Multilingualism in semantic dementia: language-dependent lexical retrieval from degraded conceptual representations

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Abstract

Background: Patients with the semantic variant of Primary Progressive Aphasia (svPPA) offer a unique opportunity to study the relationship between lexical retrieval and semantics, as they are characterised by progressive degradation of central semantic representations. However, there are few studies of how lexical retrieval across languages is affected in multilingual speakers.

Aims: We examine the impact of conceptual degradation in a trilingual patient (TC) with svPPA, to investigate whether the semantic memory breakdown affects her three languages similarly (English-Catalan-Spanish) in different linguistic tasks.

Methods & Procedures: We followed up her performance over one year in several tasks including: a) naming with or without semantic interference contexts, b) word translation, c) word- and sentence-picture matching, d) associative semantic priming and e) language switching.

Outcomes & Results: There was significant response consistency between languages in the items that were relatively well-known and more semantically degraded, at least in a standard picture naming task. The patient's sentence-to-picture matching did not show progressive deterioration in any language. However, some aspects of lexical retrieval showed language-dependency, as indexed by different patterns of performance in semantically-blocked cyclical naming task across languages.

Conclusions: These data suggest that while degradation of central semantic representations affects all languages, this deficit can be amplified or ameliorated by the strength of conceptual to lexical mappings, which varies across languages.

Keywords: bilingualism, multilingualism, semantic control, semantic memory

Number of words: 7993

1. Introduction

Neuropsychological studies have helped to delineate separate but interacting neurocognitive components that support semantic cognition (Jefferies, 2013; Lambon Ralph et al., 2017). They reveal a dissociation between the pattern of impairment in semantic dementia (SD) or the semantic variant of Primary Progressive Aphasia (svPPA) – characterised by degraded conceptual knowledge across modalities following atrophy of the ATLs bilaterally – and at least two types of semantic access disorders (Jefferies & Lambon Ralph, 2006; Thompson, Robson, Lambon Ralph, & Jefferies, 2015; Warrington & Cipolotti, 1996), involving difficulties in a specific input or output pathway, or poor control over conceptual retrieval.

SvPPA can be categorised as a semantic 'storage' deficit (Gorno-Tempini et al., 2011) and it is characterized by atrophy within the anterior temporal lobes (ATLs), which are thought to provide a central conceptual store or 'hub' which integrates different sources of information – i.e., visual, auditory and motor features and language representations, forming the 'spokes' of the 'hub and spoke' model (Patterson, Nestor, & Rogers, 2007). At the behavioral level, these patients show a high degree of response consistency in the items that they understand well and poorly across tests of semantic access from different modalities, such as word-picture and environmental sound-picture matching for the same items (e.g. Bozeat, Lambon Ralph, Patterson, Garrard, & Hodges, 2000; Garrard et al., 2001; Jefferies, Baker, Doran, & Ralph, 2007; Jefferies & Lambon Ralph, 2006). However, despite evidence of consistent semantic deficits on word comprehension and production, few studies have investigated this issue in multilingual patients across languages. Here, we aimed to explore the relationship between central conceptual deficits and impairment on lexical tasks by studying a multilingual patient with svPPA in a range of language production and comprehension tasks including: a) naming with or without semantic interference contexts, b) word translation, c) word- and sentence-picture matching, d) associative semantic priming and e) language switching.

The question of how svPPA affects lexical retrieval in word production tasks across languages has been examined in few bilingual cases. Mendez, Saghafi, and Clark (2004) described two multilingual patients with semantic dementia, who showed greater impairment in their less proficient languages in naming and word comprehension. However, studies that examined patients in more depth have shown highly similar deficits across languages (Hernández et al., 2008; Hernández, Costa, Caño, Juncadella, & Gascón-Bayarri, 2010). In the first study by Hernández et al. (2008), patient JPG had similar category-specific deficits in both languages (Spanish and Catalan), with poorer performance when naming verbs than nouns. Similarly, the semantic memory deficits of JFF (a Catalan-Spanish bilingual patient) described by Hernández et al. (2010) had a similar influence on word translation in both language directions. The language-independent effects of semantic degradation on lexical retrieval seem to extend to word recognition, as the SD patient (SN) described by Siyambalapitiya, Chenery, and Copland (2013) showed intact semantic priming in both languages and in the cross-language condition (from English to Spanish), in line with studies of healthy bilinguals in these types of tasks (e.g., Perea, Duñabeitia, & Carreiras, 2008; Travis, Torres Cacoullos, & Kidd, 2017; Zeelenberg & Pecher, 2003).

These findings from bilingual patients with semantic deficits support the idea of a shared conceptual/semantic system across languages (Francis, 1999, 2005), as proposed in some models of bilingual production and comprehension (BIA+ model: Dijkstra & van Heuven, 2003; ICM: Green, 1986) and in models that propose that lexical selection in bilinguals is qualitatively similar to that in monolinguals (Caramazza & Costa, 2000; Costa, Miozzo, & Caramazza, 1999; Finkbeiner, Gollan, & Caramazza, 2006; La Heij, 2005). Similarly, neuroimaging studies have found a consistent neural pattern for the same words presented in different languages in anterior temporal cortex, reflecting their shared underlying meaning (Buchweitz, Shinkareva, Mason, Mitchell, & Just, 2012; Correia et al., 2014).

According to these findings, svPPA patients who speak more than one language should show consistency in the items that are impaired across languages, reflecting degradation of central semantic concepts. However, phonological and orthographic representations of word forms in different languages will differ in strength, reflecting their frequency of use, and consequently the connections between heteromodal concepts within the semantic ‘hub’ in ATL and spoken and visual lexical forms in ‘spoke’ regions should also vary. In tasks involving semantically-driven lexical retrieval, this might give rise to different levels of impairment across languages in multilingual speakers, for languages that do not have the same degree of proficiency. This hypothesis stems from the well-established association between degradation of central conceptual representations and lexical deficits – for example, svPPA patients have more impaired verbal short-term memory and reading performance for items that have degraded conceptual representations (Hoffman, Jefferies, Ehsan, Jones, & Lambon Ralph, 2009; Jefferies, Bott, Ehsan, & Lambon Ralph, 2011; Jefferies, Grogan, Mapelli, & Isella, 2012; Jefferies, Jones, Bateman, & Lambon Ralph, 2005; Wilson et al., 2009; Woollams, Ralph, Plaut, & Patterson, 2007). While these studies show a high degree of consistency across language (and non-language) tasks, the capacity of the semantic system to drive the correct lexical response is assumed to partly depend on the strength of the target phonological or orthographic pattern within the relevant ‘spoke’. This is because, according to the hub and spoke account, knowledge is distributed across both components, and they mutually-constrain each other. Strong input from the hub is particularly needed when the target lexical representation is more weakly represented in the spoke region, in much the same way that conceptual degradation has a larger impact on the ability of patients with svPPA to read aloud words with irregular spellings (Graham, Patterson, & Hodges, 2000).

In bilinguals, Crinion et al. (2006) showed a dissociation between language-independent and language-dependent areas in semantic priming, consistent with the view that separable conceptual and lexical representations contribute to linguistic performance. In this study, bilinguals showed language-independent activation in the left ATL when they saw word-pairs that were semantically related, but language-specific activation in left caudate nucleus. This would suggest a certain degree of language dependency in lexical retrieval that depends on the strength of the lexico-semantic connections between L1 and L2 (Kroll & Stewart, 1994; Kroll, Van Hell, Tokowicz, & Green, 2010) and on the frequency of language usage (Gollan, Montoya, Cera, & Sandoval, 2008; for language-dependent effects on semantic priming: Basnight-Brown & Altarriba, 2007; Silverberg & Samuel, 2004; in bilingual aphasia: Sebastian, Kiran, & Sandberg, 2012; Siyambalapitiya et al., 2013)

In this study, we investigated the performance of an English-Catalan-Spanish trilingual individual with svPPA, to chart the effects of deteriorating conceptual knowledge on different languages in different tasks. We used a range of different tasks across languages, including word and sentence comprehension, picture naming**,** word translation, semantic priming of lexical decision and language switching measures. We would expect item-by-item consistency across languages, since the extent to which the representation of a particular concept is degraded should drive performance across all tasks (Patterson et al., 2006). However, we also considered whether there are potential differences in semantic 'access' between languages, in line with the observation that lexical retrieval is likely to be influenced by language proficiency and use (e.g., Abutalebi et al., 2008; 2012). We used a blocked cyclic naming task to determine the nature of this hypothesised access deficit. Conceptually-guided linguistic behaviour will involve interactions of heteromodal semantic representations with lexical represention s, which may vary in strength across languages. This may give rise to differences in the capacity to activate meaning across languages, and the capacity to drive word production from conceptual information. However, since semantic control processes are expected to be intact in svPPA, we would not expect declining semantic access following the repetiton of sets of semantically-related items.

In our previous study with bilingual aphasia patients, in which we used the semantic blocked cyclic naming task, we found an increased semantic interference in terms of the difference in naming latencies between pictures grouped by the same semantic category or different categories (Calabria, Grunden, Serra, García-Sánchez, & Costa, 2019). However, these patients had spared conceptual knowledge and their deficits in word production were more compatible with a 'control deficit', such as an excessive amount of inhibition during lexical retrieval over semantic competitors. This pattern of results is also similar to what is found in patients with semantic access deficits that they are unable to retrieve conceptual knowledge in certain circumstances (Jefferies & Lambon Ralph, 2006; Rapp & Caramazza, 1993; Thompson, Robson, Lambon Ralph, & Jefferies, 2015; Warrington & Cipolotti, 1996). That is, just as interactions between the ATL 'hub' and verbal and visual 'spokes' underpin conceptual computation, interactions between shared concepts and language-specific representations might underpin aspects of lexical-semantic 'access'.

2. Patient description

We report a 57-year-old woman English-Catalan–Spanish trilingual (TC). She was diagnosed with svPPA by experienced neurologists in neurodegenerative diseases in Barcelona (Spain). Her level of education was high (Bachelor's degree in Spanish and French from the United States) and she was editorial manager of a media company for thirty-five years. The patient was referred to the specialist because of progressive word-finding difficulties and problems in word comprehension (especially less frequent words) in the last year. This progressive deterioration of language was confirmed by her husband, who also reported mild behavioural symtoms such as mild disinhibition, hyperorality, stereotyped speech and impairment of irony and sarcasm comprehension. The patient met clinical criteria for the diagnosis of svPPA (Gorno-Tempini et al., 2011) and shortly after diagnosis, she stopped working due to language problems.

Language profile. TC's native language was English (close to 100% of language usage until the age of 18). Aged 18 years, she studied Spanish and French at a US University (although her language usage was still dominated by English). At the age of 21, she moved to Spain, and from 21-28 years she used English about 40-50% of the time, at work, and Spanish 50-60% of the time (at home and with her friends). From the age of 28, she started also to speak Catalan frequently with her husband and sons, and she reported using Catalan more than Spanish with friends. From this age, her language usage was approximately 40-50% English (at work), 40% Catalan and she only spoke Spanish rarely, with friends. Her husband reported that, before disease onset, TC was highly proficient both in Catalan and Spanish. At the time of testing, she reported feeling more comfortable speaking Catalan than Spanish. Her language proficiency in French was very low at the time of testing. For this reason, this language was not assessed. In summary, while her first-acquired language was English, her preferred second language at the time of testing was Catalan, and her third language was Spanish.

Neuropsychological assessment. TC's cognitive functioning was evaluated using tests of visuo-spatial ability, language, memory and attention (see Table 1). An experienced clinical neuropsychologist who is a proficient Catalan–Spanish bilingual performed the assessment, which used a published test battery (Sala et al., 2017). Catalan was used to give instructions, as TC stated this to be her preferential language for communicating. Spanish was used for those tests only available in Spanish (Buschke Selective Reminding Test, CERAD Test, some subtests of the Boston Diagnostic Aphasia Examination).

She scored in the normal range for all visuo-spatial tests. Long-term term memory was impaired both for verbal [Buschke Selective Reminding Test (Campo & Morales, 2004), delayed recall: 0/16; CERAD Test (Morris et al., 1989), delayed recall: 0/10] and non-verbal [Recall of the Rey-Osterriech Complex Figure (Palomo et al., 2012): 0/36] material. She showed difficulties switching between numbers and letters in the Trail Making Test (Tamayo et al., 2012) (157 seconds, 3 errors). Linguistic abilities were assessed with the Token Test and (Aranciva et al., 2012) the Boston Diagnostic Aphasia Examination (BDAE-Spanish version: García-Albea, del Viso Pabón, & Sánchez Bernardos (1996). Auditory comprehension was impaired (Token test: 13/36), especially for complex commands (4/12), and naming [16/30 from BDAE; also tested with the Boston Naming Testn (Peña-Casanova et al., 2009): 32/60]. Measures of repetition, reading, writing and articulation from the BDAE were spared when tested in Spanish, consistent with previous research showing that phonological skills are largely intact in SD (Jefferies et al., 2005; Jefferies, Crisp & Lambon Ralph, 2006; Reilly et al., 2007). Semantic judgements involving pictures were below the normal range for her age. On the picture-version of the Camel and Cactus Test (Bozeat, Lambon Ralph, Patterson, Garrard, & Hodges, 2000), she scored 30/64, well below the normal range (cut-off: 51/64). On the picture version of the Pyramids and Palm Trees Test (Howard & Patterson, 1992) she was slightly below normal performance (48/52), using normative data from Gudayol-Ferré et al. (2008). She was retested one year later and her score was unchanged.

TABLE 1 ABOUT HERE

Neuroimaging findings. MRI at the time of diagnosis revealed prominent atrophy of the left ATL (see Figure 1**).** The observed pattern of atrophy is consistent with the diagnosis of svPPA.

FIGURE 1 ABOUT HERE

3. Experimental tasks

The experimental software for all experiments was DMDX (Forster & Forster, 2003), and when necessary spoken responses were recorded and analysed off-line with Checkvocal (Protopapas, 2007). We first report two tasks used to assess comprehension at the single-word and sentence level. Next, we describe word production, including picture naming, word translation, and semantically-blocked cyclical naming tasks. These were first administrated during a period of three moths after the diagnosis ("baseline") and re-tested one year later during a second three-month period ("12-month follow-up"). Different languages were tested across different sessions. In the baseline period, we also assessed SC's linguistic control using language switching tasks that employed both pictures and digits, and during the 12-month follow-up period, we assessed semantic memory using associative primes within- and between-languages.

3.1. Word-picture matching task

Sixty pictures from six different semantic categories were selected from two databases (Snodgrass & Vanderwart, 1980; Szekely et al., 2004). Each picture was presented with three distractor pictures, which were semantically, phonological or visually related (similar shape) to the target picture. The target word was presented in the middle of the screen along with the pictures, and SC was asked to point to picture that matched the presented word. The word frequencies for Spanish names of the pictures were obtained from the LEXESP database (M = 9.38, range = .18-65.18) (Sebastian-Galles, Cuetos, Martı, & Carreiras, 2000), for Catalan from the Catalan Dictionary of frequencies (M = 1144.26, range = 15-16516) (Rafel i Fontanals, 1998), and for English from CELEX lexical database (M = 26.63, range = .39-387.88) (Baayen, Piepenbrock, & Gulikers, 1996). Only accuracy was collected as dependent variable.

At baseline, patient performance was almost flawless in this task across the three languages. Her word comprehension significantly declined over time for Spanish only (χ^2(1) = 4.81, $p < .05$) (See Table 2).

TABLE 2 ABOUT HERE

3.2. Sentence-picture matching task

Sentence comprehension was tested using a translation of the Italian version of the 'Batteria per l'Analisi dei Deficit Afasici—BADA' (Miceli, Laudanna, Burani, & Capasso, 1994). Sixty sentences were presented on the screen along with two pictures on each trial. TC was asked to point to one of two pictures that matched a written sentence. Half of the sentences were in the active voice (subject–verb–object form), half in the passive one. One of two pictures described the written sentence, while the alternative was a role reversal foil, a morphological or a lexico-semantic foil. For instance, for the sentence 'The girls applaud the boy', the role reversal foil represented a boy applauding the girls; the morphological foil represented a girl applauding the boy; the lexico-semantic foil represented the girls applauding a clown. These materials were taken from a previous study (Cotelli et al., 2007). The items in the pictures were very high frequency (e.g., dog, cat, rabbit, man, boy, girl etc.), which is expected to minimise the impairment in semantic dementia (Bird, Lambon Ralph, Patterson,

& Hodges, 2000; Jefferies & Lambon Ralph, 2006). Only accuracy was collected as dependent variable.

The patient scored similarly for the three languages (English: 83.3%; Catalan: 86.7%; Spanish: 83.3%; ps > .05) and she did not show a decline in sentence comprehension over time (see Table 3). These findings are consistent with the proposal that grammatical processing is largely preserved in svPPA (Grossman, Rhee, & Moore, 2005; Meteyard & Patterson, 2009).

TABLE 3 ABOUT HERE

3.3. Picture Naming

The patient was asked to name aloud a set of 60 pictures from six different semantic categories selected from two databases as in the word-picture matching task (Snodgrass & Vanderwart, 1980; Szekely et al., 2004). Each picture remained on the screen for a maximum of 5 seconds. Accuracy was collected as dependent variable. Errors were coded as 'omission'; 'semantic', when she produced a word semantically related to the target; 'cross-language intrusion', when she produced the correct word but in the non-requested language; and 'phonological paraphasia', when she deleted, substituted or added phonemes to the correct word related to the picture.

Accuracy. At baseline, an omnibus analysis showed a signifincant main effect of language naming (χ^2 (2) = 6.57, p < .05). TC's performance was significantly worse in Spanish (28.3%) compared to her first and dominant language English (58.3%, χ^2 (1) = 9.81, p < .001), but equivalent for English and Catalan (χ^2 (1) = .21, p = .65). SG's naming was also significantly better in Catalan (45.0%) than in Spanish (28.3%, χ^2 (1) = 2.91, p < .05). Also at the 12-month follow-up, naming performance was significantly different across languages (χ^2 (2) = 25.197, p < .001). Post-hoc comparisons showed that only naming in Spanish declined significantly between baseline and the 12-month follow-up (χ^2 (1) = 8.31, p < .001). Naming was substantially more impaired than word-picture matching, even for tests including the same items, in line with previous findings (Bozeat et al., 2000; Ralph, Graham, Ellis, & Hodges, 1998) – although, for Spanish, both tasks declined over time.

Since naming in svPPA is sensitive to word frequency and familiarity (Bozeat et al., 2000; Jefferies et al., 2007), we assessed the influence of these variables and visual complexity in the three languages, using a median split of the items (median values: word frequency = 8.88 (English), 4.73 (Spanish), 543.5 (Catalan); familiarity = 9.46 (English), 6.16 (Spanish); visual complexity = 2.84; see Table 4). Word frequency modulated TC's naming performance in English at baseline and in Catalan at 12 months ($p_s < .05$). Familiarity was found also to have an effect on naming accuracy in English and Catalan, both at baseline and 12 months ($p_s < .05$). Visual complexity did not significantly modulate naming performance.

TABLE 4 ABOUT HERE

Response consistency. Logistic regression analyses were performed to assess whether performance in one language would predict which trials were correct and incorrect in another language, and also to assess consistency across the two time points (baseline and 12 months). We also calculated contingency coefficients (C) as an additional measure of response consistency, in line with previous studies (e.g. Jefferies et al., 2007; Lambon Ralph, 1998).

The analyses were conducted for English and Catalan, since there were few correct responses in Spanish. At baseline, trial-by-trial naming accuracy in English predicted performance in Catalan (Wald = 7.18, $p < 0.05$; C = .30, $\chi^2(1) = 5.17$, $p < .01$), consistent with the view that central concepts are degrading in svPPA (Bozeat et al., 2000; Jefferies & Lambon Ralph, 2006). The same cross-language consistency was found 12 months later (Wald = 4.97, $p < 0.05$; C = .34, $\chi^2(1) = 7.63$, $p < .01$). There was also consistency across time in both languages (English: Wald = 13.82, $p < 0.001$; C = .46, $\chi^2(1) = 16.19$, $p < .001$; Catalan: Wald = 20.09, $p < 0.001$; C = .55, $\chi^2(1) = 26.52$, $p < .01$).

3.4. Word translation

Printed words were presented one at a time and the patient was asked to choose the translation in another language, from amongst four options. These were: a) the target; b) the same word in the non-required language (i.e., Spanish if the task was to translate from English to Catalan); c) a semantically-related word in the required language; d) a semantically-related word in the non-required language. The words to be translated (n=60) were the same as in the word-picture matching task. Half of the words were cognate between Spanish and Catalan, but there were all non-cognate words between Spanish and English and between Catalan and English. Given that the language direction of the task was from English to the other two languages and vice versa, we can exclude a cognate effect in this task, as it was never required to translate words from Spanish into Catalan or vice versa.

Word translation was tested forwards and backwards. In the forward condition, two tasks were used to test translation from English to Catalan and from English to Spanish. In the backwards condition, testing was in the reverse direction, from Catalan to English and Spanish to English.

Results. At baseline, TC performed similarly in backward and forward translation and across languages ($\chi^2(2) = .63$, $p = .73$). However, when TC's performance was compared across time we found significant decline in some conditions. Specifically, TC worsened at 12 months when she was required to translate from English to Catalan ($\chi^2(1) = 3.60$, $p < .05$) and from English to Spanish ($\chi^2(1) = 3.60$, $p < .05$), that is, only from her native to non-dominant languages (See Table 5).

TABLE 5 ABOUT HERE

3.5. Semantic blocked cyclic naming task

The task used 16 pictures from Snodgrass and Vanderwart (1980) (4 exemplars from 4 semantic categories – animals, vegetables, kitchen tools, and furniture) that TC was still able to name. Pictures were presented in two conditions: in 4 blocks containing semantically-related items (Homogenous) and in 4 blocks containing unrelated items (Heterogeneous). Each of the four pictures was presented four times (cycles) within each of the eight blocks (4 Homogenous and 4 Heterogeneous). We used an ABBA design for block order, meaning that two Homogenous blocks were followed by four Heterogeneous and two Homogenous blocks, and vice versa. In each trial, a fixation point was presented for 750 ms and then a picture appeared for up to 2000 ms or until a response was provided. The next trial commenced immediately. After each block, TC was allowed to rest. Before the experimental task, the patient was presented with the set of pictures along with a written name in the required naming language. This was done to reduce the number of omissions during testing and to exclude errors due to name disagreement. Written names were removed from the pictures during the cyclical task. TC was tested in her three languages in three different sessions separated by a week. Each language naming condition was repeated twice in order to have enough trials for analyses.

Reaction times (RTs). Only correct trials were included in the analysis and RTs exceeding three standard deviations above or below the mean were also excluded. We used generalized linear models to compare naming latencies for the three languages at baseline and follow-up separately. In the regression we included: semantic relatedness (heterogeneous vs. homogeneous), cycle (1, 2, 3, 4), language (English, Catalan, Spanish) and the interaction between cycle and languages.

At baseline, the model (χ^2 (9) = 97.41, $p < .001$) showed a significant effect of language (Wald χ^2 (2) = 50.82, $p < 0.01$) indicating that TC's naming latencies were faster in English (928 ms) than Spanish (1108 ms, $p < .001$) and Catalan (1164 ms, $p < 0.01$), but Spanish and Catalan were not different ($p = .11$). The effect of semantic relatedness was significant (Wald χ^2 (1) = 3.62, $p = .05$), indicating that naming latencies were slower in the Homogenous (1094 ms) than the Heterogeneous condition (1040 ms). Also, the effect of cycle was significant (Wald χ^2 (3) = 51.46, $p < .001$), indicating an effect of repetition between the first (1252 ms) and second cycle (1022 ms, $p <.001$). Naming latencies were not significantly different for the third (998 ms, $p = .55$) and fourth cycles (995 ms, $p = .92$). The interaction between language and cycle was not significant (Wald χ^2 (3) = 1.62, p = 0.66), indicating that repetion effects across cycles was similar for the three languages.

At follow-up time-point, the model (χ^2 (9) = 209.85, p < .001) showed that there was a significant effect of language (Wald χ^2 (3) = 231.29, p < .001) indicating that TC was faster to name in English (1094 ms) compared to Spanish (1716 ms, p < .001), but not compared to Catalan (1086 ms, p =.85). The main effect of cycle was significant (Wald χ^2 (3) = 34.46, p < .001), indicating an effect of repetition between the first (1474 ms) and second cycle (1287 ms, p <.001) and naming latencies did not differ significantly for the third (1212 ms, p = .11) and fourth cycle (1222 ms, p = .84). The effect of semantic relatedness (Wald χ^2 (1) = .17, p = .67) and the interaction between cycle and semantic relatedness (Wald χ^2 (3) = .88, p = .83) were not significant, suggesting that there was no effect of semantic blocking across languages.

FIGURE 2 ABOUT HERE

Accuracy. At baseline, TC was more accurate in naming in English (94.2%) compared to Catalan (84.2%, χ^2 (1) = 10.95, p < .001) and Spanish (83.6%, χ^2 (1) = 13.34, p < .001). Moreover, her naming performance in this task decreased over time only in Spanish from 83.6% to 50.8% (χ^2 (1) = 8.33, p < .05) (See Table 6). A logistic regression examined effects of cycle, semantic relatedness, and language but there were no significant main effects or interactions both at baseline and follow-up.

Response consistency. We performed additional logistic regression analyses to check whether performance on each item at baseline predicted performance on the same items 12 months later, and between languages. Baseline accuracy did not predict performance at 12 months in any language (English: Wald = 2.97, p = .08; C = .11, χ^2(1) = 3.19, p = .08; Catalan: Wald =1.67, p = .20; C = .08, χ^2(1) = 1.70, p = .19; Spanish: Wald = 1.46, p = .23; C = .26, χ^2(1) = 17.90, p < .001).

Analyses of response consistency between languages were conducted on naming accuracy for English and Catalan. Unlike standard picture naming, we failed to establish consistency across languages (Wald = 0.07, p = .78; C = .01, $\chi^2(1) = .07$, p = .78).

TABLE 6 ABOUT HERE

3.6. Associative priming

Two associative priming tasks were used to assess the integrity of semantic links in different languages. Participants are typically faster to indicate that “bread” is a word if it is preceded by a related word such as “butter” as opposed to an unrelated word, such as “table” (Francis, 1999, 2005). One of the organizational principles of semantic memory is spreading activation between semantically-related words. Two versions of the associative priming task were examined, one in which words were either strongly or weakly associated (version 1) and a second one with only strongly-associated word pairs but without cognates – i.e., linguistically-associated words with a shared origin (version 2).

Associative priming - version 1. Sixty associatively- and semantically-related pairs were selected from the University of South Florida Free Association Norms (Nelson, McEvoy, & Schreiber, 2004; http://w3.usf.edu/FreeAssociation/). According these norms, 30 word pairs were classified as highly associated (M= .55, SD= ±.13) and 30 word pairs as weakly associated (M= .19, SD= ±.06). The first word of each pair served as prime and the second one as target. An additional set of 60 pseudo-words were created in English by using the ARC Nonword Database (Rastle, Harrington, & Coltheart, 2002; http://www.cogsci.mq.edu.au/research/resources/nwdb/nwdb.html). The final set of stimuli included 120 word pairs in four categories: 15 highly associated word pairs, 15 weakly associated word pairs, 30 unrelated word pairs (employing different words) and 60 unrelated trials with pseudo-word targets. The task was repeated twice for each language so there were 30 strongly and 30 weakly-associated trials, 60 unrelated word trials (i.e., 120 word targets in total) and 120 pseudo-word targets in the analysis.

For the within-language condition, prime and target words were presented in English only. For the between-language conditions, in one session, primes were in English and targets in Catalan, and in other session, primes were in English and targets were in Spanish. Catalan and Spanish words were translated from English in order to maintain the same materials. Since time limitations prevented testing of all language combinations, we only presented primes in the dominant language and targets in the second language.

Each trial started with a fixation point displayed for 850 ms followed by a prime word for 200 ms and a target word displayed until a response was made or for a maximum of 2000 ms. In order to avoid visual after-effects, a mask of hash marks was presented for 500 ms between the prime and target. TC was asked to indicate if targets were words or not by pressing one of two keys. The target words were presented in uppercase whereas prime words in lowercase.

RTs. We examined the item-by-item effect of prime condition (highly associated, weakly associated, unrelated) with a one-way ANOVA for each language separately. There was a significant main effect of condition for English-English ($F(1, 98) = 3.06$, $p = .05$), but not for English-Catalan ($F(1, 100) = 0.32$, $p = .72$) or English-Spanish ($F(1, 98) = .09$, $p = .76$). Post-hoc analysis for the English-English trials showed that only highly associated word pairs were significantly different from the other conditions ($p < .05$; see Table 7).

Accuracy. Accuracy was high in the three language conditions for both words (English-English: 83.3%; English-Catalan: 86.7%; English-Spanish: 83.5%) and pseudo-words (English-English: 91.7%; English-Catalan: 85.3%; 93.3%). A logistic analysis was performed, including prime condition (highly associated, weakly associated, unrelated), language condition (English-English, English-Catalan, English-Spanish) and word type (word vs. pseudo-words). The results showed that accuracy was not explained by these variables ($\chi^2(3) = 2.33$, $p = .51$).

Associative priming - version 2. TC showed facilitation of lexical decision with strongly- but not weakly-associated primes, but only when targets were presented in English. In version 2, we replicated this effect with a new set of stimuli and excluded cognates (to eliminate possible phonological effects between language and word pairs). We therefore selected 40 word pairs without any possible phonological overlap between the three languages; twenty of them were highly-associated (M= .51, SD= ±.131) and twenty were unrelated. To create unrelated trials, 40 pseudo-words were paired with 40 additional words. Other aspects of the procedure were as for version 1.

RTs. One-way ANOVA was used to examine the effect of prime type (related vs. unrelated), for each language separately. Again, this effect was significant for English-English pairs ($F(1, 30) = 5.66$, $p < .05$) but not English-Catalan ($F(1, 30) = 0.29$, $p = .59$) or English-Spanish ($F(1, 30) = .39$, $p = .56$) pairs.

Accuracy. Accuracy was high in the three language conditions for both words (English-English: 82.5%; English-Catalan: 85.7%; English-Spanish: 90.5%) and pseudo-words (English-English: 92.5%; English-Catalan: 90.3%; 95.3%). A logistic analysis was performed by including prime condition (associated vs. unrelated), language condition (English-English, English-Catalan, English-Spanish) and word type (word vs. pseudo-words). The results showed that accuracy was not explained by these variables ($\chi^2(3) = 5.18$, $p = .14$).

To summarize, effects of associative priming were only found for the dominant language (English) when compared to non-dominant languages (Catalan and Spanish) and for highly associated word pairs.

TABLE 7 ABOUT HERE

3.7. Language switching task

In a final study, we examined the capacity to switch between languages. We used a language switching task employed in previous studies of bilingual healthy participants (Calabria, Hernández, Branzi, & Costa, 2012; Calabria, Branzi, Marne, Hernández, & Costa, 2015) and pathological populations (Calabria, Marne, Romero-Pinel, Juncadella, & Costa, 2014; Cattaneo et al., 2015). We examined switching between both objects and number words in two language – English and Catalan – and examined the number of errors as an index of control failure (Calabria et al., 2014). This task was employed to test the role of the ATL in language switching. Indeed, the ATLs, the focus of atrophy in svPPA, are not thought to contribute to language switching (Abutalebi & Green, 2007; 2016; Calabria, Costa, Green, & Abutalebi, 2018) - rather left caudate, left inferior frontal gyrus, and middle temporal gyrus are implicated (Coderre, Emily, Smith, Jason, van Heuven, & Horwitz, 2015; Garbin et al., 2011; Luk, Green, Abutalebi, & Grady, 2011). Therefore, we expected that TC would not be impaired at this task, since deficits in language switching are more associated with dysfunction in frontal-striatal connections (Cattaneo et al., 2015; Cattaneo, Costa, Gironell, & Calabria, 2019) or lesions in basal ganglia (Mariën, Abutalebi, Engelborghs, & De Deyn, 2005).

3.7.1. Pictures

Eight pictures of objects were selected from Snodgrass & Vanderwart (1980). The patient was required to name the picture in English or Catalan, indicated by a Catalan or American flag, presented alongside the picture. There were two types of trials: a) naming the picture in the same language as the preceding trial (repeat trial), b) naming in a different language from the previous trial (switch trial). There were a total of 320 trials divided in two blocks with 160 trials each. The total distribution of trials was: 128 repeat trials in Catalan, 128 repeat trials in English, 32 switch trials in Catalan and 32 in English. The picture appeared for 3000 ms and the patient was asked to name the picture as fast as possible. The experiment started with a practice session of 10 trials.

RTs. The item analysis showed a significant effect of type of trial ($F (1,7) = 24.72$, $p< .01$) indicating that TC was slower in switch (1594 ms) than repeat (1195 ms) trials. However, her naming latencies were the same for Catalan (1396 ms) and English (1393 ms) ($F (1,7) = 0.05$, $p = .83$). The interaction between language and type of trial was not significant ($F (1,7) = .09$, $p = .76$), suggesting the magnitude of the switch costs for the two languages was the same.

Accuracy. She produced a similar number of errors in switch trials (n= 7/64, 10.9%) and repeat trials (24/256, 9.4%; χ^2 (1) = 0.14, p = .70) suggesting that she did not have a major deficit of language switching. Also, the error rate for English (18/160, 10.0%) and Catalan (15/160, 9.4%) was the same (χ^2 (1) = 0.30, p= .58). The errors comprised 7.8% omissions and 1.9% cross-language intrusions.

Also, we performed a logistic regression analysis to check whether performance in English predicts that in Catalan, and the results showed that there was response consistency between languages (Wald = 4.04, p < .05).

3.7.2. Digits

While many of the errors above would have reflected the degradation of conceptual knowledge in TC, number knowledge has been shown to be relatively intact in SD (Cappelletti, Kopelman, & Butterworth, 2002; Jefferies, Bateman, & Lambon Ralph, 2005; Julien, Thompson, Neary, & Snowden, 2008) and this supports linguistic processing (Jefferies, Patterson, Jones, Bateman, & Lambon Ralph, 2004). We therefore examined language switching in a task employing Arabic digits. Deficits in this task should more directly reflect impaired control.

The patient named the digits (1, 2, 3, 4, 5, 7, 8, 9) in English or Catalan [English/Catalan names: 'One'/'Un'; 'Two'/'Dos'; 'Three'/'Tres'; 'Four'/ 'Cuatre'; 'Five'/'Cinc'; 'Seven'/'Set'; 'Eight'/'Vuit'; 'Nine/ 'Nou']. As before, there were two types of trials: a) naming the digit in the same language as the preceding trial (repeat trial), b) naming in a different language (switch trial). There were 160 trials with 64 repeat trials in English, 64 repeat trials in Catalan, 16 switch trials in English and 16 in Catalan. Other methodological details are as above.

RTs. The item analysis showed a significant effect of type of trial (F (1, 7) = 20.43, p< .01) indicating that TC was slower in switch (1117 ms) than repeat (861 ms) trials. However, her naming latencies were the same for Catalan (1024 ms) and English (955 ms) (F (1,7) = 1.12, p = .32). The interaction between language and type of trial was not significant

(F (1,7) = .36, p= .57), suggesting the magnitude of the switch costs for the two languages was the same.

She produced few errors in both switch (n= 3/32, 9.4%) and repeat trials (5/128, 3.9%; χ^2 (1) = 0.66, p= 0.42). There was also no difference in errors between English (5/80; 6.2%) and Catalan (3/80; 3.8%) (χ^2 (1) = 0.53, p= 0.47).

4. Discussion

We had a rare opportunity to study the impact of conceptual degradation in a trilingual patient with svPPA across languages. We assessed different aspects of linguistic processing across English, Spanish and Catalan – including syntax, word recognition and production, translation, conceptual representation and language switching. The patient showed the classic hallmarks of a semantic storage deficit, in line with the expected pattern in svPPA. However, she also had greater difficulties accessing the meaning of words in one of her non-dominant languages (Spanish) across multiple tasks. Below, we discuss how this access deficit might arise and what it reveals about the neurocognitive components that underpin language processing.

4.1. Evidence for degraded conceptual knowledge

There was significant consistency between languages in the items that were relatively well-understood and more semantically degraded, at least in a standard picture naming task. Similarly, svPPA or SD patients typically show difficulties on the same items across verbal and non-verbal tasks (Bozeat et al., 2000; Jefferies & Lambon Ralph, 2006). This is consistent with the view that central concepts are degrading in svPPA, and these are accessed by multiple languages and modalities, which are then all affected in parallel ways. fMRI studies of healthy bilinguals similarly show overlapping brain regions are implicated in the processing of word meaning across languages, in areas that have been related to semantic cognition (Buchweitz et al., 2012; Correia et al., 2014). Studies also show language-independent processing of semantic associations in the ATLs (Crinion et al., 2006). Also, these results agree with bilingual models of word production which anticipate that conceptual knowledge is shared across languages (Branzi, Calabria, & Costa, 2018), irrespective of the mechanisms underlying lexical retrieval, such as whether this is mediated by competition or not.

In addition, in line with previous reports, this patient showed an influence of frequency/familiarity in the concepts that she understood relatively well and poorly: this is another of the hallmarks of semantic ‘storage’ deficits (Bozeat et al., 2000; Jefferies & Lambon Ralph, 2006; McCarthy & Warrington, 1994; Warrington & Cipolotti, 1996). Frequent concepts appear to be relatively robust in the face of semantic degradation, perhaps because they form stronger representations following more learning experiences, and because they continue to be encountered and re-learned as the semantic store degenerates. In contrast, patients with semantic access deficits typically have absent or reversed effects of frequency (Almaghyuli, Thompson, Lambon Ralph, & Jefferies, 2012; Hoffman et al., 2009; Hoffman, Rogers, & Ralph, 2011; Jefferies & Lambon Ralph, 2006), which reflects the fact that high-frequency words have greater contextual diversity – they are encountered in a wider range of circumstances and this increases the need to selectively focus retrieval on currently-relevant aspects of knowledge pertaining to these words. Nevertheless, there were also performance differences between languages, which might be explained in terms of how readily lexical access can be achieved from these degraded sematic representations.

4.2. Evidence for dissociations across and within languages

Many language skills were largely intact across languages. In particular, sentence-to-picture matching did not show a deterioration over time in any language, at least when high-frequency vocabulary was used. This suggests that this patient had broadly intact verbal short-term memory and syntax. These aspects of language are already known to be largely spared in svPPA (Breedin & Saffran, 1999; Jefferies et al., 2011; Jefferies, Jones, Bateman, & Lambon Ralph, 2004; Jefferies, Jones, et al., 2005; Jefferies, Patterson, et al., 2004; Patterson, Tyler, & Hodges, 1994), consistent with fMRI studies which implicate ventral frontal and temporoparietal cortex in these functions, as opposed to the ATLs. In contrast, tasks that tapped word knowledge, including word-picture matching and picture naming, showed greater deterioration, especially when tested in Spanish. Likewise, in the word translation task, performance deteriorated over time when non-native words had to be retrieved from concepts presented in English, and not vice versa. These results suggest an interaction between the degradation of conceptual knowledge and lexical retrieval in this patient. Since there was clear evidence of semantic but not lexical weakness in this individual, we anticipate that conceptual deterioration had a greater influence on the retrieval of word forms for non-dominant languages.

Patients with svPPA can have problems driving speech production from meaning, even while word-picture matching remains relatively good (e.g., Lambon Ralph, Mcclelland, Patterson, Galton, & Hodges, 2001; Ralph et al., 1998). This pattern is thought to arise because picture naming is a less-constrained task and therefore more vulnerable to degradation of lexical-semantic knowledge. The weakness of word forms for non-dominant languages might exacerbate retrieval difficulties in a similar way.

A related pattern was also observed in a priming paradigm involving lexical decision. A difference between strongly and weakly-associated primes was only found when the target words were presented in English. This suggests that the processing of orthographic forms was less readily influenced by patterns of spreading conceptual activation in non-native languages. Patients with SD have greater loss of knowledge about weak than strong associations (Jefferies & Lambon Ralph, 2006), and the performance of patient TC is consistent with this, as she failed to show any semantic priming for weak associations – they were equivalent to unrelated prime trials, even when tested in English. Moreover, the fact that the effect of semantic priming was restricted to the within-language condition might reflect processing within brain areas that were not affected by the disease. Crinion et al. (2006) found that the left caudate, one subcortical area that was spared in our patient, was responsive to semantically-related word pairs only when bilinguals performed the task in a within- but not cross-language condition. Cross-language priming might require greater engagement of ATL and therefore TC did not show priming when English words primed the other two non-dominant languages (Spanish and Catalan).

The three languages spoken by this patient allowed a natural separation of the influence of age-of-acquisition (AoA) and recent frequency of language usage, two factors that are thought to contribute to the degree of language deterioration in bilingual patients with semantic deficits and dementia (for a review on bilingual AD patients, see Stilwell, Dow, Lamers, & Woods, 2015; for bilingual SD patients, see Chitnis, Bhan, Alladi, Rupela, & Ray, 2010; Hernández et al., 2008, 2010; Mendez et al., 2004). English was TC's native language; in contrast, Catalan was acquired later in life although used more frequently during several years before the time of testing. Catalan showed performance advantages over Spanish, another late-acquired language, in many tasks, including picture naming and word-picture matching, suggesting that ongoing use of words helps to protect the capacity to generate phonological forms from degrading concepts. In some tasks (translation, cyclical naming), there was also better performance for English than Catalan, revealing an influence of AoA. English was better than Catalan in the semantic blocked cyclic naming task at baseline, although at follow-up TC's naming latencies were the same for these two languages. Taken together, these findings suggest that the processing advantages enjoyed by a native language are not necessarily eradicated by later lack of use, since at the time of testing, TC preferred to converse in Catalan.

Finally, the reduced or null effects of semantically-related items which act as distractors in the cycling naming task might reflect degradation of semantic knowledge. In our study with Catalan-Spanish biliguals with aphasia we found a negative effect of semantically-related items when they named in their L2, compared to healthy individuals (Calabria et al., 2019). This effect was interpreted as difficulty in the face of semantic competition that possibly reflected excessive inhibition of targets, or ongoing activation of distractors which were targets on previous trials (Jefferies et al., 2007; McCarthy & Kartsounis, 2000; Schnur, Schwartz, Brecher, & Hodgson, 2006). That is, the semantic similarity among items was thought to increase the spread of competition or inhibition, making the target items less accessible. In our svPPA patient, conceptual degradation might be expected to reduce this semantically-mediated spreading activation, such that semantically-related items no longer act as strong competitors. Therefore, lexical retrieval was not significantly modulated at the semantic level (Nozari & Novick, 2017), possibly because semantic categories were partially degraded.

In summary, the results suggest that the ability to retrieve phonological forms referring to concepts was impaired in TC, while other aspects of language such as syntax and verbal short-term memory were largely preserved – there was a dissociation between different aspects of language processing, in line with studies of monolingual participants with svPPA. Consequently, significant differences between dominant and non-dominant languages were largely restricted to tasks that involved generating the phonological forms of concepts. When the phonological forms corresponding to partially-degraded concepts had strong representations (i.e., in native English), difficulties driving phonological access from meaning were attenuated, perhaps because the relative strength of the phonological representation helped to drive a mutually-reinforcing pattern of interactive-activation between semantic and phonological codes. An alternative interpretation involving degradation of the word forms themselves is not consistent with the significant item-by-item consistency across languages which we also observed.

<u>4.3. Lexico-semantic access vs. bilingual language control</u>

Recent studies have shown that semantic access deficits can arise for at least two reasons: first, there can be a breakdown in the pathway from a specific input modality to conceptual representations, and second, there can be a failure to control conceptually-driven lexical retrieval, so that it is appropriate for the current task (Thompson et al., 2015). For example, patients with Wernicke's aphasia show a modality effect in cyclical matching tasks – they can access concepts better from pictures than words, suggesting they have difficulty driving semantic access from words. In contrast, patients with semantic aphasia and deregulated conceptually-driven lexical retrieval have equivalent difficulties across modalities (Gardner et al., 2012), yet declining comprehension across cycles when the same items are tested repeatedly. This is thought to reflect difficulties overcoming strong competition from recently-selected items that are now distracters and selecting previous distractors that are now targets. These findings are consistent with the claim that semantic control mechanisms, a bit like conceptual representations, are shared between modalities (Gardner et al., 2012; Jefferies, 2013; Krieger-Redwood, Teige, Davey, Hymers, & Jefferies, 2015; Noonan, Jefferies, Visser, & Lambon Ralph, 2013).

In the current study, degradation of semantic representations likely due to neurodegeneration in the ATLs had somewhat different effects on the abilities to switch between languages. The ATLs, the focus of atrophy in svPPA, are not thought to contribute specifically to bilingual language control (Abutalebi & Green, 2008, 2016; Calabria, Costa, Green, & Abutalebi, 2018) and language switching. Instead, left caudate, left inferior frontal gyrus, and middle temporal gyrus are implicated (Coderre, Emily et al., 2015; Garbin et al., 2011; Luk et al., 2011) that also support semantic control (Davey et al., 2016; Noonan et al., 2013). In line with these observations, TC could perform the language switching task largely without errors, suggesting the ATLs are not a critical region for this form of control. In contrast, an earlier study found a very different pattern in a bilingual patient with poor bilingual language control control deficits but without semantic memory impairment (Calabria et al., 2014). This result adds neuropsychological evidence that at least ATLs are not crucial for the control of the two languages in bilinguals and it supports the dissociation between semantic control and bilingual language control (for evidence that the semantic interference is blind to language in bilinguals, see Runnqvist, Strijkers, Alario, & Costa, 2012).

In conclusion, the results suggest that semantic degradation interacts with lexical representations, giving rise to some degree of semantic access deficit for non-dominant languages in svPPA, even though the primary impairment is to conceptual representations. Nevertheless, this type of semantic access deficit clearly dissociates from deregulated semantic cognition.

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Disclosure of interest

The authors report no conflict of interest

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Table 1 - TC's performance on neuropsychological tests

Name of test	Score	
Minimental State Examination	24/30	in normal range
Visual and visuo-constructional abilities		
Rey–Osterrieth Complex Figure - Copy	29/36	in normal range
Poppelreuter Test - part 1	5/5	in normal range
Poppelreuter Test - part 2	5/3	in normal range
Visual Object and Space Perception Battery		
Number localization	10/10	in normal range
Letter identification	19/20	in normal range
Language		
Token Test	13/36	**impaired**
Phonetic Fluency	2	**impaired**
Semantic Fluency	9	**impaired**
Boston Naming Test	32/60	**impaired**
Fluency		
Phrase Length	6/7	in normal range
Melodic Line	7/7	in normal range
Grammatical Form	7/7	in normal range
Articulation		
Nonverbal Agility	12/12	in normal range
Verbal Agility	14/14	in normal range
Auditory Comprehension		
Basic Word Discrimination	69.5/72	in normal range
Commands	8/15	**impaired**
Complex Ideational Material	4/12	**impaired**
Naming		
Responsive Naming	16/30	**impaired**
Special categories - Animals	8/12	in normal range
Reading		
Oral Word Reading	30/30	in normal range
Oral Sentence Reading	10/10	in normal range
Repetition		
Words	10/10	in normal range
Sentences	8/10	in normal range
Recitation and music	2/2	in normal range
Automatized Sequences	7/8	in normal range
Recitation	0/2	**impaired**
Melody	2/2	in normal range
Rhythm	2/2	in normal range
Writing		
Simple Dictation	15/15	in normal range
Oral Spelling	10/10	in normal range
Written Picture Naming	7/10	in normal range
Sentences	9/12	in normal range

Short-term memory		
Forward Digit Span	7	in normal range
Backward Digit Span	3	in normal range
Long-term episodic memory		
Buschke Selective Reminding Test		
Short-term retrieval	12/48	**impaired**
Long-term retrieval	4/16	**impaired**
Delayed Recall	0/16	**impaired**
CERAD Test		
Recall	0/10	**impaired**
Retrieval	20/20	in normal range
Rey–Osterrieth Complex Figure - Recall	0/36	**impaired**
Semantic Memory		
Pyramids and Palm Trees Test	48/52	**impaired**
Executive functions		
Trial Making Test part A	19	in normal range
Trial Making Test part B	157	**impaired**

Table 2 – TC's performance in the word-picture matching task

	Baseline		12-months follow-up	
	%	*N*	*%*	*N*
English	98.3%	59/60	98.3%	59/60
Catalan	96.7%	58/60	93.3%	56/60
Spanish	98.3%	59/60	88.3%	53/60

Table 3 - TC's performance in the sentence-picture matching task

	Baseline		12-months follow-up	
	%	*N*	*%*	*N*
English	**83.3%**	50/60	**80.0%**	48/60
Errors				
Role reversal foil	8.3%	5	8.3%	5
Morphological foil	5.0%	3	8.3%	5
Lexico-semantic	3.4%	2	3.4%	2
Catalan	**86.7%**	52/60	**86.7%**	47/60
Errors				
Role reversal foil	8.3%	5	6.7%	4
Morphological foil	1.7%	1	11.6%	7
Lexico-semantic	3.4%	2	3.4%	2
Spanish	**83.3%**	50/60	**83.3%**	50/60
Errors				
Role reversal foil	10.0%	6	1.7%	1
Morphological foil	5.0%	3	13.3%	8
Lexico-semantic	1.7%	1	1.7%	1

Table 4 - TC's performance (accuracy) in the picture naming task

	Baseline		12-months follow-up	
English	***%***	***N***	***%***	***N***
Correct Responses	58.3%	35/60	46.7%	28/60
Omissions	30.0%	18/60	45.0%	27/60
Semantic errors	11.7%	7/60	8.3%	5/60
Catalan				
Correct Responses	45.0%	27/60	38.3%	23/60
Omissions	28.3%	17/60	46.7%	28/60
Semantic errors	21.7%	13/60	15.0%	9/60
Cross-lang.	5.0%	3/60		
Spanish				
Correct Responses	28.3%	17/60	6.7%	4/60
Omissions	65.0%	39/60	91.7%	55/60
Semantic errors	21.7%	4/60	1.6%	1/60

Linguistic variables (Frequency, Familiarity, Visual complexity)

	Baseline		12-months follow-up	
English	***High***	***Low***	***High***	***Low***
Frequency	76.7%	30.0%	53.3%	36.7%
Familiarity	76.7%	30.0%	60.0%	30.0%
Visual complexity	56.6%	60.0%	40.0%	50.0%
Catalan	***High***	***Low***	***High***	***Low***
Frequency	50.0%	40.0%	53.3%	23.3%
Familiarity	56.6%	33.3%	56.6%	20,.0%
Visual complexity	43.3%	46.7%	33.3%	43.3%
Spanish	***High***	***Low***	***High***	***Low***
Frequency	26.7%	30.0%	6.7%	6.7%
Familiarity	33.3%	23.3%	3.3%	10.0%
Visual complexity	36.3%	20.0%	6.7%	6.7%

Table 5 - TC's performance (accuracy) in the word translation task

	Baseline		at 12 months	
	%	*N*	*%*	*N*
Forward translation				
English to Catalan (CR)	**83.3%**	50/60	**66.7%**	40/60
Errors				
Semantic	11.7%	7/60	21.7%	13/60
Cross-language intrusions	5.0%	3/60	11.6%	7/60
English to Spanish (CR)	**83.3%**	50/60	**66.7%**	40/60
Errors				
Semantic	13.4%	8/60	28.3%	17/60
Cross-language intrusions	3.3%	2/60	5.0%	3/60
Backward translation				
Catalan to English (CR)	**80.0%**	48/60	**81.7%**	49/60
Errors				
Semantic	20.0%	12/60	18.3%	11/60
Cross-language intrusions	-		-	
Spanish to English (CR)	**79.7%**	46/60	**70.0%**	42/60
Errors				
Semantic	23.3%	14/60	30.0%	18/60
Cross-language intrusions	-		-	

Table 6 – TC's performance (accuracy) in the semantic blocked cyclic naming task

English	**Baseline**		**12 months**	
	%	**N**	**%**	**N**
Homogeneous	96.8%	124/128	90.6%	116/128
Heterogeneous	92.9%	119/128	93.7%	120/128
Catalan	**%**	**N**	**%**	**N**
Homogeneous	82.8%	106/128	82.1%	105/128
Heterogeneous	86.7%	111/128	89.1%	114/128
Spanish	**%**	**N**	**%**	**N**
Homogeneous	82.1%	105/128	45.3%	58/128
Heterogeneous	85.2%	109/128	56.2%	72/128

Table 7 - TC's performance (RTs and priming effects) in the two versions of the associative priming task

Version 1

	English-English	English-Catalan	English-Spanish
Highly associated	1424 (283)	1904 (570)	1949 (727)
Weakly associated	1717 (442)	1949 (501)	1884 (571)
Unrelated	1788 (583)	1979 (505)	1942 (687)
Priming Highly (ms)	363	75	-7
Priming Weakly (ms)	71	30	58

Version 2

	English-English	English-Catalan	English-Spanish
Highly associated	1212 (119)	1499 (215)	1449 (225)
Unrelated	1385 (258)	1445 (324)	1420 (245)
Priming (ms)	173	-54	26

Figure captions

Figure 1.

Magnetic resonance imaging findings. Top-panel: Magnetic resonance image of the patient showing cerebral altrophy of the ATL (dashed rectangles). **Bottom-panel:** Single-subject cortical thickness analysis on Freesurfer v6.0. The areas with cortical thinning of the patient compared to a group of 15 healthy controls are marked in blue. Only clusters that survived family-wise error correction P<0.05 are shown.

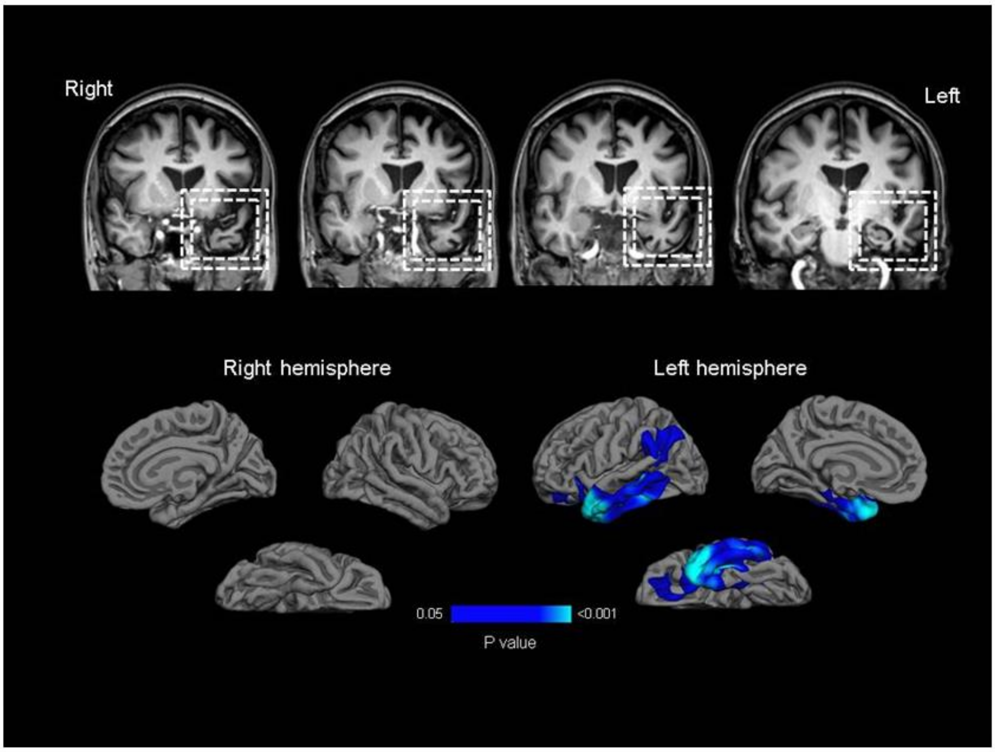

Figure 2.

Naming latencies in semantic blocked cyclic naming task broken by languages, semantic condition, and time-points.