regularly during, at least, the last 60 years. Participants can be considered early bilinguals since, on average, they were firstly exposed regularly to their L2 at the age of 3.6 years, and none of them was exposed to it later than the age of 10. The L2 age of acquisition (AoA) was slightly different between the three groups (p=0.07). However, it is important to note that no differences between the moderate AD and the other two groups were found ($p_s > 0.09$), allowing for the comparison between the advanced and the early stages of the disease.

Table 2

Also, quite a few of the participants reported to have started learning the two languages simultaneously (about 30%), and all of them reported using them continuously.

This early and high level of bilingualism creates the problem of determining the L1 and L2 of the participants in terms of AoA. To circumvent this problem, instead of treating the two languages in terms of when they were acquired, we treat them in terms of their relative dominance, which was determined by asking participants about the language they feel more comfortable with. Not surprisingly, the dominant language corresponded in most of the cases (90%) to the one participants considered to be also their L1 and the one they reported to use more often. Because of these correlations, performing the analyses considering the first-acquired language or the dominant language does not change significantly the pattern of results.

Following this criterion, 55 participants had Catalan as a dominant language and sixteen had Spanish as a dominant language. The distribution of the language dominance (Catalan/Spanish) across the different groups was as follows: MCI= 16/8; Mild AD= 20/3; Moderate AD= 19/5, and it did not differ across groups ($p < .05$). The AoA of the non-dominant L2 was not different for the three groups (MCI= 4.6 y.o.; Mild AD= 2.6 y.o.; Moderate AD=3.5 y.o.; $p=.11$).

The study procedure was approved by the local Ethics Committees of the hospitals. Informed consent was obtained from patients and caregivers prior to testing, after a full explanation of the study.

2.2. Materials

The same set of words was used for the three tasks: Picture Naming, Word-Picture matching and Word Translation. The materials consisted of 54 words representing objects belonging to various semantic categories: animals, vegetables, body parts, etc. In the case of the Picture Naming and Word-Picture matching tasks, we used black-and-white line drawings from Snodgrass and Vanderwart (1980) depicting these 54 objects.

The frequencies for the Spanish and Catalan names were obtained from the LEXESP (Sebastian-Galles, Cuetos, Martí, & Carreiras, 2000) and the Catalan Dictionary of frequencies (Rafel i Fontanals, 1996) databases, respectively. The Spanish and Catalan names did not differ in terms of mean phonological length (Spanish: 5.27, Catalan: 5.20, p=0.80), mean letter length (Spanish: 5.64, Catalan: 5.66, p=0.95), or mean syllable length (Spanish: 2.51, Catalan: 2.31, p=0.15). Half of the items were cognates and half were non-cognates. The words in the two sets (cognates and non-cognates) were matched for frequency both in Spanish (Cognates: 54.65, Non-cognates: 54.65, p=1) and Catalan (Cognates: 4156.55, Non-cognates: 3341.81, p=0.63). Cognates and non-cognates were also matched for familiarity (Cognates: 6.1, Non-cognates: 6.1, p= 0.98) and visual complexity (Cognates: 3.0, Non-cognates: 2.8, p= 0.39) according to the Spanish norms (Sebastian-Galles et al., 2000).

2.3. Procedure

Participants were tested in the two languages in two different sessions a week apart. The order of language testing was counterbalanced. Thus, half of the participants were tested in their dominant language in the first session, and the other half in the second session. Before the first testing session, the MMSE and the different questionnaires about socio-demographic information and bilingualism were administered. In the first session, participants were tested in the Picture Naming, Word-Picture matching and Word Translation tasks in one of the two languages; and the following tests were also administered: Benton Visual Retention Test (Sivan, 1992) that measures the visual memory, Digit spans forward and backward (Peña-Casanova, 2005) that measure short-term memory and working memory respectively. In the second session, participants were tested in the three tasks in the other language, and the following tests were also administered: the CERAD Word List Memory (Morris et al., 1989) measuring long-term episodic memory and the Pyramids and Palm Trees Test measuring semantic memory (Howard & Patterson, 1992).

In the Picture Naming task, participants were asked to name aloud the pictures presented on a computer screen. The experimental software was DMDX (Forster & Forster, 2003) and the verbal responses were recorded. Each picture remained on the screen until the participant responded or for a maximum of 5 seconds.

In the Word Translation task, the experimenter read words aloud one at a time and participants were asked to provide the translation word in the other language.

In the Word-Picture matching task, each target picture was presented with three distractor pictures. Each distractor picture was either semantically, phonological or visually related (similar shape) with the target picture. The experimenter read the target word aloud and the participant was asked to point to picture that matched the presented word.

2.4. Data Analyses

The results of the Picture Naming and Word Translation tasks were submitted to the following analyses. First, we calculated the percentage of correct performance for each participant in each language. Incorrect responses included failures to come up with any word (anomic states) or the production of an incorrect name (semantic or phonological errors) for a given picture or the incorrect translation word. Also, words produced in a different language than the one expected were regarded as errors (wrong language errors). The resulting percentages were submitted as dependent variable to two ANOVAs, with participants (F1) and items (F2) as random variables respectively. The two independent variables were Group of Participants (MCI, mild AD and moderate AD) and Language Dominance (dominant vs. non-dominant).

Second, a more detailed look at the variables that predict performance in this task was taken by assessing the extent to which “MMSE”, “Age”, “Years of education”, “Age of non-dominant language acquisition”, and “Non-dominant proficiency Level” predict the scores of performance in the two languages. The “Non-dominant proficiency Level” was calculated for each participant by averaging the score of “Speaking” and “Comprehension” of the non-dominant language from the questionnaire of bilingualism history. The score was from 0 to 4, where 0 indicated the lowest level of proficiency and 4 the highest level.

In these analyses, we also included the dependent variable “Differences in the performance between languages”, which was calculated by subtracting the accuracy percentage in the non-dominant language from that in the dominant language for each participant. The resulting value indexes the extent to which performance in one language is better than in the other language.

Third, for the sake of clarity, we assess the effect of the word-frequency and cognate variables in independent analyses.

In the following we present the results obtained for the three groups in each task separately.

3. Results

3.1. Picture Naming Task

ANOVA. There was a main effect of “Group of Participants” ($F1$ (2, 68) = 26.32; MSE = 84.41; $p < .01$; $F2$ (2, 106) = 40.11, MSE = 106.99, $p < .01$), revealing that the MCI participants were more accurate than the two groups of AD patients. There were also significant differences between the two groups of AD patients (all *p*s < .05) (see Table 3). In addition, the main effect of “Language Dominance” ($F1$ (1, 68) = 14.98; MSE = 26.01, $p < .01$; $F2$ (1, 53) = 10.48, MSE = 88.61, $p < .01$) revealed a better performance when naming in the dominant than in the non-dominant language. Importantly, and crucial for our present purposes, the interaction between “Group of Participants” and “Language Dominance” was not significant (both *F*s < 1). This lack of an interaction reveals that the better performance in the dominant language over the non-dominant language was of similar magnitude for the three groups of participants (see Table 3).

Table 3

A detailed analysis and a description of the type of errors are reported in Appendix B. The pattern of errors was similar for the three groups of participants. Most of the errors were semantic errors and wrong language errors. The number of wrong language errors increased as the cognitive decline progressed ($p < 0.05$). Furthermore, the percentage of wrong language errors was larger when naming in the non non-dominant language than in the dominant language ($p<0.05$). However, this tendency to produce more cross-linguistic intrusions when naming in the non-dominant language as compared to naming in the dominant language was of similar magnitude for the three groups of participants. In other words, as the disease progresses the number of cross-linguistic errors increases regardless of the response language (for the effects of aging on cross-linguistic errors see also Gollan, Sandoval, & Salmon, 2011).

Regression analyses. We assessed the extent to which "MMSE", "Age", "Years of education", "Age of non-dominant language acquisition", and "Non-dominant proficiency Level" predicted: "Naming accuracy in the dominant language", "Naming accuracy in the non-dominant language", and "Differences in naming accuracy between languages".

Naming accuracy in the "Dominant Language" was significantly predicted only by the "MMSE" (F (1, 69) = 64.70, MSE= 40.94, $p < 0.01$), which explained the 48% of the variance (R^2= .48; $p < .01$). Naming accuracy in the "Non-dominant Language" was significantly predicted by "MMSE", "Age of non-dominant language acquisition" and "Age". The resulting model (F (3, 67) = 23.92, MSE = 46.92, $p < 0.01$) explained the 52% of the variance of the naming performance in the non-dominant language.

Perhaps more interesting for our purposes here is whether the difference in the naming accuracy between languages was predicted by any of these variables. Differences in accuracy between languages was only significantly predicted by “Age”, accounting for the 10% of the variance (R^2 = .10, p < .01) (Age: F (1, 69) = 7.33, p < .01). All the other variables did not significantly predict the differences between naming in the dominant and non-dominant language.

The crucial observation in the regression analyses refers to whether the index of cognitive decline (MMSE) captures participants’ variability in the naming performance (see Figure 1). This variable is the best predictor of the naming performance in the two languages (dominant: R^2 = .48; and non-dominant languages: R^2 = .44), indicating that naming accuracy decreases as a function of the cognitive decline. Crucially, however, the MMSE has no explanatory power when accounting for differences in the performance between languages. In other words, cognitive decline (as measured by the MMSE) is not correlated with differences in accuracy between languages, suggesting that an increase in cognitive decline does not affect the dominant and non-dominant languages differently.

Figure 1

Cognate and Frequency Effects. In a further analysis we assessed the effects of two lexical variables in the naming performance of the participants: cognate status and word-frequency. Cognate words were named more accurately than non-cognate words (see Figure 2- $F1$ (1, 68) = 32.09, MSE = 45.95, p < .01; $F2$ (1, 52) = 2.21, MSE = 949.96, p = .14). This cognate effect did not differ across groups (Group of participants X Cognate status: $F1$ (2, 68) = 2.06, MSE= 45.95, p = .13; $F2$ (2,104) = 0.94, MSE = 107.11, p = .39). Although the cognate effect was significantly present in the two languages, its magnitude was larger in the non-dominant than the dominant language (Language dominance X Cognate status: (F (1, 68) = 8.52, MSE= 40.55, $p < .01$; *F2* (1, 52) = 4.38, MSE = 83.29, $p < .05$). However, and crucial for our purposes, the 3-way interaction among Cognate Status, Language Dominance and Group of Participants was not significant (*F1* (2, 68) = .51, MSE= 40.55, $p = .60$; *F2* (2, 104) = .43, MSE = 25.95, $p = .65$). This indicates that differences across groups of participants when performing the task in the dominant and non-dominant languages was similar for cognates and non-cognates. In fact, if we consider only the naming performance for the more demanding items, namely non-cognates, we found significant main effects of "Group of Participants" (*F1* and *F2* > 19.64, *ps* < .01) and "Language Dominance" (*F1* and *F2* > 13.06, *ps* < .01) but no significant interaction between them (*F1* and *F2* < 1, *ps* > .56). Thus, even for the more demanding items, the two languages seem to be affected by cognitive decline to similar extents.

Figure 2

To assess the word frequency effect, the whole set of pictures was split in two subsets of high- and low-frequency words according the median value of Spanish and Catalan frequencies separately. The mean value of the "high frequency" Spanish words was 101.18, and 8.11 for the "low frequency". The mean value of the "high frequency" Catalan words was 6888.74, and 609.63 for the "low frequency" ones. There was main effect of word frequency (*F1* (1, 68) = 103.28, MSE= 45.22, $p < .01$; *F*2 (1, 52) = 5.37, MSE= 897.71, $p = .02$), indicating higher accuracy for high-frequency relative to low-frequency words. Interestingly, this frequency effect was modulated by Language dominance (Frequency X Language dominance: *F*1 (1, 68) = 37.63, MSE = 34.05, $p < .01$; *F2* (1, 52) = 12.77, MSE = 72.50, $p < .01$), that is, the frequency effect was smaller in the dominant than in the non-dominant language ($p < .01$). The effects of frequency increased as a function of the disease progression (Frequency X Group: *F1* (2, 68) = 10.23, MSE = 45.22, $p < .01$; *F2* (2, 104) = 3.88, MSE = 101.47, $p < .05$). For the dominant language, the frequency effect was larger in the moderate AD compared to the MCI group. For the non-dominant language, the frequency effect was larger in both mild and moderate AD groups relative to the MCI group. However, the three-way interaction among "Frequency", "Language dominance" and "Group of Participants" was not significant (*F1* (2, 68) = 1.77, MSE= 34.05, p = .18; *F2* (2, 104) = .85, MSE = 28.93, p = .45) indicating that the decrease in performance among the three groups and between the two languages was not modulated by word-frequency. Indeed, when considering only, the most difficult items (low-frequency words), the effects of "Group of participants" (*F1* and *F2* > 20.31, *ps* < .01) and "Language Dominance" (*F1* and *F2* > 20.65, *ps* < .01) were significant, but not the interaction between these two main effects (*F1* and *F2* < 1.26, *ps* > .11). Hence, even when considering the most difficult stimuli, cognitive decline appears to affect the two languages of a bilingual similarly.

Figure 3

3.2. Word translation Task

ANOVA. There was a main effect of "Group of Participants" (*F1* (2, 68) = 20.61; MSE = 77.74, p < .01; *F2* (2, 106) = 35.60, MSE = 100.30, p < .01), indicating significant, although small, differences among the three groups in their ability to perform the word translation task (see Table 3). The MCI group performed more accurately than the two groups of AD patients and the mild AD patients performed more accurately than the moderate AD patients (all *p*s < .05). There was also a main effect of "Translation direction" (*F1* (1, 68) = 5.36, MSE= 26.50, p < .05; *F2* (1, 53) = 3.29, MSE = 130.40, p = .07) revealing a better performance when translating into the dominant language than into the non-dominant language. Importantly, and crucial for our present purposes, the interaction between "Group of participants" and "Translation direction" was not significant (*F1* (2, 68) = .46, MSE = 26.50, p = .63; *F2* (2, 106) = 1.07; MSE = 28.85, p = .35), indicating that the relatively more accurate performance in the dominant as compared to the non-dominant language was similar for the three groups of participants. Hence, this observation suggests that an increase in cognitive decline affects the word translation performance similarly in the two languages. Given the relatively small number of errors we did not perform qualitative analyses, although we report them in Appendix B.

Regression Analyses. We performed the same type of regression analyses as we did for the Picture Naming task. Translation accuracy was significantly predicted only by the "MMSE" in both directions of translation (into the dominant; F (1, 69) = 38.44, $p < .01$; $R^2 = .36$; $p < .01$; and into the non-dominant languages; F (1, 69) = 42.83, $p < .01$, $R^2 = .38$; $p < .01$). Importantly, however, differences in the word translation performance between the two languages were not predicted by the MMSE, and only a small portion of the variance was explained by "Age of non-dominant language acquisition" ($R^2 = .06$, $p < .01$) (F (1, 69) = 4.74, MSE = 49.54, $p < .05$). Thus, as the cognitive decline increases, the word translation performance in the dominant and non-dominant languages decreases. More importantly, this decrease is similar for the two languages of a bilingual[1].

Cognate and Frequency Effects. In a further analysis we assessed the effects of the cognate status and word-frequency on the translation performances.

Cognate words were translated more accurately than non-cognate words ($F1$ (1, 68) = 87.57, MSE= 103.73, $p < .01$; $F2$ (1, 52) = 9.69, MSE = 1496.62, $p < .01$). The magnitude of this cognate effect differed across groups (Group of participants X Cognate status: $F1$ (2, 68) = 3.58, MSE= 103.73, $p < .05$; $F2$ (2, 104) = 7.53, MSE = 89.30, $p < .01$). Post-hoc analyses showed that the cognate effect was smaller in the MCI than the mild and moderate AD groups (all ps = .05). Finally, the cognate effect was modulated by "Translation Direction" (Translation direction

[1] The three groups were slightly different in terms of age and age of Non-dominant language acquisition. To be sure that these two variables do not affect the results, we re-run the analysis with a sub-sample of patients matched for these demographic and linguistic characteristics (n= 58, 19 MCI, 19 Mild AD and 19 Moderate AD). We found the same results as with the whole sample both for the Picture naming and the Word Translation task. That is, non-significant interaction between "Group of participants" and "Language dominance" (Fs < 1), suggesting parallel deterioration of the two languages as the disease progresses.

X Cognate status: (*F1* (1, 68) = 15.14, MSE = 48.55, $p < .01$; *F2* (1, 52) = 7.35, MSE = 116.98, $p < .01$), that is, it was larger in the non-dominant than in the dominant language. Crucially, the three-way interaction among "Cognate Status", "Translation Direction" and "Group of Participants" was not significant (*F1* (2, 68) = 1.06, MSE = 48.55, $p = .35$; *F2* (2, 104) = 2.64, MSE = 27.98, $p = .08$) indicating that the decrease in performance among groups and between languages was similar both for cognates and non-cognates.

In fact, if we consider only the more demanding items, such as the non-cognates, the main effects of "Group of participants" (*F1* and *F2* > 20.80, *ps* < .01) and "Translation direction" (*F1* and *F2* > 52.64, *ps* < .01) were significant, but not the interaction between these two main effects (*F1* and *F2* < 2.02, *ps* > .14). Again, the decrease in performance between languages and among groups was similar for these more demanding items.

High-frequency words were translated more accurately than low frequency words (*F1* (1, 68) = 183.15, MSE= 48.1, $p < .01$; *F2* (1, 52) = 13.32, MSE = 1413.33, $p < .01$). This frequency effect was modulated by "Translation direction" (Frequency X Translation direction: *F1* (1, 68) = 19.49, MSE = 29.89, $p < .01$; *F2* (1, 52) = 18.16, MSE = 98.96, $p < .01$), being the performance in the dominant language less affected by frequency than the performance in the non-dominant language. Interestingly, the effects of frequency appeared to increase as the disease progresses (Frequency X Group of participants: *F1* (2, 68) = 12.97, MSE = 48.91, $p < .01$; *F2* (2, 104) = 15.44, MSE = 78.83, $p < .01$), being larger in the Mild (12.6%) and Moderate (15.6%) AD compared to the MCI patients (5.5%, all $p_s < .05$), but not between Mild and Moderate AD. However, the three-way interaction among "Frequency", "Translation direction" and "Group of Participants" was not significant (*F1* (2, 68) = .05, MSE= 29.89, $p = .95$; *F2* (2, 104) = .85, MSE = 28.93, $p = .45$) indicating that the decrease in performance among groups and between language was similar both for the high and low frequency words.

In fact, when we looked at the most difficult material, namely low-frequency words, the effects of ‘Group of participants’ (*F1* and *F2* > 20.74, *p* < .01) and ‘Translation direction’ (*F1* and *F2* > 16.82, *ps* < .01) were significant, but not the interaction between these two main effects (*F1* and *F2* < 1, *p* > .80). Again, performance declines as the disease progresses but to the same extent in the dominant and non-dominant language.

3.3. Word-picture matching task

In these analyses, we first calculated the percentage of correct word-picture matching responses for each participant in each language. The resulting percentages were submitted to an ANOVA with two factors: “Group of Participants” (MCI, mild AD and moderate AD) and ‘Language dominance’ (dominant vs. non-dominant).

We only found a main effect of “Group of participants” (F (1, 68) = 8.66, MSE = 14.98, p < .01) revealing that moderate AD performed slightly worse (96.6%) than mild AD (99.3%) and MCI (99.6%). Performance was similar in both languages (Language dominance: F (1, 68) = 1.27, p =.26), and there was no significant effect of interaction of “Group of participants” and “Language dominance” was found (F < 1).

3.4. Overall Analysis

The results of the two tasks presented above (Picture naming and Word translation) yield qualitatively similar results. In order to gain more statistical power and reduce variability, we decided to conduct a joint analysis of the two tasks. In this analysis, we averaged the performance in the two tasks, resulting in one value for each participant for each of the two languages.

When submitting the different composite scores to a regression analysis, performance in the dominant language was explained only by “MMSE” (F (1, 69) = 67.75, MSE = 34.52, p <

.01; R^2 = .49). In contrast, “MMSE” and “Non-dominant language proficiency” contributed significantly to explain the variability on the performance in the non-dominant language (F (2, 68) = 40.99, MSE = 29.55, p < .01; for a global explanation of R^2 = .56). Importantly, however, the difference in performance between the two languages was completely uncorrelated with any of these variables (see Figure 4).

By the way, we assessed the effects of the cognate status and word-frequency on the composite score. Both “Cognate status” and “Frequency” interacted with “Group participants” (p_s < .05). Crucially, the three-way interactions Cognate Status x Language dominance X Group of Participants and Frequency x Language dominance X Group of Participants were not significant (p_s > .22). This indicates that the frequency and the cognate effects increase as the disease progresses, but with the same magnitude for both languages.

Figure 4

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4. General Discussion

The aim of the present research was to explore how a neurodegenerative disease such as AD affects the deterioration of the two languages of bilingual speakers, and specifically the deterioration of lexical processing. We pursued this issue by testing the linguistic performance in various tasks of three groups of early and high-proficient Catalan-Spanish bilinguals diagnosed with: a) MCI, b) mild AD, and c) moderate AD. The linguistic performance of the two groups of AD patients was compared with that of the MCI patients that served as controls. The results of the picture naming and word-translation tasks reveal the following main observations:

i) Picture Naming: The picture naming accuracy declines as the severity of the disease increases. That is, the naming accuracy of Moderate AD patients was lower than that of mild AD patients, which in turn was lower than that of MCI patients. The picture naming accuracy was lower for the self-reported non-dominant language than for the dominant language. Importantly, the difference in performance between dominant and non-dominant languages was of similar magnitude for the three groups of bilinguals. That is, the cognitive decline associated to AD decreases the ability to name pictures in the two languages to a comparable extent.

ii) Word Translation: The word translation task showed basically the same pattern of results, although the performance of the three groups of participants was more accurate than in the picture naming task overall. That is, translation ability was affected by cognitive decline, and also by translation direction. Of crucial interest is the observation that differences in the word translation ability between the two languages were of comparable magnitude for the three groups of participants. This is an indication that as the cognitive decline increases due to AD, word translation performance decreases to similar extents in the two languages.

iii) Cognate and Frequency status: The results of these two variables were very similar in both tasks. First, the performance of the three groups of participants was affected by cognate status and word-frequency, that is, cognates and high-frequency words were better preserved than non-cognates and low-frequency words. Second, these effects were larger in the non-dominant language than in the dominant language. Third, cognate and word-frequency effects tend to be larger as the cognitive decline increases, especially for the word-translation task. Fourth, and crucial for our purposes here, the general pattern of deterioration associated with cognitive decline across languages was not affected by the cognate and word-frequency variables. In other words, cognitive decline affects the two languages of a bilingual similarly, irrespective of the cognate status and word-frequency.

Overall, these results reveal that in cases of early and high-proficient bilinguals, lexical processing in the two languages is similarly affected by cognitive decline due to the neurodegeneration associated with AD. Hence, it does not seem to be the case that first-learnt memories (related to the language firstly learned) enjoy a relative invulnerability, at least not for early bilinguals. At the same time, these results reveal that AD does not necessarily damage the dominant language of bilinguals to a larger extent than the non-dominant language. These two observations fit relatively well with what was previously reported by Gollan et al. (2010). Recall that in such a study, the dominant language of unbalanced English-Spanish bilinguals was more affected than the non-dominant language. However, the authors also reported that such a difference between performance in the dominant and non-dominant languages becomes much smaller (without reaching significant differences) for those bilinguals that are more balanced in the two languages (but see below).

Our observations are also consistent with the pattern of results that is commonly observed when exploring the brain activity of healthy bilinguals performing tasks in the dominant and non-dominant languages. The most common observation when testing high-proficient bilinguals is that the neural substrates recruited when performing the task in the two languages overlap largely, sometimes leading to non observable differences between the languages. This has led some researchers to argue that the brain tissue representing the two languages is shared (see for reviews, Abutalebi & Green, 2007; Indefrey, 2006; Perani & Abutalebi, 2005; Rodriguez-Fornells et al., 2002), at least at the macroscopic level, for early and high proficient bilinguals. In this view, the existence of certain linguistic dissociations in bilingual brain damaged patients is better accounted for by deficits in the control network responsible for selecting the representations of the intended language while avoiding massive interference from the other. Hence, considering that AD affects brain tissue responsible for lexico-semantic processing and conceptual representations (temporal lobes), the observation that the two languages of a bilingual speaker are affected in the same manner is the expected outcome. It is important to note here that these conclusions refer to the processes and representations involved in lexical processing.

It could be argued that the relative richness of the lexico- semantic associations of two languages plays a role in the language deterioration. For instance, the lexical items of the dominant language may have richer associations with semantic representations than lexical items from the non-dominant language. As AD affects the semantic representations it could be the case that the two languages are differentially affected by disease, that is the dominant more protected than the non-dominant (but see also Gollan et al. 2000 for a different explanation). However, if the semantic deficit affects equally and with same probability the two languages, the lexico-semantic representations will deteriorate in a similar manner. As a consequence, as AD disease progresses the deterioration of the two languages will be parallel and not relatively affected.

Future research needs to be conducted to assess whether other linguistic domains, such as for example grammatical or morphological processing, are equally affected by neurodegenerative diseases (see Hernández, Costa, Sebastián-Gallés, Juncadella, & Reñé, 2007; Hernández et al., 2008). A further relevant issue would be to explore the impact of neurodegenerative diseases such as Frontotemporal dementia (FTD) in the cortical and subcortical network implicated in language control (for a review see Abutalebi and Green, 2007; for evidence from bilingual aphasic patients see also Abutalebi, Miozzo, & Cappa, 2000; Fabbro, Skrap, & Aglioti, 2000; Mariën, Abutalebi, Engelborghs, & De Deyn, 2005). Within the spectrum of the FTD pathology, the behavioral variant (bv-FTD) is characterized, since the onset, by executive dysfunctions, attention and working memory deficits (e.g., Stopford et al., 2011). Bv-FTD patients show atrophy of the anterior cingulate cortex (ACC), middle and inferior frontal areas (Boccardi et al., 2005). Interestingly, these areas are also functionally activated in tasks involving bilingual language control (Abutalebi & Green, 2008; Abutalebi et al., in press; Garbin et al., 2010). Hence, assessing bilingual patients with FTD would allow exploring whether the lack of control affects the two languages differently, fixing their productions in one of the languages, resulting in larger impairment for the other (for evidence relating a decrease of attentional abilities and deficits in language control see also Junco-Rabadan & Iglesias, 1994; Gollan et al., 2011).

A potential caveat of our study lies in the possible lack of power to detect differences between the two languages given the relatively high performance of the participants tested in our study. For example, comparing the performance of our participants with that of the participants tested by Gollan et al. (2010), one can easily appreciate the large difference in overall scores between the two studies. That is, the performance of the participants in the present study was much more accurate than in Gollan's et al. (2010). Hence, one could argue that our stimuli were too easy to allow detecting significant differences between the performance in the two languages, or that our AD patients were still relatively cognitively intact for the specific demands of these tasks. Therefore, the performance of the participants would approach ceiling values. Although this caveat can only be convincingly addressed by using more difficult materials or more impaired individuals, we can offer some additional evidence that renders this explanation unlikely.

Picture naming and word-translation performance were sensitive to a wide range of variables. For example, performance in these tasks was highly correlated with the degree of cognitive impairment (as assessed by the MMSE), revealing that this task and the materials used were sensitive enough to lead to observable differences associated to the degree of cognitive decline. Given this correlation, one could then ask the question of whether those individuals with a larger cognitive impairment also showed larger differences between naming in the dominant and non-dominant languages. That is, if one of the languages is more affected by cognitive decline than the other, one should expect that the larger the decline the larger the difference. The results are clear in this respect, since MMSE scores were completely uncorrelated with differences in performance between the two languages. This is even so when considering only the AD patients (Mild and Moderate).

Participants' naming performance was also sensitive to item specific variables, such as cognate status and word-frequency. These variables affected performance in the expected direction: the larger the cognitive decline the larger the cognate and word-frequency effects, and the less dominant the language the larger the cognate and word-frequency effects. These results replicate previous observations (Costa, Santesteban, & Cano, 2005; Kohnert, 2004; Robert & Deslauriers, 1999). Furthermore, given that the effect of these two variables is related to difficulty, we can assess whether increased task difficulty (i.e., sub-sampling only the difficult items) could lead to a differential degree of impairment between the two languages. The results of these analyses did not show any significant difference, suggesting that the pattern of linguistic impairment associated with cognitive decline was similar for all types of words.

Perhaps the best way to assess whether a more severe cognitive decline would eventually reveal differences between the two languages is to follow up the patients' performance across time. Although at present we only have preliminary data from a sub-sample of the current study, there are no indications of a differential performance between the two languages.

Thus, although at present it is impossible to give a definitive answer to whether a more difficult task or a more severe cognitive decline would have led to differences between the two languages, the available information does not provide any hint that such expectation is correct. All in all, we believe that our results allow us to draw the conclusion that AD affects lexical processing similarly in the two languages of early and high-proficient bilinguals

Given this conclusion, it is worth discussing whether the parallel impairment of the two languages of a bilingual is expected to be the most common outcome of any neurodegenerative disease. Our view on this is based on the "shared bilingual neural substrate" hypothesis according to which the neural substrates of the lexico-semantic representations are largely shared (at least at macroscopic level) between the two languages. Given this common representation we hypothesize that any other neurodegenerative disease that affects the lexico-semantic system in a global manner would lead to a comparable lexical deficit in the two languages of a bilingual, at least for early and high-proficient bilinguals (see above). Thus, to the extent that diseases such as semantic dementia and primary progressive aphasia affect the lexico-semantic system, they will affect the two languages of a bilingual similarly. Future research should determine whether other neurodegenerative diseases actually affect the two languages in a differential manner, and whether variables such age of acquisition and proficiency in the L2 and non-dominant language affect the linguistic impact of the disease.

Before concluding we would like to mention that our study also provides convergent evidence regarding the relative preservation of cognate words in comparison to non-cognate words in cases of brain damage. There is ample evidence that cognate words enjoy a processing benefit in healthy adults and in individuals with aphasia (Costa, Caramazza, & Sebastian-Galles, 2000; Gollan & Acenas, 2004; Kirsner, Lalor, & Hird, 1993; Kohnert, 2004; Robert & Deslauriers, 1999). Our contribution here is to introduce the first group study with AD patients in which such an effect is reported both in picture naming and word translation tasks. Furthermore, as expected, the cognate effect was larger in the non-dominant language than in the dominant one, suggesting that the weaker language is more aided by the phonological similarity between translation words (Kroll & Stewart, 1994). At present, the origin of the cognate effect is still an open issue, and the results reported in our study cannot shed much light on it.

However, our results can be used to put forward some tentative predictions about potential patterns of language deterioration. For example, one way to give a unified interpretation of the relative invulnerability of cognate and high-frequency words to brain damage is to understand the cognate effect as a word frequency effect in disguise. On this view, the actual frequency of a cognate word is the result of the frequency with which such a word is used irrespective of the language in which it is produced. That is, a given word in language A will benefit from having a translation word with similar phonological/orthographic form in language B, in the sense that the independent word frequencies will add each other. This combination of frequencies would not happen in the case of non-cognate words, given the formal disparity between the translation words. Hence, overall, and being everything else equal, cognate words will have higher frequency values than non-cognates words. And, given the well-known effect of word-frequency in the vulnerability of lexical items to word retrieval failures (in all sorts of speakers, e.g. Gollan and Brown, 2006; Kittredge, Dell, Verkuilen, & Schwartz, 2008; Navarrete, Basagni, Alario & Costa, 2006), one would expect cognates to be better preserved than non-cognates. This explanation makes two interesting cross-linguistic predictions regarding the deterioration of the two languages of a bilingual. First, in conditions of similar brain damage, bilingual speakers of two dissimilar languages (in terms of lexical similarities) would show more pronounced lexical deficits than those of two similar languages. This is because similar languages probably have a larger amount of cognate words than dissimilar languages. And, given that cognates are more resistant to brain damage, then performance will be overall better. This should be so in both of the two languages of the bilingual. Second, as the disease progresses to very advanced stages the speech produced in the two languages by neurodegenerative patients will tend to become more and more similar, in terms of lexical elements. That is, given that cognates will be more preserved, bilinguals will tend to use them more often compared to healthy individuals. Hence, the prediction is that lexical choices in any of the two languages will become more sensitive to the formal properties of lexical items across languages. These two tentative predictions would have to be tested in a relatively large sample of speakers.

At any rate, the presence of robust cognate effects in this study should serve as an indication to clinicians of the need for testing both cognate and non-cognate words during screening sessions, since the results may vary considerably.

5. Conclusion

In this study we assessed to what extent a neurodegenerative disease such as AD affects the two languages of early and high-proficient bilinguals differently. The results reveal that the picture naming and word translation ability appear to be similarly affected in the two languages as a consequence of the cognitive decline associated with AD. These results indicate that neurodegenerative diseases affecting the lexico-semantic system seem to have similar consequences for the two languages of early and high-proficient bilinguals. This observation is consistent with the notion that, for these bilinguals, the two languages are represented within a common underlying brain network.

Table 1. Mean values (M) and Standard Deviations (SD) for Age, Education, and neuropsychological tests, broken by Group of participants (MCI, Mild and Moderate AD). P values indicate differences between the three groups.

	MCI		**Mild AD**		**Moderate AD**		
	n=24		n=23		n=24		***p values***
Gender (Female / Male)	**11/13**		**17/6**		**18/6**		
	M	**SD**	**M**	**SD**	**M**	**SD**	
Age (years)	**75.7**	5.0	**76.7**	6.7	**79.8**	5.8	0.05[a]
Education (years)	**12.7**	4.4	**10.4**	4.9	**10.8**	5.8	0.26
MMSE	**26.6**	1.6	**22.3**	0.9	**17.6**	2.4	*<0.0001*[b]
GDS	**3.0**	0.9	**3.8**	0.6	**4.6**	0.5	*<0.0001*[b]
CERAD Word list -Total trials	**11.2**	3.3	**8.8**	3.1	**7.7**	2.3	*<0.0001*[b]
CERAD Word list - Delayed recall	**1.8**	1.9	**0.4**	0.6	**0.1**	0.6	*<0.0001*[b]
CERAD Word list - Recognition	**15.2**	2.7	**13.8**	3.7	**10.7**	3.9	*<0.0001*[c]
Pyramids and Palm Trees Test	**50.7**	1.6	**48.5**	2.9	**43.4**	4.9	*<0.0001*[c]
Semantic Fluency	**12.1**	3.4	**9.3**	3.8	**7.8**	1.8	*<0.0001*[b]
Benton Visual Retention Test	**5.8**	1.9	**4.9**	1.7	**3.0**	1.7	*<0.0001*[c]
Digit span forward	**4.8**	0.8	**4.7**	0.8	**4.5**	1.0	0.41
Digit span backward	**3.1**	0.8	**2.9**	0.6	**2.6**	0.9	0.11

(a) No significant difference between groups in the post-hoc analysis (Bonferroni correction)

(b) All groups significantly different, $p < 0.05$

(c) MCI vs. Moderate AD $p < 0.05$

Table 2. Mean values (M) and Standard Deviations (SD) for the variables related to the linguistic profile of the participants broken down by Group of participants (MCI, Mild and Moderate AD).

	MCI		Mild AD		Moderate AD		
	n=24		n=23		n=24		
	M	**SD**	**M**	**SD**	**M**	**SD**	***p values***
L1/L2 (Catalan/Spanish)	**16/8**		**20/3**		**19/5**		
Age of regular L1 use	**2.0**	0.2	**2.1**	0.3	**2.0**	0.0	0.15
Age of regular L2 use	**5.6**	3.0	**3.9**	1.7	**5.4**	2.8	0.07
L1 speaking [a]	**4.0**	0.0	**4.0**	0.0	**3.8**	0.7	0.10
L1 comprehension	**4.0**	0.0	**4.0**	0.0	**3.9**	0.3	0.14
L1 reading	**3.5**	1.1	**3.5**	1.1	**2.8**	1.0	0.06
L1 writing	**2.2**	1.6	**2.0**	1.5	**1.3**	1.3	0.09
L2 speaking	**3.7**	0.5	**3.6**	0.6	**3.2**	0.8	*0.03*[b]
L2 comprehension	**3.9**	0.4	**4.0**	0.0	**3.8**	0.4	0.14
L2 reading	**3.7**	0.2	**3.4**	0.2	**3.0**	0.2	*0.01*[a]
L2 writing	**2.5**	1.3	**2.7**	1.1	**1.9**	1.0	0.06

(a) Rating for speaking, comprehension, reading and writing was on a four-point scale: 1= poor, 2= regular, 3= good, 4= perfect.

(b) MCI vs. Moderate AD p <0.05

Table 3. Percentage accuracy (Acc %) and Standard Deviations (SD) for the three experimental tasks broken by Language dominance and Group of participants.

	Picture Naming				**Word Translation**				**Word-Picture Matching**			
	Dominant		***Non-Dominant***		***into Dominant***		***into Non-dominant***		***Dominant***		***Non-dominant***	
	Acc (%)	*SD*	*Acc (%)*	*SD*	*Acc (%)*	*SD*	*Acc (%)*	*SD*	*Acc (%)*	*SD*	*Acc (%)*	*SD*
MCI	**97.1**	2.7	**94.3**	5.8	**95.7**	4.2	**92.8**	6.3	**99.8**	0.6	**99.5**	1.6
Mild AD	**92.4**	6.0	**87.7**	6.3	**89.6**	6.7	**87.3**	4.6	**99.2**	1.7	**99.4**	1.7
Moderate AD	**83.4**	9.4	**80.9**	10.4	**83.1**	9.8	**82.2**	8.6	**97.1**	4.0	**96.2**	5.0

Figure 1

Panel A: Correlation between picture naming performance (% of correct responses) in the dominant and non-dominant languages and the MMSE scores (Dominant Language: r = .70; Non- dominant Language r = 0.67). Each observation corresponds to one participant.

Panel B: Correlation between the difference in performance between languages (subtraction of percentage correct in the dominant minus percentage correct in the non-dominant languages) and the MMSE scores. Each observation corresponds to one participant.

Figure 2

Picture Naming (Panel A) and Word Translation (Panel B) accuracy broken down by Group of Participants, Language Dominance and Cognate Status of the pictures' names. Error bars represent standard errors.

Figure 3

Picture Naming (Panel A) and Word Translation (Panel B) accuracy broken down by Group of Participants, Language Dominance and Frequency of the pictures' names. Error bars represent standard errors.

Figure 4

Correlation between the composite index of performance (Picture Naming performance averaged with Word Translation performance) and MMSE scores for the two languages (Dominant Language: R^2 = .70; Non- dominant Language R^2 = 0.72).

Appendix A. *Description of the Sociolinguistic Environment of the participants and description of the language typology.*

In Barcelona (Catalonia, Spain) both Catalan and Spanish have been official languages for more than 30 years after the authoritarian franquist regime (1939–1977). Thus, both languages are used in public administration and also in everyday life. In addition, both languages are present in mass media, as radio and television programs broadcast in Catalan and in Spanish, and many newspapers contain articles written in Catalan and Spanish. Furthermore, in many families both Catalan and Spanish are used on a daily basis leading to bilingual conversations among relatives and friends. This makes it usual that a given speaker switches between the two languages according to whom s/he is speaking to at that moment. That is, Catalonia is a privileged bilingual context in the sense that the whole population is massively exposed to both Catalan and Spanish. This means that Catalan citizens are able to read, write, speak, and understand both languages at a native level and, in many cases, it is hard to determine which of the two languages is the L1.

Due to the age of the participants included in our study, it is also relevant to mention that during the authoritarian regime, Catalan was banned from the public administration and educational system. Thus, at the time our participants attended the school, children were exclusively taught in Spanish. This means that, even if most of our participants had Catalan as L1, they were first exposed to Spanish at a very early age, acquiring a high-proficient level of Spanish. However, despite being immersed in that exclusively Spanish educational system Catalan was still regularly used on a daily basis with school-mates, relatives, and friends. This was so, not only at home but also, in businesses and all sorts of casual conversations and events.

Regarding the linguistic properties of Catalan and Spanish, both of them are Romance languages with similarities at the lexical level, since phonological overlapping between equivalent translations (i.e., cognate words) occurs in about the 70% of the words. Also, nouns are marked for gender and number in both languages with the same inflections – grammatical features governing agreement inside the noun phrase. Catalan and Spanish are also similar at the syntactic level, since they are both pre-drop (allowing the omission of the subject in the sentence) SVO (Subject Verb Object) languages with relatively free order.

Despite all these similarities, there are also some differences between the linguistic properties of Catalan and Spanish, with those at the phonological level being perhaps the most relevant ones. The two languages have different vowel repertoires. Spanish has a relatively small inventory of five vowels (/a/, /e/, /i/, /o/, /u/), which can be realized both in stressed and unstressed positions. The consonant repertoire is also different. In addition to the Spanish /tS/, Catalan contains three affricate consonants (/dz/, /dZ/, /ts/). Also, the Spanish fricative unvoiced consonants /T/ and /x/ are replaced by /S/ and /Z/, respectively. In addition, the /j/, /l/, and /w/ allophones are differently realized in each language.

There are also differences in the orthographic systems. Only Spanish has the grapheme ñ and only Catalan has the graphemes ï, and ç. Finally, in Catalan two signs are used to indicate stress (as in é and è) but only one in Spanish (é).

Appendix B. *Description of the types of errors committed in the Picture naming task and word translation tasks broken by Language dominance and Group of participants.*

An error was classified as "semantic" if participants produced a word that was semantically related to the target, or when they started producing several words that were semantically related to the target, or when they gave some semantic information (category membership or some property) about the target but were unable to come up with the response. These errors may stem from his semantic deficit or from a failure to retrieve the correct lexical representation. "Phonological" errors were those responses in which participants added, omitted, or replaced some phonemes of the correct response. This type of errors indicated that participants had access to (at least) some lexico-semantic information about the target, but that they had difficulties accessing its phonological information. Responses that are indicated that patients did not properly perceive well the picture were classified as ''visual'' errors. Those responses in the non-target language which was not tested at that moment were counted as ''wrong language'' errors ("repetition" in the word translation task). "Unrelated" errors refer to those responses that had nothing to do with the target, which led us to suspect that no (or little) conceptual information was accessed. Incomplete sentence frames or definitions that gave enough conceptual information with respect to the target were classified as ''circumlocutions''. Responses were classified as "Neologisms" when participants produced a non-existing word. Finally, "regularizations" were those responses in which participants adapted the target word to the response language by adding some suffixes.

Table B1. Distribution of error types in the Picture naming task broken by Language dominance and Group of participants.

	Dominant Language					
	MCI		Mild AD		Moderate AD	
Type of error	N. of errors	%	N. of errors	%	N. of errors	%
No Response	3	(0.8)	12	(3.1)	39	(10.1)
Semantic	13	(3.4)	45	(11.7)	74	(19.3)
Phonological	2	(0.5)	7	(1.8)	20	(5.2)
Visual	9	(2.3)	16	(4.1)	21	(5.5)
Wrong language	11	(2.9)	24	(6.3)	50	(13.0)
Unrelated	3	(0.8)	1	(0.3)	13	(3.4)
Circumlocution	-		5	(1.3)	13	(3.4)
Neologism	-		1	(0.3)	1	(0.3)
Total errors	**41**		**111**		**231**	

	non-Dominant Language					
	MCI		Mild AD		Moderate AD	
Type of error	N. of errors	%	N. of errors	%	N. of errors	%
No Response	6	(1.0)	25	(4.3)	41	(7.0)
Semantic	23	(4.0)	47	(8.1)	77	(13.2)
Phonological	7	(1.2)	9	(1.5)	15	(2.6)
Visual	7	(1.2)	19	(3.3)	33	(5.7)
Wrong language	51	(8.8)	70	(12.0)	106	(18.0)
Unrelated	3	(0.5)	2	(0.3)	4	(0.7)
Circumlocution	2	(0.3)	8	(1.4)	22	(3.8)
Neologism	-		1	(0.2)	3	(0.5)
Total errors	**99**		**181**		**301**	

Table B2. Distribution of error types in the Word translation task broken by Language dominance and Group of participants.

	into Dominant Language					
	MCI		Mild AD		Moderate AD	
Type of error	N. of errors	%	N. of errors	%	N. of errors	%
No Response	15	(3.8)	58	(14.8)	108	(27.4)
Semantic	11	(2.8)	12	(3.0)	32	(8.1)
Phonological	4	(1.0)	8	(2.0)	15	(3.8)
Repetition	26	(6.6)	35	(8.9)	43	(10.9)
Regularization	-		5	(1.3)	10	(2.5)
Circumlocution	1	(0.2)	1	(0.2)	4	(1.0)
Unrelated	-		1	(0.2)	4	(1.0)
Total errors	**57**		**120**		**216**	

	into non-Dominant Language					
	MCI		Mild AD		Moderate AD	
Type of error	N. of errors	%	N. of errors	%	N. of errors	%
No Response	49	(12.5)	70	(17.8)	144	(36.6)
Semantic	13	(3.3)	24	(6.1)	17	(4.3)
Phonological	2	(0.5)	7	(1.8)	17	(4.3)
Repetition	21	(5.3)	51	(13.0)	38	(9.7)
Regularization	3	(0.8)	5	(1.3)	4	(1.0)
Circumlocution	3	(0.8)	-		2	(0.5)
Unrelated	1	(0.2)	1	(0.2)	8	(2.0)
Total errors	**92**		**158**		**230**	

Acknowledgment

This work was supported by grants from the Spanish government (PSI2008-01191, Consolider Ingenio 2010 CSD2007-00012) and the Catalan government (Consolidat SGR 2009-1521). Marco Calabria was supported by a postdoctoral fellowship from the Spanish Government (Juan de la Cierva fellowship). This research was also supported by a Marie Curie International Outgoing Fellowship within the 7th European Community Framework Programme awarded to Mireia Hernández.

The authors are grateful to Ian FitzPatrick for the comments on previous versions of this manuscript.

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