A case study about the interplay between language control and cognitive abilities in bilingual differential aphasia: Behavioral and brain correlates

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Abstract

The current study examines the hypothesis that differential aphasia may be due to a problem with language control rather than with language-specific impairment and how this is related to non-linguistic cognitive control abilities. To this end, we report a case study of an L2 dominant French-English bilingual aphasia patient with larger impairments in French than in English. We assessed cross-language interactions using cognates in three lexical decision (LD) tasks, and non-linguistic cognitive control with a flanker task. We also examined functional connectivity between brain regions crucial for language control and language processing. We observed the preservation of cognate effects in a generalized lexical decision task requiring little language control, which indicates intact functionality (and cross-lingual interactivity) of lexical representations. On the other hand, we found diminished linguistic as well as non-linguistic control abilities, suggesting a domain general control impairment. Resting-state functional Magnetic Resonance Imaging (rs-fMRI) analysis revealed altered connectivity between the patient's language control and processing network, consistent with the behavioral data. Altogether, these results are in line with the hypothesis that differential aphasia may originate from general cognitive control difficulties.

Keywords: Differential aphasia, non-linguistic control, inhibition, bilingualism, language control, functional connectivity

1. Introduction

In these times of globalization and cultural exchange, the prevalence of bilingualism is constantly increasing and today more than half the world's population is considered to be bilingual (Grosjean, 2010). It is well documented that bilinguals experience cross-language activation when conducting a task that in essence only requires one language (Colomé, 2001; Costa & Caramazza, 1999; Costa & Santesteban, 2004; Duyck, Van Assche, Drieghe, & Hartsuiker, 2007; Kaushanskaya & Marian, 2007; Meuter & Allport, 1999; Van Assche, Duyck, Hartsuiker, & Diependaele, 2009). Most of these studies have included experiments using cognates. Cognates are words that share their meaning and their orthography and/or phonology between two different languages (e.g., the Dutch-English example *film-film* (shared orthography and phonology) or *appel-apple* (shared phonology and large orthographic overlap)). Typically, bilinguals are faster in recognizing cognates compared to noncognates, a phenomenon known as the cognate facilitation effect (Duyck, et al., 2007; Van Hell & Dijkstra, 2002), which reveals activation of multiple languages during word recognition.

1.1. Consequences of bilingualism for the cognitive system

Bilingualism, and the resulting continuous activation of multiple languages, has positive consequences for the cognitive system, above and beyond the advantage of speaking more than one language (e.g., Bialystok, 2010; Bialystok, 2011; Bialystok & Barac, 2012; Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Craik, & Luk, 2008; for review see Bialystok, Craik, Green, & Gollan, 2009). According to the inhibitory control model (Green, 1998), this bilingual advantage is a consequence of the continuous need to inhibit the (lexical) activation of the non-target language while producing or comprehending speech in the target language. How this language control is accomplished, however, is still under debate (Costa & Santesteban, 2004; Costa, Santesteban, & Ivanova, 2006; Dijkstra & Van Heuven, 2002; Gray & Kiran, 2016; Green, 1998; Hermans, Bongaerts, De Bot, & Schreuder, 1998). It is still not clear whether the mechanism that controls this cross-language activation is specific to the language domain or whether it extends to the entire cognitive system. Bilingualism has been shown to increase language abilities, like novel word learning (Kaushanskaya & Marian, 2009; Papagno & Vallar, 1995), but many researchers observed an advantage outside the language domain for bilinguals over monolinguals as well. For instance, bilingualism has been found to improve non-verbal cognitive control skills (e.g., Bialystok, 2010, 2011; Bialystok, et al., 2004; Bialystok, et al., 2008; Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Costa, Hernández, & Sebastián-Gallés, 2008) and to protect against cognitive decline by aging or Alzheimer’s dementia (Bialystok, et al., 2004; Craik, Bialystok, & Freedman, 2010; Woumans, et al., 2015). Although some authors contest the bilingual advantage (e.g., Paap & Greenberg, 2013; Paap, Johnson, & Sawi, 2015; Paap & Sawi, 2014), perhaps the strongest evidence available for a non-linguistic control advantage is the meta-analysis of de Bruin, Treccani, and Della Sala (2015), who reported a modestly-sized, but significant difference between monolinguals and bilinguals. The observation of a bilingual advantage suggests that linguistic and non-linguistic control abilities are linked to an at least partly shared system, although some researchers also argued for two distinct control processes (Calabria, Branzi, Marne, Hernández, & Costa, 2015; Calabria, Hernández, Branzi, & Costa, 2012; Magezi, Khateb, Mouthon, Spierer, & Annoni, 2012; Weissberger, Wierenga, Bondi, & Gollan, 2012). Altogether, these findings seem to suggest that language control and non-linguistic cognitive control are not fully independent, but it is still a matter of debate whether they refer to a single, domain general control mechanism or whether they can be considered as two domain-specific mechanisms.

1.2. The control hypothesis in differential aphasia

In the present study, we aimed to investigate the above concepts of language control and non-linguistic control in a bilingual patient with differential aphasia. Aphasia is defined as a disturbance in understanding, formulating or using verbal messages and it is caused by a brain dysfunction in language-related brain areas (Damasio, 1992). Until recently, most research on aphasia focused on the representation and use of one single language. Also in neuropsychological or logopaedic practice, knowledge or impairments in other known languages are often not considered, neither in diagnostics nor in therapy. However, as more and more people nowadays are bilingual, also the number of bilinguals suffering from aphasia is growing (Faroqi-Shah, Frymark, Mullen, & Wang, 2010). Research conducted so far showed that bilingual patients with aphasia do not always recover their native (L1) and second language (L2) to the same degree (Giussani, Roux, Lubrano, Gaini, & Bello, 2007) in the sense that different recovery or impairment patterns can be identified (Paradis, 1977, 2004). One such pattern, which is the focus of the current study, is differential aphasia. In bilinguals with differential aphasia, the patients have difficulties in both languages, but one language is more severely impaired than the other.

Given the important assumption that bilinguals have one integrated lexicon that contains word representations of both languages that are always simultaneously active (Van Heuven, Dijkstra, & Grainger, 1998), it seems hard to conceive how brain damage to a language area could result in more pronounced impairments in one of the languages in particular, or why bilinguals with aphasia sometimes better recover one language than the other. A number of researchers therefore proposed that better recovery of one language may be a consequence of language control deficiencies rather than of the loss of linguistic knowledge or lexical representations (e.g., Abutalebi & Green, 2007; Abutalebi, Rosa, Tettamanti, Green, & Cappa, 2009; Aglioti, Beltramello, Girardi, & Fabbro, 1996; Pitres, 1895; Verreyt, De Letter, Hemelsoet, Santens, & Duyck, 2013). Accordingly, a control-related brain lesion may affect the activation and inhibition levels of (words in) one language more than the other, so that the preserved functionality of languages differs.

Although this control hypothesis has the potential to explain how languages may be affected in a different way in bilingual aphasia, thus far there has only been sparse evidence for preserved linguistic knowledge and loss of language control in bilingual aphasia. At least, some evidence of preserved linguistic representations was found in patients with parallel aphasia, a recovery pattern of aphasia where both languages are equally impaired (Detry, Pillon, & De Partz, 2005; Roberts & Deslauriers, 1999; see Verreyt, et al., 2013, for a review). These studies reported better recognition of cognates compared to noncognates, which indicates that, although a language might be impaired, it may still be sufficiently active to influence the processing of the other language.

Evidence for the impact of cognitive control on (differential) aphasia is more rare. According to Abutalebi and Green (2007), language control involves the same neural network as non-linguistic cognitive control. This language control network consists of the anterior cingulate cortex (ACC), the pars orbitalis (Brodmann area (BA)47) and the head of caudate (HC). The ACC has been shown to contribute in response monitoring, but also in language switching, language selection and in cross-linguistic conflict resolution. BA47 is important for response control in general, such as response selection and suppression (Green & Abutalebi, 2013). Finally, the HC is assumed to be important for translation, language selection and switching in production and in comprehension. However, the HC also plays a key role in non-linguistic cognitive functioning, such as in goal-directed behavior (Grahn, Parkinson, & Owen, 2009). See Abutalebi and Green (2016) for an extensive overview of the functionality of each of these brain areas.

If the same neural network is responsible for linguistic and non-linguistic control, non-linguistic control abilities should be affected when linguistic control is impaired. At present, there are only a few studies that examined (impairments in) non-linguistic cognitive control in bilingual aphasia (Dash & Kar, 2014; Gray & Kiran, 2016; Green, et al., 2010) and only one that examined this in differential aphasia in particular. Verreyt, et al. (2013) reported a case study of a French-Dutch patient who showed larger impairments in Dutch than in French. They administered three lexical decision (LD) tasks which differed in language control demands: a generalized LD task, where no language control is required ("Is it an existing word, in any of the two known languages?") and a selective LD task in each language, where the non-target language needs to be inhibited ("Is it an existing word in Dutch/French?"). The patient showed a significant cognate facilitation effect in the generalized task in both languages, when language control demands are low, while no such effect was observed in the two selective variants. Moreover, in the selective task, the patient's performance in the most affected language (Dutch) was worse for cognates than for noncognates. These findings are in line with the control hypothesis in differential aphasia which states that a language control impairment makes the less affected language harder to suppress (e.g., Abutalebi & Green, 2007; Abutalebi, et al., 2009; Aglioti, et al., 1996; Pitres, 1895). As such, they show that even the most impaired language (Dutch) in differential aphasia can still facilitate the recognition of a word in the most recovered language (French), but only under conditions where no language control is needed. In addition to impaired linguistic control, Verreyt, et al. (2013) also observed non-linguistic control difficulties with a flanker task. Participants were asked to indicate in which direction a central arrow is pointing, by ignoring non-target flanking arrows that either point in the same (i.e., congruent) or opposite (i.e., incongruent) direction of the central arrow. A stronger congruency effect (i.e., difference in performance between congruent and incongruent trials) was observed for the patient relative to the controls, which reveals difficulties to suppress the information of the non-target arrows. Taking the linguistic and non-linguistic findings together, their patient thus seemed to suffer from a domain general control problem, which resulted in language control difficulties, and therefore in a reduced ability to inhibit the less impaired language.

1.3. Overview of the study aims

In the present study, we aimed to investigate the control impairment hypothesis in differential aphasia more thoroughly. First, investigating cognitive control impairment in differential aphasia, using other patients with varying psycholinguistic profiles should add to the generalizability of the results that were obtained in the case study of Verreyt, et al. (2013). Second and more importantly, we aimed to investigate the above explanation for differential aphasia more directly by looking at converging evidence from other research methods in cognitive neuroscience. More precisely, in the same patient, in addition to the behavioral paradigms to measure linguistic and non-linguistic cognitive control that were used by Verreyt, et al., we explored altered connectivity between the brain areas important for language control (Abutalebi & Green, 2007) and those implicated in language comprehension and production (Tomasi & Volkow, 2012) with a rs-fMRI. Our main goal was to detect neural evidence for a language control impairment in differential aphasia. For this purpose, we tested for altered connectivity between brain structures important for language control and those for language comprehension and between the language control and language production network (Figure 1). Thus, the neuroimaging part was aimed to confirm the control impairment hypothesis at the neural level, which has to the best of our knowledge never been done before.

INSERT FIGURE 1 AROUND HERE

2. Materials and methods

2.1. Participants

We recruited an L2 dominant French-English bilingual man, TD, who suffered from differential aphasia after a traumatic brain injury. Besides TD, we recruited two groups of control subjects: one group of ten participants for the behavioral part of the study (i.e., the lexical decision and flanker tasks) and one group of 26 individuals for the rs-fMRI. All participants gave informed consent under a protocol approved by the biomedical ethic committee of the Université catholique de Louvain.

2.1.1. Case Description.

TD was a 32-year-old right-handed bilingual man. He was born in the French part of Belgium and had formal schooling in French (L1, his first acquired language). TD studied civil engineering in French, followed by a PhD in the United States, where he became very proficient in English (L2, his second acquired language). Although French was his native language prior to the accident, TD's language usage was mainly in English (63.75%), which therefore had become his most dominant language (Gathercole & Thomas, 2009). More precisely, he spoke 45% English and 55% French with his family and friends and listened equally often to English as French radio (50%). However, he followed TV programs only in English; read most of the time in English (80%) and this was the most frequently used language at the workplace, a multinational company (80%). According to a self-evaluation with the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfeld, & Kaushanskaya, 2007), his premorbid language abilities were rated on a scale from 1 (minimal ability) to 10 (high proficiency) as 9/10 for French and 8/10 for English. In sum, prior to the onset of aphasia, TD was an L2-dominant French-English bilingual. TD estimated himself as slightly more proficient in his first-acquired L1, French, despite the fact that English was his dominant language. This pattern is not uncommon in late bilinguals that become L2 dominant, given that the age of acquisition of an L2 is negatively correlated with L2 proficiency, regardless of the frequency of L2 use (e.g., Bialystok & Miller, 1999; McDonald, 2000).

In January 2013, TD suffered a traffic accident that caused a severe head injury. He presented a left-sided skull fracture (with an underlying parenchymal cortico-subcortical contusion) for which craniotomy was performed. As shown by MRI scanning that was conducted in January 2016 (Figure 2), TD showed left-sided parenchymal damage to the parietal lobe with prominent corticoclastic encephalomalacia resulting in focal loss of brain tissue together with secondary ex vacuo enlargement of homolateral ventricular trigone.

INSERT FIGURE 2 AROUND HERE

In May 2013, TD's French-language functions were assessed prior to intensive logopaedic treatment in French. He was diagnosed with aphasia, mainly reflected in anomia (i.e., word-finding difficulties) during spontaneous and narrative speech production. TD also showed semantic difficulties at the receptive level, reflected in reduced written and listening comprehension (i.e., impaired synonym judgements). Working memory storage capacity, as measured with a span task and the Brown-Peterson task (Brown, 1958; Peterson & Peterson, 1959), was normal. To estimate the IQ of our patient, we administered the Advanced Progressive Matrices (Raven, Raven, & Court, 1998), on which TD obtained a high score. Scores on the different tests can be found in Table 1. During logopaedic treatment, semantic knowledge was trained by contrasting forgotten concepts (e.g., raspberry) with known concepts (e.g., strawberry; Heit, 1994). Lexical access was also trained by means of oral repetition of forgotten items in order to make these items more accessible (Hillis & Caramazza, 1994) and by teaching how to use mnemonic processes, such as mental imagery (Wilson, 1987).

In January 2015, after logopaedic treatment and at the moment of testing, TD still showed difficulties in French, particularly with word finding in spontaneous speech and with semantic induction ("Name as many animals as possible in two minutes"). From a qualitative perspective, TD explicitly mentioned to the speech therapists that het experienced clearly more difficulties with French than English and therefore requested that the therapy focused on French only. Because no objective data were available with respect to English-language abilities and how the ability to use this language was preserved in comparison with French, we administered the short version of the bilingual aphasia test (BAT; Paradis & Libben, 2014). This test examines comprehension and production abilities and allows the direct comparison of these competences across languages. The results of the BAT indicated differential aphasia at the receptive level with more language loss in French. We observed difficulties in syntactic comprehension in both English and French (e.g., show me the image where *the truck is not* *pulled by the car*), but TD made more errors in French. Furthermore, TD also showed problems in reading comprehension in French (e.g., read the sentence *the truck is not pulled by the car* and then touch the picture that corresponds with its meaning), while a perfect score was obtained in English. Finally, a deviant score for semantic opposites in production was observed in French but not in English (e.g., say a word which has the opposite meaning of *soft*). Although the differences in performance between French and English, for reading comprehension and semantic opposites, were rather small, the observation of a deviant score in only one language (French) further supports the diagnosis of differential language loss. Individual scores on each test can be found in Table 1.

In sum, the results from the BAT indicated that TD suffered from aphasia that was more severe in French, the patient's L1, than in English, his later acquired but dominant language. This differential aphasia was mainly reflected in impaired semantic and syntactic comprehension abilities, although TD also had word finding difficulties in French.

2.1.2. Control group for the behavioral part.

Like TD, all ten control participants had French as the native language and became very proficient in English during their PhD or work experience in a multinational company. Furthermore, all controls were technical engineers, just like TD. They all filled in the LEAP-Q (Marian, et al., 2007)[1]. The mean scores of the control group and the results of the comparison between the score of the patient and the control group can be found in Table 1. Differences were tested with Singlims_ES *t*-tests (Crawford, Garthwaite, & Porter, 2010). This technique provides a powerful statistical method to compare the results of an individual case with a small control sample. It treats the normative sample statistics as sample statistics rather than as population statistics, which is used in other analyzing techniques (e.g., ANOVA). Furthermore, besides the standard significance test (e.g., *t*-test), the program also provides point and interval estimates of the effect size for the difference, as well as point and interval estimates of the percentage of controls that will have a larger difference than observed for

[1]Because the LexTALE is part of a standard battery that we administer in language studies in our lab, we also dispose of LexTALE vocabulary scores from our bilingual participants in both English (Lemhöfer & Broersma, 2012) and French (Brysbaert, 2013). These data could however not be used to evaluate differential language loss in patient TD because the LexTALE is not ready for cross-language comparisons.

the case. In addition to providing evidence for a difference, these statistics thus quantify the abnormality of the difference between TD and the control group.

INSERT TABLE 1 AROUND HERE

2.1.3. Control group for the functional connectivity.

Besides TD, data of 26 neurotypical individuals (12 men, age: *M* = 31.00 years, *SD* = 11.19) were selected from an in-house rs-fMRI database. Individuals were selected as control participants if they had the same resting-state sequence and protocol as TD. These participants were recruited from a bilingual population but more detailed information was not available.

2.2. Study design

The patient was tested in two parts: (1) A behavioral assessment of the severity of aphasia in French and English (BAT) as well as an examination of the behavioral tasks to test linguistic and non-linguistic control abilities. (2) A rs-fMRI recording session to examine functional connectivity loss.

2.3. Behavioral tasks

2.3.1. Linguistic cognitive control

To investigate language control abilities, we conducted three versions of a LD task, similar to the three tasks of Verreyt, et al. (2013) explained earlier. More precisely, we conducted a generalized (“Is the word on the screen an existing word, in any language?”) and two selective LD tasks, one in each of the patient’s known languages (“Is the word on the screen an existing word in French/English?”). The stimuli that were presented visually in each LD task were 30 French-English identical cognates, 30 French noncognates, 30 English noncognates, and 90 nonwords. The selective LD tasks thus also contained words in the non-target language to increase language control demands. Different stimuli were used for the three tasks. Stimuli for each task were matched for word length, frequency and neighborhood size using Wordgen (Duyck, Desmet, Verbeke, & Brysbaert, 2004). The selected stimuli and their linguistic characteristics for the generalized, French selective and English selective LD task can be found in Appendices A, B and C respectively. The three tasks were administered in different testing sessions with extensive breaks of 90 minutes between them to exclude possible training effects. A black fixation cross (‘+’) was presented for 500ms, which was immediately followed by a letter string. The letter string remained on the screen until the participants responded. A schematic representation of the three tasks can be found in Figure 3.

INSERT FIGURE 3 AROUND HERE

2.3.2. Non-linguistic cognitive control

We administered a flanker task (Eriksen & Eriksen, 1974) to explore non-linguistic cognitive functioning[2]. All participants were asked to attend to the central arrow and ignore the six flanker arrows. They were asked to press the left key (i.e., V) when the central arrow pointed to the left and to press the right key (i.e., N) when the central arrow pointed to the right. All the flanking arrows pointed either in the same (congruent) direction as the central arrow or in the opposite (incongruent) direction. Two concepts were assessed and compared: non-linguistic control efficiency and attention modulation. Efficiency of inhibitory control was indexed by the congruency effect, which is the decline in performance on incongruent trials relative to congruent trials. Attention modulation was indexed by the effect of the previous trial type (i.e., Gratton effect; G. Gratton, Coles, & Donchin, 1992). Typically, there is less interference after an incongruent than after a congruent trial because of top-down adaptation. A white fixation cross (‘+’) was presented for 200ms, immediately followed by a horizontal array of seven equally sized and spaced white arrows for 500ms. There was an inter-trial interval of 200ms. All participants carried out a total of 360 trials in random order, requiring an equal number of left and right responses.

2.4. Functional connectivity

Images were acquired using a 3T scanner (Achieva, Philips Healthcare, Eindhoven, The Netherlands) with a 32-channel phased array head coil. The patient and the control group were scanned using resting-state (eyes closed) MRI using repeated single-shot echo-planar imaging. The following parameters were used: TE = 30ms, FA = 90°, in plane resolution = 3.438 x 3.438mm², 35

[2]The flanker task is one of the most frequently used tasks to test non-linguistic cognitive control.

slices acquired in an ascending order, slice thickness = 3.44mm, TR = 2000ms and number of TR = 200 (6min 40s). A 3D heavily T1-weighted image was also recorded at the end of the MRI session. This anatomical 3D sequence consisted of a gradient echo sequence with an inversion prepulse (Turbo Field Echo –TFE) acquired in the sagittal plane using the following parameters: TR/TE/flip angle = 9.1ms/4.6ms/8°, 150 slices, slice thickness = 1mm, in-plane resolution = 0.81 x 0.95mm² (acquisition) reconstructed in 0.75 x 0.75mm², FOV = 220 x 197mm², acquisition matrix = 296 x 247 (reconstruction 320²), SENSE factor = 1.5 (parallel imaging).

2.4.1. MRI pre-processing and Data Analysis.

The MRI data were analyzed using BrainVoyager QX (Version 2.8, Brain Innovation, Maastricht, The Netherlands; Goebel, Esposito, & Formisano, 2006). Preprocessing of the data consisted of a linear trend removal to exclude scanner-related signal drift. We applied a temporal high-pass filter to remove frequencies lower than 2 cycles per run and corrected for head movements using a rigid body algorithm for rotating and translating each functional volume in 3D space. Data were corrected for time differences in the acquisition of the different slices. Data were smoothed in the spatial domain (Gaussian filter: Full Width at Half Maximum = 5mm), co-registered with their 3D T1-weighted scans and normalized in the Talairach space. All co-registrations were manually corrected and movement corrections were optimized, using a sinc interpolation. The resting-state data were analyzed using a seed-based approach. Because spontaneous low-frequency fluctuations are not exclusively BOLD-related fluctuations, but are also contaminated by non-neural signals (i.e., artifacts), several additional pre-processing steps were added to remove these undesirable sources of variance. Regression analyses were performed to remove artifacts due to residual motion (the six movement regressors were obtained via rigid body correction of head motion as implemented in BrainVoyager) and changes in ventricles (the signal from a ventricular region of interest defined in the patient and in each of our 26 subjects).

We used BrainVoyager and a customized Matlab code (The Mathworks) to calculate cross-correlations between the average time-course signals, extracted from the regions of interest (ROIs). These ROIs included the language control (Abutalebi & Green, 2007), the language comprehension and production network (Tomasi & Volkow, 2012) in each individual subject (Figure 1). The language control network consisted of the left ACC, left BA47 and the left HC. The language comprehension areas included the left angular gyrus (BA39), the right inferior parietal cortex (BA40), the left supramarginal gyrus (BA 40), the left middle frontal cortex (BA46), the left and right inferior temporal cortices (BA21/20), the left planum temporale and left prefrontal regions (BA9 and BA10). The brain areas that were included in the language production network included left Broca's area (BA45), the right pars triangularis (BA45), the left and right pars orbitalis (BA47), and the left and right pars opercularis (BA6, BA37 and BA44). Talairarch coordinates that were used to generate the spherical regions (radius = 6mm) can be found in Table 2. These regions were intersected with the individual brain mask of each subject to avoid voxels in a damaged brain area. The number of undamaged voxels within the left supramarginal gyrus was significantly lower for TD relative to the control group (M_{controls} = 801.08, SD_{controls} = 79.77; M_{TD} = 293.00), $t(25) = 6.37$, $p < .001$. Nevertheless, only undamaged voxels were considered in the analysis. Functional connectivity of TD was compared to the control group within the language production, language comprehension and language control areas. Furthermore, TD's pattern of functional connectivity between comprehension and control areas, as well as between production and control areas were compared with those of the control group.

INSERT TABLE 2 AROUND HERE

3. Results

Original data of this study are available at Mendeley data (http://dx.doi.org/10.17632/4nd4gvbf7m.1).

3.1. Linguistic cognitive control

Each trial was classified according to its Word Status (cognate, French word, English word or nonword). Mean accuracy for each task is summarized in Figure 4. Mean reaction times (RTs), as well as the results of the comparison between TD and the control group are presented in Table 3. Similar to other studies on bilingual aphasia, only differences in accuracy will be used for interpretation because RTs are highly variable in LD for patients with aphasia (e.g., Lalor & Kirsner, 2001; Verreyt, et al., 2013). They are nevertheless included in Table 3 for the interested reader. For each LD task, we first conducted repeated measures ANOVA on accuracy for the control group with Word Status (cognate, French word, English word, or nonword) as within-subjects factor. Then, we compared performance between the control group and TD with Bayesian hypothesis tests (SingleBayes_ES; Crawford, et al., 2010)[3].

3.1.1. *Generalized LD Task.*

For the control group, Mauchly's Test of Sphericity indicated that the assumption of sphericity was violated for word type, $\chi^2(5) = 23.15$, $p < .001$. Greenhouse-Geisser corrections were applied. There was a main effect of Word Status, $F(1.58, 14.20) = 22.32$, $p < .001$. Accuracy was higher for cognates compared to English words as well as to French words, $F(1, 9) = 27.40$, $p < .001$ and $F(1, 9) = 22.23$, $p < .001$, respectively. Thus, we observed significant cognate facilitation for both English and French. Furthermore, accuracy was higher for French words than for English words, $F(1, 9) = 8.78$, $p = .02$.

There was no difference between the patient and the control group, neither for the French nor for the English cognate facilitation effect. Patient TD was less accurate on French words compared to the control group, although this difference just failed to reach significance.

3.1.2. Non-dominant (French) Selective LD Task.

For the control group, Mauchly's Test of Sphericity indicated that the assumption of sphericity was violated for Word Status, $\chi^2(5) = 20.18$, $p < .001$. Greenhouse-Geisser corrections were applied. We observed a main effect of Word Status, $F(1.34, 12.08) = 5.16$, $p = .03$. Accuracy was higher for nonwords than cognates, $F(1, 9) = 11.38$, $p = .01$. There was no significant cognate facilitation effect (i.e., difference between cognates and French words), $F(1, 9) = 3.30$, $p = .10$. Furthermore, there was

[3]SingleBayes_ES is highly similar to Singlims_ES (Crawford, et al., 2010). Rather than a frequentist test, it uses Bayesian Monte Carlo methods to test whether a patient's score is below the scores of the control group. Bayesian inferential methods do not require *p*-value adjustments for multiple comparisons and yield more efficient estimates than classical approaches, such as *t*-tests (Gelman, Hill, & Yajima, 2012).

no difference between cognates and English words, or between English and French words, $F(1, 9) = 2.18$, $p = .17$ and $F < 1$, respectively.

Comparing the control group with TD, we observed a significantly stronger cognate facilitation effect for the patient compared to the control group. Furthermore, we observed a significant difference between English and French words, meaning that the patient made significantly more errors on French words compared to English words. Note that this difference between English and French words was not significant for our control group.

3.1.3. Dominant (English) selective LD task.

For the control group, the main effect of Word Status just failed to reach significance, $F(3, 27) = 10.19$, $p = .07$. There was no difference between cognates and English words, $F(1, 9) = 1.21$, $p = .30$, meaning that there was no cognate facilitation. Performance was better on French words compared to cognates, $F(1, 9) = 10.30$, $p = .01$, as well as on nonwords compared to cognates, $F(1, 9) = 41.32$, $p < .001$. The difference between French and English words was near significance, $F(1, 9) = 4.05$, $p = .08$, suggesting a trend towards participants being slightly more accurate on French words.

There were no significant differences between the patient and the control group, except with respect to French words: TD was significantly more accurate in discarding a French word as a word compared to the control group.

INSERT FIGURE 4 AROUND HERE

INSERT TABLE 3 AROUND HERE

3.2. Non-linguistic control

Each trial was classified according to its Previous Congruency (congruent or incongruent) and the Congruency (congruent or incongruent), resulting in four transitions. Mean accuracy and RTs for the patient and the control group as a function of Previous Congruency and Congruency, as well as the comparison between TD and the control group are presented in Table 4. We first conducted a repeated measures ANOVA on accuracy and RTs for the control group with Previous Congruency and Congruency as within-subjects factors. RTs for incorrect trials, for trials following an incorrect trial and outliers were excluded from the analysis. Outlier RTs were trimmed individually by calculating a mean RT on each of the four transitions and excluding any response that had a RT of 2.5 SD of the mean. This resulted in the exclusion of 7.94% of RT data for the control group and 9.17% for TD. Performance between the control group and TD were then compared using SingleBayes_ES Bayesian inferential methods (Crawford, et al., 2010).

The ANOVA on accuracy for the control group showed a main effect of Congruency, $F(1, 9) = 7.78$, $p = .02$. The main effect of Previous Congruency just failed to reach significance, $F(1, 9) = 4.26$, $p = .07$, indicating a trend towards higher accuracy on trials that were preceded by incongruent trials compared to congruent trials. The interaction of Previous Congruency and Congruency was not significant, $F < 1$. Thus, we observed a congruency effect, but the Gratton effect was not significant. Comparing TDs performance with the control group, we did not find a significant difference, neither with respect to the congruency effect, nor the Gratton effect.

For RTs, the control group had a significant congruency effect, $F(1, 9) = 48.97$, $p < .001$. The main effect of Previous Congruency was not significant, $F < 1$. The interaction of Previous Congruency and Congruency was significant, $F(1, 9) = 7.15$, $p = .03$. Planned comparisons revealed that participants were significantly slower on a congruent trial after an incongruent trial than after a congruent trial, $F(1, 9) = 7.18$, $p = .03$, while this was not significant for incongruent trials, $F < 1$. Thus, the congruency and Gratton effect were significant for the control group. Comparing the performance of TD with the control group, the congruency effect was larger for TD than for the controls. We did not observe a significant difference between the patient and control group with respect to the Gratton effect. Thus, our results suggest impaired non-linguistic control efficiency, but preserved attention modulation. The RT data as a function of Congruency for TD and the control group are summarized in Figure 5.

INSERT TABLE 4 AROUND HERE

INSERT FIGURE 5 AROUND HERE

3.3. Functional connectivity

Results are summarized in Table 5. The functional connectivity of TD between the different structures within the three networks (control, comprehension and production) and between the control and the two language processing networks were compared with the control group by means of SingleBayes_ES (Crawford, et al., 2010).

Concerning within-network interactions, we observed aberrant connectivity in TD, relative to the control group, within the language comprehension and the language production networks. In contrast, we did not observe differences in connectivity within the language control network between TD and the control group. More precisely, considering interactions within the language comprehension network, the following connections showed significantly reduced connectivity for TD relative to the control group: left angular gyrus with left middle frontal cortex, right inferior parietal region with left supramarginal gyrus, left supramarginal gyrus with left middle frontal cortex and left planum temporale with left middle frontal cortex. The functional connectivity between several regions was, on the other hand, increased for TD relative to the control group: the left angular gyrus with left inferior temporal cortex, left angular gyrus with right inferior temporal cortex, right inferior parietal cortex with left inferior temporal cortex and right inferior parietal cortex with right inferior temporal cortex. With respect to the functional connectivity within the language production network, we observed decreased connectivity for TD between the right pars triangularis and the left pars opercularis. We did not observe evidence for increased connectivity within this production network for TD relative to the control group.

Comparing the connectivity between the different networks, we observed that patient TD showed aberrant connectivity between brain structures important for language control and those important for language comprehension. More precisely, the following set of regions showed decreased connectivity: the left head of caudate with the left angular gyrus and the left pars orbitalis with the left middle frontal cortex. Furthermore, there was increased connectivity for TD relative to the control group for the left planum temporale with the left anterior cingulate cortex and for the left prefrontal region 1 with the left pars orbitalis. Finally, and crucially, we also observed aberrant connectivity for TD relative to the control group with respect to the connectivity between the language control and the language production network. TD showed decreased connectivity between the left head of caudate and left Broca's area. Furthermore, the connectivity was increased for TD relative to the control group between the left head of caudate and the left pars opercularis 1 and between the left anterior cingulate cortex and the left pars opercularis 1.

Taken together, the functional connectivity analyses revealed that TD had aberrant connections within the language comprehension and production network, but not within the language control network. Both within the comprehension and production network, we observed decreased connections. Furthermore, the patient showed some stronger connections relative to the controls mainly with inferior temporal cortices within the comprehension network, while such increased connectivity was not found within the production network. The same pattern of results was observed when we compared the crucial connectivity between the language control and production and between the language control and comprehension network of TD relative to the control group. Both with respect to the interactivity between the language comprehension and control network and between the language production and control network, we observed evidence for increased as well as for decreased connections. It is precisely these connections that are crucial for our cognitive control account of differential aphasia.

INSERT TABLE 5 AROUND HERE

4. Discussion

In the current study, we examined the hypothesis of language control loss in differential aphasia and how this affects non-linguistic control. To this end, we directly compared the results of a 32-year old L2 dominant French-English bilingual patient with differential aphasia and a matched bilingual control group on LD performance, with varying language control demands, as well as on a flanker task. Furthermore, we explored the functional connectivity within and between cognitive control and language processing networks by comparing the rs-fMRI of TD with a control group that was selected from an in-house fMRI database.

Considering language control, we observed similar cognate facilitation effects for TD and the control group when comparing cognates with both French and English noncognate words in the generalized LD task, consistent with Verreyt, et al. (2013). This shows that representations of French words, the most impaired language, were not (functionally) lost for TD. French words were still active and even able to facilitate the recognition of cognates in English, the most preserved language, as shown by a better recognition of cognates over English noncognates. Importantly, we did not observe cognate facilitation for the control group in the French selective LD task. This shows that the control group successfully inhibited English, the irrelevant language, so that it did not affect French word recognition and hence, eliminated cognate facilitation. However, the cognate facilitation effect was significant for TD. This indicates that TD was not able to properly inhibit English, the non-target language, as the controls were, because it still facilitated the recognition of French words. Finally, we did not find cognate facilitation for both TD and the control group on the English selective LD task, showing that, just like the control group, TD was able to inhibit French, his non-dominant language, during this task. The three LD tasks together thus clearly support the idea that differential aphasia should not be unambiguously attributed to the loss of language representations, but that a deficit in language control offers a, perhaps theoretically more plausible, alternative account. These findings are consistent with previous studies that showed better recognition of cognates over noncognates for patients with aphasia in general (Detry, et al., 2005; Kohnert, 2004; Roberts & Deslauriers, 1999; Verreyt, et al., 2013). More importantly, these findings are in line with previous studies that suggested language control difficulties in patients with aphasia (Abutalebi & Green, 2007; Abutalebi, et al., 2009; Aglioti, et al., 1996; Pitres, 1895; Verreyt, et al., 2013).

In the French selective LD task, TD recognized less French words than the control group, while there was similar performance on English words in the English selective variant. Furthermore, TD was better than the control group in discarding French words as words, suggesting that TD recognized less French words than the control group, which in this case facilitated his performance. Importantly, we did not observe this pattern of altered performance on French words in the generalized LD task, in line with the hypothesis that increased language control demands cause the impaired performance.

The observation of cognate facilitation in the French selective LD task for the patient in the current study was not observed by Verreyt, et al. (2013), who found a cognate interference effect for their patient when conducting the selective task in the most impaired language. However, this previously observed interference effect was small as the patient only made 10% more errors (i.e., 3 items) on cognates than on noncognates. Furthermore, while the patient of the current study was tested in the chronic phase of aphasia (i.e., two years post onset) and after intensive speech therapy, the patient of the Verreyt et al. study did not yet receive any speech or language therapy and was still in the acute phase of aphasia (i.e., three weeks post onset). During the acute phase, spontaneous restoration of some language functions in aphasia is common and fast (Lazar, Speizer, Festa, Krakauer, & Marshall, 2008) because of spontaneous neuroplasticity (i.e., neurophysiological repair and cortical reorganization of language functions; Robertson & Fitzpatrick, 2008). This spontaneous recovery tends to level off within the first year after stroke (Berthier, 2005; Pedersen, Stig Jørgensen, Nakayama, Raaschou, & Olsen, 1995), resulting in chronic aphasia that needs to be treated. Consequently, the observed impairments of Verreyt, et al. (2013) may be reflecting temporary difficulties rather than chronic aphasic symptoms.

The lack of cognate facilitation for the bilingual control group in the selective lexical decision tasks differs from the results of previous studies that did report such facilitation effects within both L1 (e.g., Van Assche, et al., 2009; Van Hell & Dijkstra, 2002) and L2 (e.g., Duyck, et al., 2007; Lemhöfer & Dijkstra, 2004). However, the comparability of these studies with the present one is limited. First, we tested highly proficient, balanced, bilinguals, while the latter studies mainly recruited unbalanced bilinguals. Typically, cognate facilitation is larger in L2 word processing than in L1 because words are faster processed within the most proficient language (e.g., Kroll, Dijkstra, Janssens, & Schriefers, 1999). Hence, because the participants of the current study were balanced bilinguals, cognate facilitation might have been reduced because words were processed equally fast within both languages, making it no longer observable in our sample. Furthermore, note that frequently switching between languages enhances (general) cognitive control abilities (Verreyt, Woumans, Vandelanotte, Szmalec, & Duyck, 2016), which could potentially affect lexical selection because (words of) the non-target language can be more efficiently inhibited. Second, language control demands may influence cognate effects. Bilinguals may control (inhibit) the activation of the nontarget language when language decisions are important for task completion. Brenders, van Hell, and Dijkstra (2011), for example, showed that the inclusion of homographs (i.e., words that exist in both languages, but have a different meaning, such as the Dutch-English example *room*, which is cream in Dutch) in a selective LD task reduces cognate effects. In the current study, we included words belonging to the nontarget language to increase the language control demands in the selective tasks. For each recognized word (cognate, French or English noncognate), participants therefore had to decide whether the item was a word in the target language or not. The results of the current study indicate that the control group inhibited the nontarget language in both selective tasks, thereby eliminating cognate facilitation. In contrast, patient TD did show cognate facilitation in the French-selective LD task, providing evidence that TD was not able to inhibit the activation of his better preserved language (English).

When comparing the results of the patient with those of the control group on the non-linguistic control (flanker) task, both the patient and the control group showed the typically observed congruency effect, both on accuracy and RTs. We did not observe a difference with respect to accuracy between TD and the control group, which can be explained by a ceiling effect for both the patient as well as the control group. However, crucially and in line with Verreyt, et al. (2013), for RTs, the differential aphasia patient showed a larger congruency effect, indicating that the patient with differential aphasia encountered stronger interference from the incongruent flankers than the control group. This finding suggests that TD had more difficulties in focusing on the relevant information (i.e., the central arrow), while ignoring the irrelevant and interfering information (i.e., the flanker arrows that were pointing to the opposite direction of the central arrow), although he eventually was able to inhibit the irrelevant information, just like the control group.

We did not observe evidence in favor of impaired attention modulation capacity in patient TD, since the Gratton effect of TD was similar to the effect observed for the control group. According to the conflict adaptation hypothesis (Botvinick, Carter, Braver, Barch, & Cohen, 2001), the control that is required to resolve the conflict on a previous incongruent trial manifests in an increase of response times and a reduction of error rates on the subsequent trial. The equivalent Gratton effect between patient TD and the control group is in accordance with the normal working memory capacity for TD. Working memory is part of the cognitive control system and is responsible for the maintenance and updating of task goals and task-relevant information (De Fockert, Rees, Frith, & Lavie, 2001; Lavie &

De Fockert, 2005; Long & Prat, 2002), which is thus important to adapt response strategies after an incongruent trial. Maintaining information in memory and inhibitory control are proven to be two closely related but separate processes (Diamond, 2006; Gernsbacher & Faust, 1991; Levy & Anderson, 2002; Shing, Lindenberger, Diamond, Li, & Davidson, 2010). In fact, working memory is composed of short term memory, which refers to the passive temporary storage of information, and cognitive control (Baddeley, Eysenck, & Anderson, 2015). The differentiation between a normal working memory capacity for TD, which was measured by a span task, and impaired inhibitory control abilities, reflected in an impaired congruency effect, in the current study further supports the existence of two distinct processes. Taking the results of the flanker task together, we observed a non-linguistic control impairment for patient TD, which is specific to inhibitory control efficiency rather than to attention modulation.

Finally, and importantly, the functional connectivity analyses revealed that TD had *decreased* connections within the language comprehension and production network. The observed deregulation of the interactions within, and between, the three language networks of the patient may represent crucial pathological mechanisms of differential aphasia. Of importance for the current study, we observed decreased connectivity between areas important for language control and those implied in language processing. It is precisely this pattern that should be expected in an account that explains differential language production loss with preserved lexical representations, but an impaired ability to inhibit the dominant language during non-dominant language production. As such, we observed decreased connectivity between the left angular gyrus, important for the integration of lexical-semantic information (Price, Peelle, Bonner, Grossman, & Hamilton, 2016) and HC, which is important for translations, language selections and switching (Abutalebi, 2008; Abutalebi & Green, 2007; Crinion, et al., 2006; Wang, Xue, Chen, Xue, & Dong, 2007). The connectivity of the HC with Broca's area was also decreased for TD relative to the control group. Broca's area has a crucial role in syntactic processing (Kaan & Swaab, 2002) and is important for semantic retrieval operations, such as the selection and comparison of a semantic response (Collette, et al., 2001; Demb, et al., 1995; Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997). Finally, we also observed decreased connectivity for TD between BA47, involved in response selection and suppression (Green &

Abutalebi, 2013) and the middle frontal cortex, important for semantic processing (Demb, et al., 1995). It is clear from previous research that decreased connectivities reflect functional deficits. The more a connection is weakened, the more likely behavioral difficulties will occur. Such associations have been found in a variety of disorders, including aphasia (e.g., Sandberg, 2017).

In addition, the patient showed some *increased* connections mainly with inferior temporal cortices. Based on the literature, two possible explanations can be put forward for the occurrence of the numerous increased connectivities (in addition to the decreased connectivities discussed above). A first possible explanation is that they represent how the brain tries to cope with or compensate for the loss and recovery of language abilities. Such compensatory mechanisms were previously found in rs-fMRI results of monolinguals with aphasia (Duncan & Small, 2016; Sandberg, 2017; Sandberg, Bohland, & Kiran, 2015). For example, Duncan and Small (2016) compared the rs-fMRI of 19 patients with aphasia before and after logopaedic treatment. The authors observed that improvement in language abilities following therapy was associated with increased activation among functional networks in patients with aphasia. In the latter study, connectivity was not compared with a neurotypical control group. Therefore, it is not clear whether the observed resting-state connectivities before and after therapy are deviant from neurotypical individuals. Nevertheless, these results suggest that the functional connectivity between different brain structures may increase as a result of successful therapy. The patient of the current study received intensive logopaedic treatment in French prior to his participation. Although this cannot be tested empirically here, the observed increased connectivities may thus be due to language improvements after therapy. As such, they may reflect a reorganization that enabled recovery of language abilities for TD and indicate that other brain regions have taken over tasks of those areas that show reduced connectivity.

On the other hand, increased connectivities may also reflect decreased abilities at the behavioral level. Such associations have been observed in patients with multiple sclerosis (Muthuraman, et al., 2016) and schizophrenia (Venkataraman, Whitford, Westin, Golland, & Kubicki, 2012). Venkataraman, et al. (2012), for example, compared the rs-fMRI of 18 patients with schizophrenia with that of 18 healthy control individuals. Rather than observing uniformly increased or decreased connectivity in patients with schizophrenia, relative to healthy controls, they reported both increased *and* decreased connections. The authors concluded that distinct patterns of functional connectivity abnormalities can be observed in patients, but also that they may manifest themselves in opposite directions. As such, certain connections may have decreased functional connectivity, while others show increased connectivity. Duncan and Small (2016) recently proposed a similar idea. They argued that a U-shaped curve reflects the implications of an aberrant organization of resting-state interactions between different brain structures. According to these authors, abilities at the behavioral level for which two brain areas are responsible should be impaired if their resting-state connectivity is either too weak or too strong. Thus, increased connections between two brain structures may also reflect behavioral difficulties. As we make comparisons between the patient and a control group, we examined weaker or stronger connectivities. The alteration in connectivity between language control and language processing networks is thus likely to explain the differential recovery pattern and the impaired linguistic and non-linguistic control abilities in the patient. However, the resting-state connectivity technique is relatively new, especially in research on aphasia, and further research on the implications of increased connectivity would be highly informative to further clarify this matter. In any case, despite the complex relation between brain connectivity and behavior, especially in patients that suffered brain trauma, it remains a fact that connectivity analyses yielded differences between patient TD and controls.

The loss in connectivity between language control and language processing networks is thus likely to explain the differential recovery pattern and the impaired linguistic and non-linguistic control abilities in the patient. Recent evidence has shown that the left caudate plays a decisive role in the selection of the less dominant language (Li, Emmorey, Feng, Lu, & Ding, 2016). Therefore, language problems may arise in patient TD because of difficulties with the retrieval of items in French under conditions of increased language control (i.e., conditions where one language must be inhibited). Furthermore, the observation of decreased connectivity within the language comprehension network is in line with the observed difficulties of the patient at the receptive level in both languages. Taken together, both at the behavioral and the neural level, our data support the hypothesis of a general control impairment leading towards differential aphasia[4]. These results nevertheless require further

[4]We are aware of the fact that assessment of linguistic and non-linguistic control was rather of a limited scope in this patient

replication and perhaps extension with a larger group of patients with differential aphasia to reach firm conclusions. The current findings are in line with a recent study in which we used only behavioral measures to compare non-linguistic control performance of two groups of parallel and differential aphasia patients and observed stronger non-linguistic control impairment for the patients with differential aphasia (Van der Linden, et al., in press).

The differential pattern of language impairment in the patient of the current study showed more functionality loss in his L1 (French) relative to his L2 (English). This finding seems to contradict most studies on differential aphasia that generally reported more difficulties in L2, relative to L1 (e.g., Azarpazhooh, Jahangiri, & Ghaleh, 2010; Fabbro, Peru, & Skrap, 1997; Reynolds, Turner, Harris, Ojemann, & Davis, 1979; Verreyt, et al., 2013). However, in these earlier studies, the first-acquired language was also the most dominant language. Here, it was the other way around, with a dominant L2. Because we believe that language dominance, rather than age of acquisition, determines the relative language loss in differential aphasia, it is important to emphasize that the present patient also showed a larger loss in his non-dominant language (even though it was first acquired), just like in previous studies. The assumption that differential aphasia is dependent upon language dominance rather than age of acquisition is theoretically very likely. The two languages of bilinguals are continuously activated in parallel (Colomé, 2001; Costa & Caramazza, 1999; Costa & Santesteban, 2004; Duyck, et al., 2007; Kaushanskaya & Marian, 2007; Meuter & Allport, 1999; Van Assche, et al., 2009). Therefore, a bilingual requires inhibitory control to overcome interference from dual-language activation. Most importantly, more inhibitory control is required to control the (more active) dominant language (i.e., English for TD) relative to the weaker language (i.e., French for TD; Meuter & Allport, 1999). As such, our results suggest that patient TD is no longer able to fully inhibit English, his most dominant language, when using French, his non-dominant language. Future studies with L2-dominant differential aphasia patients should further confirm that language dominance, rather than age of acquisition determines the pattern of relative language loss.

The patient of the current study acquired English (his dominant language) at a later moment in

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(using different LD tasks and the flanker task). For further research, we suggest testing linguistic and non-linguistic control more profoundly (e.g., using Stroop interference for verbal control and a switching paradigm, a go-no go task, etc. for non-verbal control).

his life (at the age of 23). The cortical language distribution in bilinguals has been found to be influenced by the age of acquisition. As such, native and early-acquired languages are largely represented within the same perisylvian left fronto-parieto-temporal areas. Although the networks involved in the processing of late-acquired languages usually overlap neuroanatomically (Fernández-Coello, et al., 2017), it is possible that representations of the current patient's dominant language (English) are more distributed than those of his native language (French). So given that our patient has a native and late-acquired dominant language, in combination with left parieto-temporal damage, this may have led to unbalanced or differential recovery.

The differential aphasia in the patient reported here was due to a left subcortical lesion to the parietal lobe. Previous studies showed that focal brain lesions may affect the connectivity between different functional networks (Eldaief, McMains, Hutchison, Halko, & Pascual-Leone, 2017; C. Gratton, Nomura, Pérez, & D'Esposito, 2012) and therefore have the potential to affect abilities that do not involve the impaired brain tissue. Thus, decreased connectivity between different regions as observed in the current study, even when the regions are 100% spared, are possible and clinically relevant. Subcortical damage in bilingual aphasia has already been linked to impaired language control, such as asymmetric translation deficits and pathological language mixing (e.g., Abutalebi, Miozzo, & Cappa, 2000; Adrover-Roig, et al., 2011; Ansaldo, Saidi, & Ruiz, 2010). Subcortical lesions are also known to be correlated with diaschisis (i.e., disruption of connectivity between lesioned and intact brain areas; Vallar, 1998) or hypoperfusion (i.e., decrease of blood supply to the brain; Hillis, et al., 2002). In the patient of the current study, we observed decreased functional connectivity between brain areas that were assumed to be intact, suggesting the occurrence of diaschisis due to subcortical damage. However, the brain lesion of our patient was due to a focal traumatic brain injury, in which there was a subcortical as well as a cortical contusion. Therefore, it is possible that the patient experienced a coup-countrecoup injury, which caused a diffuse axonal injury (i.e., more extensive damage than just to the language-eloquent cortex), which may not be visible on an MRI scan. Consequently, one could argue that the impairments observed in the current patient are perhaps not aphasia-based symptoms, but rather problems related to other cognitive deficits. Although this alternative cannot be completely ruled out, the patient only reported word finding and semantic difficulties and no cognitive complaints (e.g., attention problems), suggesting that the observed problems are indeed aphasia-based rather than due to other cognitive deficits.

What are the implications of our findings for the treatment of bilingual aphasia? There is a lot of debate whether linguistic treatment should be given in one or in both languages of a bilingual patient. Some researchers found that the effects of language therapy in one language generalize to the other, untrained, language (Edmonds & Kiran, 2006; Filiputti, Tavano, Vorano, de Luca, & Fabbro, 2002; Kiran & Edmonds, 2004; Marangolo, Rizzi, Peran, Piras, & Sabatini, 2009; Miertsch, Meisel, & Isel, 2009), while others were not able to observe such generalization (Abutalebi, et al., 2009; Galvez & Hinckley, 2003; Meinzer, Obleser, Flaisch, Eulitz, & Rockstroh, 2007). In recent years, the importance of training control abilities for cross-linguistic recovery of aphasia becomes more and more recognized (e.g., Abutalebi, et al., 2009; Ansaldo & Saidi, 2014; Brownsett, et al., 2014; Kohnert, 2004; Radman, et al., 2016), although control abilities are still rarely trained in aphasic patients. The current study further supports the assumption that a cognitive control deficit underlies the differential aphasia impairment, which is therefore a disorder that does not seem to be limited to the linguistic domain. Intensive training of cognitive functions and, more particularly of inhibition and resistance to interference, might aid the recovery of both languages. Kohnert (2004) reported the results of two treatment types for a Spanish-English bilingual with aphasia. Treatment 1 was a cognitive-based treatment where non-linguistic skills (e.g., visual scanning) were trained. Treatment 2, on the other hand, was linguistic. In this treatment, cognates and noncognates were trained. Treatment 1 resulted in overall better performance in both Spanish and English. Also for treatment 2, marked gains from Spanish and English were observed for cognates and noncognates, but the generalization from Spanish to English was only present for cognates. Thus, training non-linguistic skills seems to have broader positive consequences than only training word representations. At the moment of testing, the patient in our study already received extensive speech therapy for two years. However, this linguistic reeducation mainly focused on the recovery of French, which moreover was the patient’s non-dominant language at the moment of the trauma. The fact that the impairment is still stronger in French, despite the extensive training in this language, is in line with the current rationale that there is an underlying deficit in people with differential aphasia that may not be targeted or that at least may not be optimally remedied by the typical linguistic therapies.

Our findings also have implications for the controversy about whether or not an overarching mechanism is responsible for language control, as well as for non-linguistic control abilities (Costa & Santesteban, 2004; Costa, et al., 2006; Dijkstra & Van Heuven, 2002; Gray & Kiran, 2016; Green, 1998; Hermans, et al., 1998). The current study suggests that linguistic and non-linguistic control are closely related at least, as we observed impairments for both types of control abilities. Recently, also other linguistic disorders, such as stuttering (Bosshardt, 2006; Vasiç & Wijnen, 2005) and specific language impairment (Henry, Messer, & Nash, 2012) have been linked to problems with non-linguistic cognitive control and more specifically, inhibitory control deficiencies. These studies suggest that inhibitory control capacities may be crucially involved in various language skills. The patient in the current study mainly showed semantic and syntactic difficulties in both languages. Sentence comprehension involves inhibitory control at the lexical level, because it requires the selection of relevant information (Carretti, Borella, Cornoldi, & De Beni, 2009; Kaushanskaya, Park, Gangopadhyay, Davidson, & Weismer, 2017). Such control is, for instance, required to select the correct meaning of an ambiguous word. . In addition, cognitive control is also important for syntactical processing, for instance to suppress the preferred interpretation of syntactically (temporarily) ambiguous sentences (Novick, Trueswell, & Thompson-Schill, 2005). And indeed, the patient mainly had difficulties with comprehending syntactically complex sentences (e.g., “the truck is not pulled by the car”). In complex sentences, the thematic roles are not in their most frequently occurring (or canonical) position and therefore, they require additional grammatical processing before they can be understood correctly (Colman, Koerts, Stowe, Leenders, & Bastiaanse, 2011). For example, in the sentence “the truck is not pulled by the car”, the truck is the theme and the car is the agent. In English (and in French), the subject is usually the agent. In this example, the theme is thus preceding the agent, while usually the agent comes first in a sentence. In order to understand this syntactically complex sentence, the individual must inhibit the expected thematic role assessment that the agent is preceding the theme before he can interpret the irregular structure of the sentence. Thus, it is likely that the same domain-general inhibitory control problem that explains the lexical problems also underlies the differential loss of syntactical processing in the patient of the present study. A possible explanation for the differential language loss at the level of syntactic comprehension is then that patient TD has impaired access to the non-canonical (or atypical) syntactic structures in French relative to English, similar to his reduced lexical access in French, because French is his non-dominant language. As a consequence, the impaired domain-general cognitive control abilities of patient TD may explain why TD has marked difficulties with semantic and syntactic comprehension in both languages. Future work should more profoundly address the link between inhibitory control capacities, language comprehension skills and their neural substrate in patients with differential aphasia.

The present study also has a number of limitations. Evidently, because this is a case study, replications with other patients and with larger patient groups are necessary to ensure generalizability of the obtained results. It should be noted that the results of the BAT showed reliable, but relatively small differences between the patient and the control group. Future patients may show even more pronounced patterns of differential language loss, or even a pattern in which language loss affects is almost complete for just one of the two languages (selective aphasia). In any case, the BAT diagnosis of differential aphasia with only moderately stronger difficulties in French than in English confirmed the clinical diagnosis by professional speech therapists at the university hospital, underlying the decision to administer speech therapy only in French. Also consistent is the qualitative self-assessment by TD, who reported that he experienced clearly more difficulties with French than with English since his accident. This pattern of differential aphasia was also supported by the lower performance on French words in the lexical decision tasks. We hypothesize that future studies with patients that show even more pronounced relative language loss should also reveal larger cognitive control dysfunctions. However, this study is, at least at the behavioral level, in line with Verreyt, et al. (2013), which reported similar results in another patient with differential aphasia. In addition, the rs-fMRI data in these follow-up experiments should be compared to the data of a control group that is matched on language proficiency. In the current study, we compared the data with individuals from an in-house database, from which we were not able to control for language proficiency. On a related note, we included two different control groups. Future studies should compare the patient’s behavioral and functional differences with the same control group in order to allow statistical associations between these measures. Also, a premorbid estimate of language proficiency was not available for the patient and was restricted to a questionnaire filled in by the patient himself. However, retrieving formal premorbid language proficiency assessments is almost unfeasible given the unpredictability of an accident or aphasia. Another limitation of this study was that we only assessed a limited number of receptive tasks. To assess language and non-linguistic control difficulties, we used three lexical decision tasks and the flanker task, respectively. We decided to test language control in a comprehension task rather than in a production task, because the patient of the current study mainly had difficulties with comprehension. However, a thorough evaluation of language comprehension and production, together with a more profound examination of non-linguistic control difficulties would allow a more complete understanding of possible difficulties. Furthermore, from the receptive tasks that were used in the current study, we cannot demonstrate that language control is causally-related to TD's aphasic symptoms. Although, the results of the current study provide a crucial step towards a better understanding of differential aphasia, it would be very interesting to test for the causal relationship with an event-related fMRI study combined with causal modeling of the data in further research.

To summarize, the results of the current study supply additional evidence that a control deficit may explain differential aphasia. We found impaired linguistic as well as non-linguistic cognitive control abilities, suggesting domain general control impairment. Furthermore, functional connectivity analysis revealed a decreased connectivity between the patient's language control and naming network, consistent with the behavioral data. These findings shed new light on the cognitive basis of differential aphasia and on the role of executive control functions in language processing more in general.

Acknowledgements

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Figure 1. Visualization of the regions of interest for the language control (yellow), language comprehension (green) and language production network (purple). Overlapping areas are presented in orange. The language control network consists of the left anterior cingulate cortex (ACC), the left head of caudate (HC) and the left pars orbitalis (LPorb). The language comprehension network contains the left angular gyrus (LAng), right inferior parietal cortex (RIPC), left supramarginal gyrus (LSupMG), left middle frontal cortex (MFC), left and right inferior temporal cortices (LITC and RITC), left planum temporale (PT), and left prefrontal regions 1 and 2 (PR1 and PR2). Finally, the left Broca's area (Broca), the right pars triangularis (PTri), the left and right pars orbitalis (LPorb and RPorb), the right pars opercularis (RPoper) and the left pars opercularis 1 and 2 (LPoper1 and LPoper2) are part of the language production network.

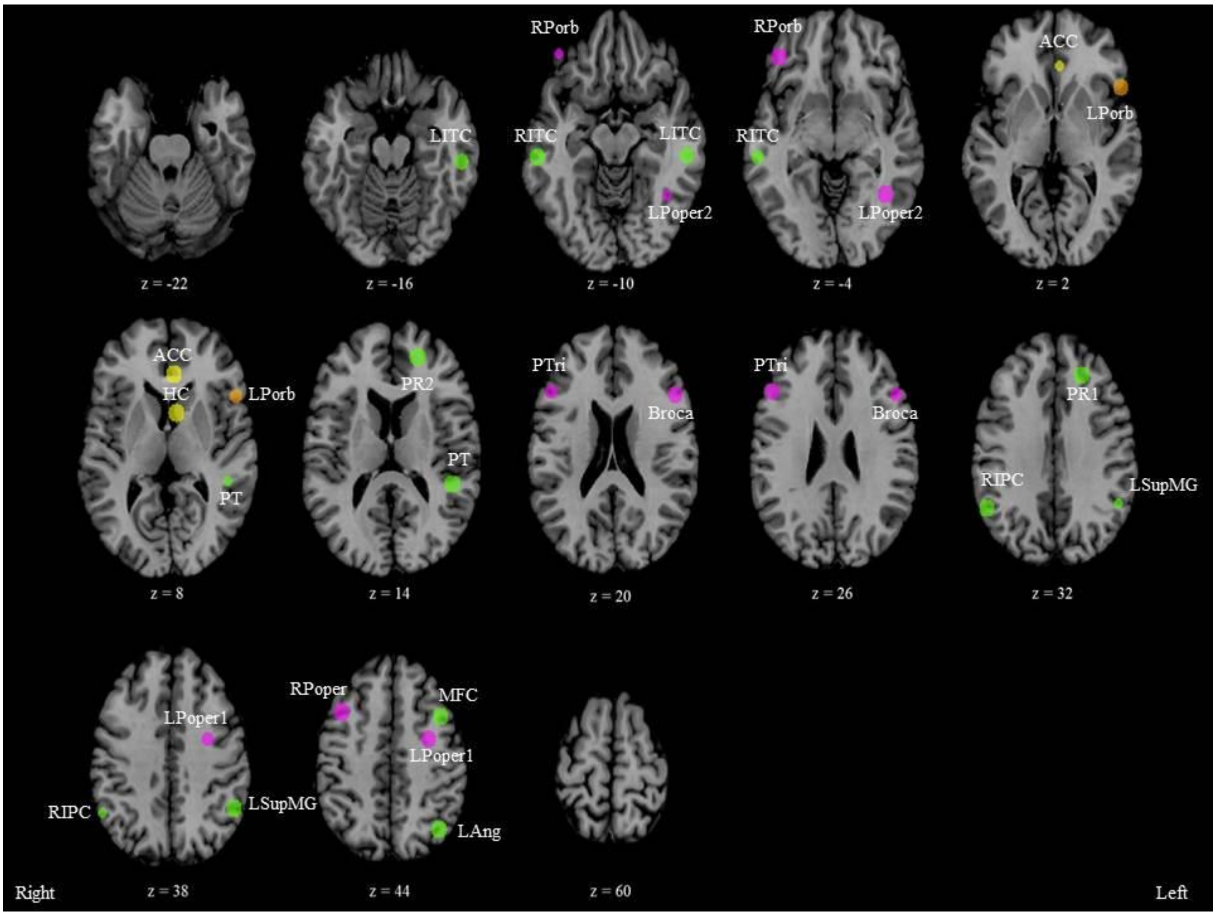

Figure 2. The T1-weighted MRI images showing left-sided parenchymal damage to the parietal lobe with prominent corticoclastic encephalomalacia resulting in focal loss of brain tissue together with secondary ex vacuo enlargement of homolateral ventricular trigone.

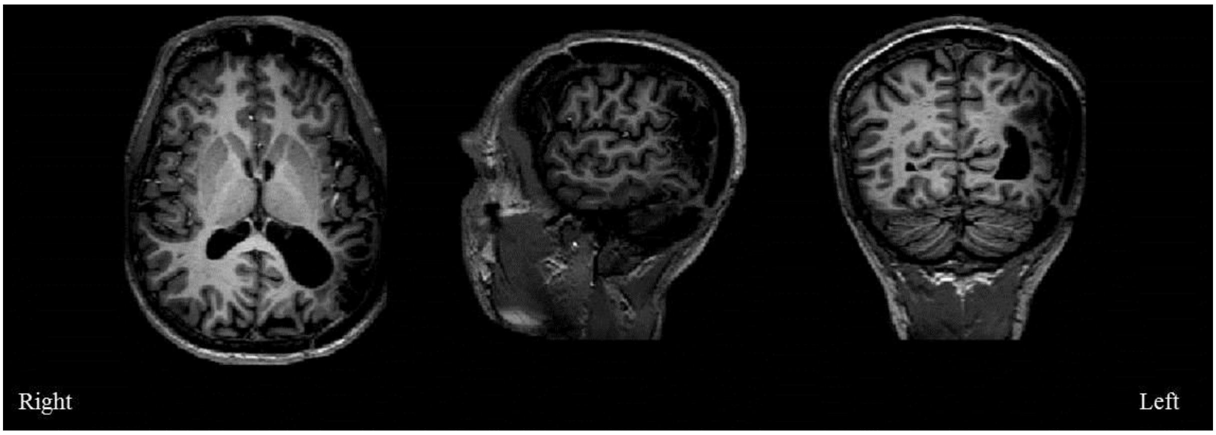

Figure 3. Schematic representation for (A) the generalized LD task, (B) the French selective LD task and (C) the English selective LD task. Participants had to decide whether the letter string on the screen was (A) an existing word in any language, (B) an existing word in French, or (C) an existing word in English.

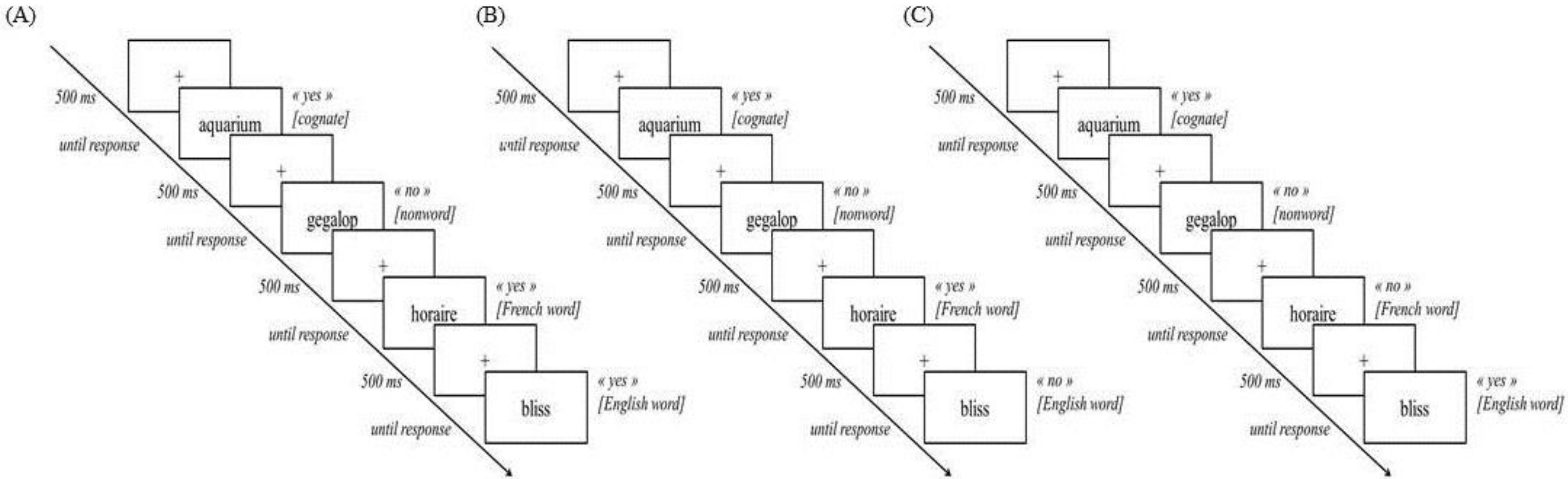

Figure 4. Mean accuracy (proportion correct) for (A) the generalized LD task, (B) the French selective LD task and (C) the English selective LD task as a function of Word Status (cognate, English word, French word and nonword) and Group (control group and patient TD). Error bars denote standard errors.

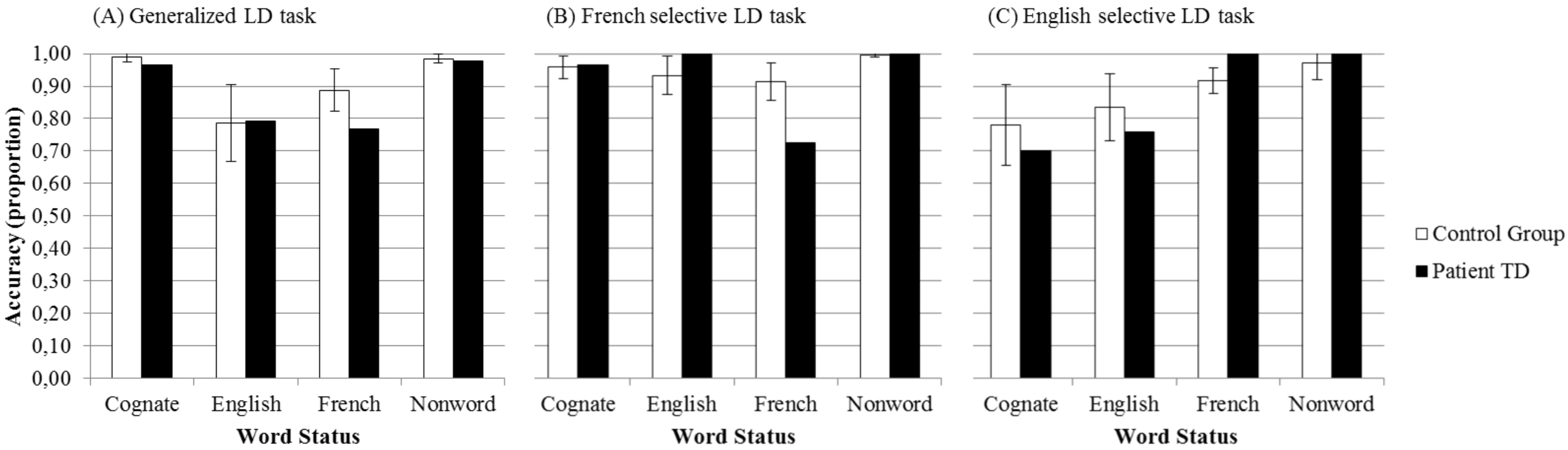

Figure 5. Mean reaction times for the flanker task as a function of Condition (congruent and incongruent) and Group (control group and patient TD). Vertical bars denote standard errors.

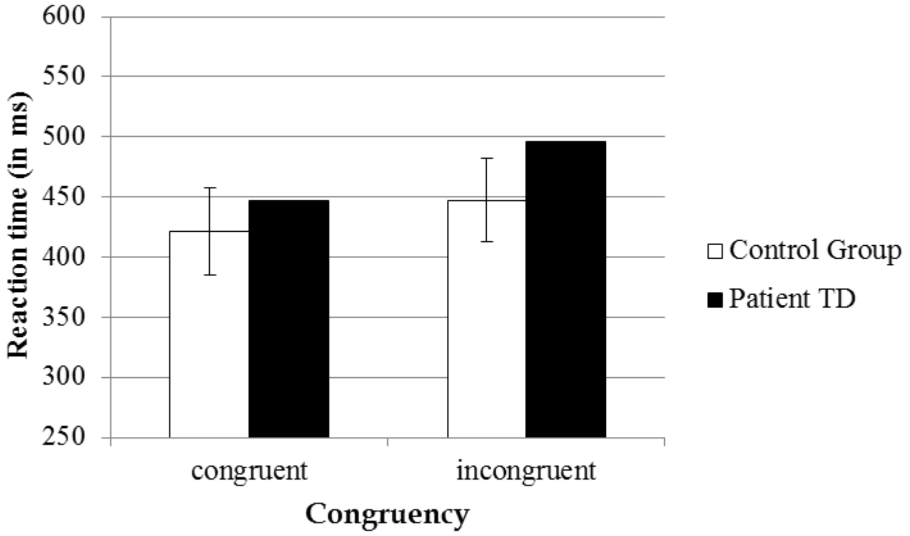

Table 1

Results of the control group and the patient on control tasks. For the control group (n = 10), mean results are presented with standard deviations between brackets. Group differences were tested with Singlims_ES t-tests(Crawford, et al., 2010). T-tests were calculated with df 9. One-tailed p-values are presented.

	Score controls	Score TD	*t*-value	Effect size (Z_{CC})	% falling below TD	% CI
Age (in years)	31.90 (3.78)	32.00	< 1	0.03	50.98	27.62 to 74.07
Raven (raw score)	58.30 (1.16)	59.00	< 1	0.60	71.04	46.48 to 89.75
Speaking L1 (scale)	9.70 (0.48)	9.00	-1.39^{+}	-1.46	9.89	0.94 to 29.71
Speaking L2 (scale)	8.60 (0.52)	8.00	-1.00	-1.15	14.99	2.57 to 37.31
Writing L1 (scale)	9.70 (0.48)	9.00	-1.39^{+}	-1.46	9.89	0.94 to 29.71
Writing L2 (scale)	8.60 (0.52)	8.00	-1.10	-1.15	14.99	2.57 to 37.31
Synonym judgement	NA	$226/240^{\$}$				
- concrete nouns		$58/60^{\$}$				
- abstract nouns		$56/60^{\$}$				
- concrete verbs		$59/60^{\$}$				
- abstract verbs		$53/60^{\$}$				
Memory span		7				
Brown-Peterson task	NA					
- 0 s interval (%)		100				
- 5 s interval (%)		94.4				
- 10 s interval (%)		88.9				
- 20 s interval (%)		100				
French BAT	NA					
- syntactic comprehension		$24/37^{\$}$				
- semantic opposites		$8/10^{\$}$				
- silent reading		5/6				
- silent reading sentences		$7/10^{\$}$				
English BAT	NA					
- syntactic comprehension		$31/37^{\$}$				
- semantic opposites		9/10				
- silent reading		6/6				
- silent reading sentences		9/10				

Note: $^{+}$ <.10, * <.05, ** <.01, *** <.001, $^{\$}$ = score not in normal range, NA = not applicable

Table 2.

Regions of interest and TAL coordinates for each resting-state language network.

Network	Region (Brodmann area)	Abbreviation	TAL x, y, z coordinates
Control	Left head of caudate	HC	-7, 7, 8
	Left pars orbitalis (BA47)	LPorb	-51, 18, 4
	Left anterior cingulate cortex	ACC	-5, 32, 7
Comprehension	Left angular gyrus (BA39)	LAng	-37, -64, 44
	Right inferior parietal cortex (BA40)	RIPC	51, -53, 33
	Left supramarginal gyrus (BA40)	LSupMG	-49, -50, 37
	Left middle frontal cortex (BA46)	MFC	-38, 11, 45
	Left inferior temporal cortex (BA21/20)	LITC	-54, -28, -13
	Right inferior temporal cortex (BA21/20)	RITC	57, -29, -8
	Left planum temporale	PT	-45, -37, 13
	Left prefrontal region 1 (BA9)	PR1	-21, 35, 32
	Left prefrontal region 2 (BA10)	PR2	-20, 47, 14
Production	Left Broca's area (BA45)	Broca	-48, 22, 22
	Right pars triangularis (BA45)	PTri	46, 24, 24
	Left pars orbitalis (BA47)	LPorb	-51, 18, 4
	Right pars orbitalis (BA47)	RPorb	41, 36, -5
	Right pars opercularis (BA44)	RPoper	37, 14, 44
	Left pars opercularis 1 (BA6)	LPoper1	-29, -4, 42
	Left pars opercularis 2 (BA37)	LPoper2	-39, -53, -5

Table 3

Results of the comparison between the matched control group (n = 10) and patient TD for the three LD tasks. Bayesian hypothesis tests on accuracy (proportion) and RTs (ms) were executed with SingleBayes_ES (Crawford et al., 2010). One-tailed probabilities that a member of the control populations would obtain a lower score than the patient are presented. Standard deviations for the control group are presented between parentheses. CI = Confidence interval; English cognate facilitation (CF) = score cognates – score English words; French cognate facilitation (CF) = score cognates – score French words.

	Generalized LD task						Non-dominant (French) LD task						Dominant (English) LD task					
	Mean controls	Mean TD	P	Effect size (Z_{CC})	% falling below TD	% CI	Mean controls	Mean TD	P	Effect size (Z_{CC})	% falling below TD	% CI	Mean controls	Mean TD	P	Effect size (Z_{CC})	% fallin g below TD	% CI
Accurary																		
Cognate	.99 (.02)	.97	.10	-1.44	10.19	1.02 to 30.19	.96 (.04)	.97	.43	0.19	57.16	33.13 to 79.27	.78 (.12)	.70	.28	-0.65	27.70	9.43 to 52.24
English	.79 (.12)	.79	.48	0.06	52.22	28.72 to 75.16	.93 (.06)	1.00	.15	1.14	84.65	52.15 to 97.27	.83 (.10)	.76	.25	-0.72	25.47	7.99 to 49.84
French	.89 (.07)	.77	.06^{+}	-1.85	5.62	0.21 to 21.58	.91 (.06)	.72	< .01**	-3.33	0.56	0.00 to 4.57	.92 (.04)	1.00	.04*	2.13	96.35	83.19 to 99.94
Nonword	.98 (.01)	.98	.35	-0.43	34.63	14.32 to 59.20	1.00 (.01)	1.00	.27	0.67	72.96	48.45 to 91.00	.97 (.05)	1.00	.29	0.60	70.94	46.35 to 89.66
English CF	.20 (.12)	.17	.41	-0.25	41.00	19.27 to 65.22	NA	NA	NA	NA	NA	NA	-.05 (.16)	-.06	.48	-0.06	47.89	24.97 to 71.40
French CF	.10 (.07)	.20	0.11	1.41	89.35	69.01 to 98.86	.05 (.08)	.24	.02*	2.51	97.99	88.46 to 99.99	NA	NA	NA	NA	NA	NA
English vs. French	-.10 (.11)	.03	0.15	1.18	85.47	63.27 to 97.60	.02 (.11)	.28	.03*	2.33	97.33	86.13 to 99.98	-.08 (.13)	-.24	.13	-1.24	13.37	1.98 to 35.04

Note: $^{+}$ <.10, * <.05, ** <.01, *** <.001

Table 3 Continued

	General LD task						Non-dominant (French) LD task						Dominant (English) LD task					
	Mean controls	Mean TD	P	Effect size (Z_{CC})	% falling below TD	% CI	Mean controls	Mean TD	P	Effect size (Z_{CC})	% falling below score	% CI	Mean controls	Mean TD	P	Effect size (Z_{CC})	% falling below TD	% CI
RTs																		
Cognate	738.23 (118.62)	1557.46	< .001***	6.91	100.00	99.99 to 100.00	778.75 (158.30)	2038.42	< .001***	7.96	100.00	100.00 to 100.00	1116.18 (310.33)	2525.33	< .001***	5.51	99.97	99.83 to 100.00
English	1058.99 (419.47)	3156.70	< .001***	5.00	99.95	99.59 to 100.00	790.82 (98.98)	1805.66	< .001***	10.25	100.00	100.00 to 100.00	972.12 (299.18)	1957.15	< .01**	3.29	99.40	95.18 to 100.00
French	834.21 (184.66)	1594.35	< .01**	4.12	99.83	98.38 to 100.00	858.01 (208.86)	2201.84	< .001***	6.43	99.99	99.97 to 100.00	873.78 (165.91)	2381.53	< .001***	9.09	100.00	100.00 to 100.00
Nonword	912.89 (333.60)	3318.35	< .001***	7.21	100.00	99.99 to 100.00	742.02 (93.02)	2418.11	< .001***	18.21	100.00	100.00 to 100.00	972.00 (198.68)	2442.30	< .001***	7.40	100.00	100.00 to 100.00
English CF	-320.80 (312.50)	-1599.00	< .01**	-4.09	0.18	0.00 to 1.67	NA	NA	NA	NA	NA	NA	144.06 (198.12)	868.18	< .01**	3.66	99.65	96.95 to 100.00
French CF	-95.97 (77.08)	-36.88	0.24	0.77	75.83	51.54 to 92.80	-68.26 (112.30)	-163.42	.22	-0.84	22.25	6.08 to 46.26	NA	NA	NA	NA	NA	NA
English vs. French	224.79 (282.88)	1562.30	< .001***	4.73	99.93	99.36 to 100.00	-67.18 (151.22)	-396.19	.03*	-2.18	3.40	0.04 to 16.00	98.34 (183.18)	-424.38	.01*	-2.85	1.18	0.00 to 8.00

Note: + <.10, * <.05, ** <.01, *** <.001, NA = not applicable

Table 4

Mean accuracy (proportion) and reaction times (ms) for the control group (n = 10) and patient TD on the flanker task (Eriksen & Eriksen, 1974). Bayesian hypothesis tests were executed with SingleBayes_ES (Crawford, et al., 2010) to compare the patient with the control group. One-tailed probabilities (P) that a member of the control populations would obtain a lower score than the patient are presented. Standard deviations for the control group are presented between parentheses. C = previous trial congruent; I = Previous trial incongruent; c = current trial congruent; i = current trial incongruent; Congruency effect = mean incongruent – mean congruent; Gratton effect = mean previous incongruent – mean previous congruent.

	Mean controls	Mean TD	P	Effect size (Z_{CC})	% falling below TD	% confidence interval
Accuracy						
Cc	.99 (.02)	.99	.43	0.19	57.01	33.00 to 79.16
Ci	.96 (.04)	.96	.45	0.12	54.51	30.74 to 77.08
Ic	.99 (.01)	1.00	.18	1.00	81.73	58.41 to 95.99
Ii	.97 (.05)	.99	.36	0.40	64.28	39.76 to 84.88
Congruency effect	-.03 (.03)	-.02	.41	0.26	59.45	35.23 to 81.12
Gratton effect	.01 (.01)	.02	.25	0.73	74.73	50.33 to 92.12
RT						
Cc	419.36 (34.82)	444.95	.25	0.74	74.94	50.57 to 92.25
Ci	447.88 (33.65)	498.33	.09^{+}	1.50	90.67	71.16 to 99.18
Ic	423.19 (37.06)	449.35	.26	0.71	74.11	49.67 to 91.73
Ii	445.07 (36.34)	494.42	.11	1.36	88.62	67.86 to 98.66
Congruency effect	25.20 (11.58)	49.22	.04*	2.07	96.03	82.34 to 99.93
Gratton effect	0.51 (4.96)	0.24	.48	-0.06	47.98	25.03 to 71.48

Note: $^{+}$ < .10, * < .05, ** < .01, *** < .001

Table 5

Results of the functional connectivity comparison between the control group (n = 26) and patient TD within language comprehension, production and control networks and between language control and comprehension regions as well as between language control and production regions (Figure 1). Bayesian hypothesis tests were conducted with the SingleBayes_ES software (Crawford, et al., 2010). Standard deviations for the control group are presented between parentheses. One-tailed probabilities (P) are presented, which reflect the probability that a member of the control population would obtain a lower score than TD.

Network	Connection	Mean controls	Mean patient	P	Effect size (Z_{CC})	% falling below score	% confidence interval
Comprehension	LAng - RIPC	.44 (.19)	.64	.16	1.05	84.42	71.33 to 93.65
	LAng - LSupMG	.57 (.17)	.51	.37	-0.35	36.60	22.79 to 51.88
	LAng - MFC	.44 (.17)	.03	.01**	-2.41	1.30	0.08 to 5.08
	LAng – LITC	.23 (.13)	.46	.05*	1.77	95.25	87.29 to 99.14
	LAng – RITC	.24 (.14)	.48	.05*	1.71	94.75	86.34 to 98.97
	LAng – PT	.16 (.14)	.13	.42	-0.21	41.76	27.40 to 57.02
	LAng – PR1	.16 (.20)	.08	.35	-0.40	34.90	21.31 to 50.15
	LAng – PR2	.19 (.17)	.17	.45	-0.12	45.45	30.79 to 60.62
	RIPC – LSupMG	.54 (.10)	.25	<.01**	-2.90	0.44	0.01 to 2.24
	RIPC – MFC	.46 (.14)	.31	0.15	-1.07	15.16	6.08 to 28.12
	RIPC – LITC	.12 (.15)	.50	<.01**	2.53	99.00	95.80 to 99.96
	RIPC – RITC	.27 (.14)	.53	.04*	1.86	95.98	88.66 to 99.36
	RIPC – PT	.16 (.17)	.08	.32	-0.47	32.41	19.18 to 47.60
	RIPC – PR1	.17 (.24)	.04	.30	-0.54	29.99	17.15 to 45.06
	RIPC – PR2	.12 (.17)	.17	.39	0.29	61.23	45.94 to 75.31
	LSupMG – MFC	.57 (.14)	-.25	<.001***	-5.86	0.00	0.00 to 0.00
	LSupMG – LITC	.23 (.18)	.31	.33	0.44	66.67	51.44 to 80.05
	LSupMG – RITC	.26 (.17)	.41	.20	0.88	80.25	66.28 to 90.82
	LSupMG – PT	.22 (.14)	.42	.09+	1.43	91.33	80.79 to 97.56
	LSupMG – PR1	.20 (.19)	.11	.32	-0.47	32.31	19.09 to 47.49
	LSupMG – PR2	.15 (.16)	.33	.14	1.13	85.99	73.34 to 94.64
	MFC – LITC	.22 (.18)	.28	.37	0.33	62.68	47.39 to 76.60
	MFC – RITC	.28 (.14)	.15	.19	-0.93	18.55	8.33 to 32.28
	MFC – PT	.22 (.12)	-.04	.02*	-2.17	2.18	0.21 to 7.36
	MFC – PR1	.24 (.23)	.10	.28	-0.61	27.79	15.34 to 42.72
	MFC – PR2	.21 (.18)	.17	.41	-0.22	41.46	27.13 to 56.72
	LITC - RITC	.53 (.18)	.69	.20	0.89	80.43	66.48 to 90.94
	LITC – PT	.15 (.15)	.15	.50	0.00	50.00	35.03 to 64.97
	LITC – PR1	.08 (.16)	.09	.48	0.06	52.42	37.34 to 67.25
	LITC – PR2	.10 (.22)	.26	.24	0.73	75.89	61.29 to 87.58
	RITC - PT	.22 (.15)	.24	.45	0.13	55.15	39.96 to 69.79
	RITC – PR1	.14 (.16)	.12	.45	-0.13	45.17	30.53 to 60.34
	RITC – PR2	.14 (.19)	.24	.31	0.53	69.49	54.37 to 82.43
	PT – PR1	.24 (.13)	.32	.28	0.62	72.43	57.49 to 84.84
	PT – PR2	.22 (.17)	.50	.06+	1.65	94.07	85.18 to 98.72
	PR1 – PR2	.44 (.12)	.56	.17	1.00	83.20	69.81 to 92.86

Note: + < .10, * < .05, ** < .01, *** < .001

Table 5 Continued

Network	Connection	Mean controls	Mean patient	P	Effect size (Z_{CC})	% falling below score	% confidence interval
Production	Broca – PTri	.60 (.10)	.70	.17	1.00	83.20	69.81 to 92.86
	Broca – RPorb	.15 (.17)	.17	.45	0.12	54.55	39.38 to 69.23
	Broca – RPoper	.30 (.17)	.36	.37	0.35	63.40	48.11 to 77.22
	Broca – LPoper1	.26 (.20)	.34	.35	0.40	65.10	49.84 to 78.71
	Broca – LPoper2	.20 (.20)	-.09	.08^{+}	-1.45	8.36	2.29 to 18.73
	LPorb – Broca	.40 (.18)	.33	.35	-0.39	35.30	21.66 – 50.55
	LPorb – Ptri	.25 (.21)	.29	.43	0.19	57.34	42.10 – 71.80
	LPorb – RPorb	.25 (.25)	.36	.33	0.44	66.52	51.28 – 79.92
	LPorb – Rpoper	.23 (.19)	.13	.31	-0.53	30.51	17.58 – 45.61
	LPorb – LPoper1	.23 (.12)	.37	.13	1.17	86.84	75.46 – 95.15
	LPorb – LPoper2	.18 (.19)	.20	.46	0.11	54.07	38.92 – 68.79
	PTri – RPorb	.19 (.23)	.07	.31	-0.52	30.66	17.71 to 45.77
	PTri – RPoper	.38 (.21)	.36	.46	-0.10	46.31	31.58 to 61.45
	PTri – LPoper1	.24 (.19)	.26	.46	0.11	54.07	38.92 to 68.79
	PTri – LPoper2	.18 (.17)	-.11	.05*	-1.71	5.33	1.06 to 13.76
	RPorb – RPoper	.22 (.20)	.54	.06^{+}	1.60	93.55	84.30 to 98.52
	RPorb – LPoper1	.10 (.16)	.22	.23	0.75	76.57	62.04 to 88.10
	RPorb – LPoper2	.14 (.15)	.38	.06^{+}	1.60	93.55	84.30 to 98.52
	RPoper – LPoper1	.23 (.20)	.20	.44	-0.15	44.21	29.64 to 59.42
	RPoper – LPoper2	.08 (.16)	.08	.50	0.00	50.00	35.03 to 64.97
	LPoper1 – LPoper2	.23 (.20)	.38	.23	0.75	76.57	62.04 to 88.10
Control	LPorb – ACC	.15 (.20)	.09	.39	-0.30	38.55	24.52 to 53.83
	LPorb – HC	.32 (.17)	.24	.32	-0.47	32.41	19.18 to 47.60
	HC – ACC	.31 (.19)	.39	.34	0.42	65.85	50.60 to 79.35
Control – Comprehension	LPorb – LAng	.26 (.15)	.19	.33	-0.47	32.55	19.30 to 47.74
	LPorb – RIPC	.22 (.15)	.13	.28	-0.60	28.07	15.57 to 43.02
	LPorb – LsupMG	.34 (.15)	.16	.13	-1.20	12.51	4.46 to 24.66
	LPorb – MFC	.40 (.19)	.07	.05*	-1.74	5.04	0.86 to 13.23
	LPorb – LITC	.34 (.24)	.28	.40	-0.25	40.41	26.18 to 55.68
	LPorb – RITC	.27 (.20)	.27	.50	0.00	50.00	35.03 to 64.97
	LPorb – PT	.28 (.14)	.16	.20	-0.86	20.42	9.65 to 34.48
	LPorb – PR1	.23 (.16)	.66	<.01**	2.69	99.29	96.75 to 99.98
	LPorb – PR2	.22 (.21)	.38	.23	0.76	76.91	62.43 to 88.36
	HC – LAng	.23 (.14)	-.08	.02*	-2.21	1.97	0.17 to 6.86
	HC – RIPC	.17 (.19)	-.01	.18	-0.95	18.08	8.00 to 31.71
	HC – LsupMG	.25 (.15)	.11	.18	-0.93	18.43	8.24 to 32.13
	HC – MFC	.26 (.18)	.28	.46	0.11	54.30	39.14 to 69.00
	HC – LITC	.29 (.17)	.14	.20	-0.88	19.74	9.17 to 33.69
	HC – RITC	.28 (.16)	.06	.09^{+}	-1.38	9.47	2.83 to 20.40
	HC – PT	.27 (.12)	.25	.44	-0.17	43.57	29.05 to 58.79
	HC – PR1	.31 (13)	.39	.28	0.62	72.43	57.49 to 84.84
	HC – PR2	.38 (.12)	.26	.17	-1.00	16.80	7.14 to 30.15

Note: $^{+}$ < .10, * < .05, ** < .01, *** < .001

Table 5 Continued

Network	Connection	Mean controls	Mean patient	P	Effect size (Z_{CC})	% falling below score	% confidence interval
Control - Comprehension	ACC – LAng	.08 (.13)	-.13	.06+	-1.62	6.28	1.41 – 15.39
	ACC – RIPC	.03 (.15)	-.04	.33	-0.47	32.55	19.30 – 47.74
	ACC – LsupMG	.02 (.15)	.15	.20	0.87	79.84	65.79 – 90.52
	ACC – MFC	.07 (.11)	.04	.40	-0.27	39.56	25.42 – 54.84
	ACC – LITC	.18 (.29)	.13	.43	-0.17	43.35	28.85 – 58.58
	ACC – RITC	.18 (.23)	.19	.48	0.04	51.68	36.63 – 66.56
	ACC – PT	.09 (.12)	.40	<.01**	2.58	99.10	96.13 – 99.96
	ACC – PR1	.21 (.14)	.29	.29	0.57	71.00	55.96 – 83.67
	ACC – PR2	.37 (.18)	.41	.41	0.22	58.54	43.28 – 72.89
Control - Production	LPorb – Broca	.40 (.18)	.33	.35	-0.39	35.30	21.66 – 50.55
	LPorb – Ptri	.25 (.21)	.29	.43	0.19	57.34	42.10 – 71.80
	LPorb – RPorb	.25 (.25)	.36	.33	0.44	66.52	51.28 – 79.92
	LPorb – Rpoper	.23 (.19)	.13	.31	-0.53	30.51	17.58 – 45.61
	LPorb – LPoper1	.23 (.12)	.37	.13	1.17	86.84	75.46 – 95.15
	LPorb – LPoper2	.18 (.19)	.20	.46	0.11	54.07	38.92 – 68.79
	HC – Broca	.35 (.10)	.08	<.01**	-2.70	0.69	0.02 – 3.17
	HC – Ptri	.27 (.12)	.07	.06+	-1.67	5.73	1.20 – 14.45
	HC – RPorb	.19 (.13)	.27	.28	0.62	72.43	57.49 – 84.84
	HC – Rpoper	.27 (.12)	.19	.26	-0.67	25.95	13.86 – 40.72
	HC – LPoper1	.21 (.21)	.47	.12	1.24	88.21	76.31 – 95.94
	HC – LPoper2	.10 (.20)	.49	.03*	1.95	96.64	89.99 – 99.54
	ACC – Broca	.09 (.14)	-.01	.24	-0.71	24.49	12.72 – 39.11
	ACC – Ptri	.04 (.16)	.03	.48	-0.06	47.58	32.76 – 62.67
	ACC – RPorb	.15 (.21)	.05	.32	-0.48	32.22	19.02 – 47.40
	ACC – Rpoper	.08 (.13)	.18	.23	0.77	77.13	62.67 – 88.52
	ACC – LPoper1	.13 (.12)	.35	.04*	1.83	95.79	88.30 – 99.30
	ACC – LPoper2	-.03 (.20)	.19	.15	1.10	85.46	72.66 – 94.31

Note: + < .10, * < .05, ** < .01, ***

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Appendix A

Stimuli and their characteristics for the Generalized lexical decision task. Word characteristics are retrieved from Wordgen (Duyck, et al., 2004). NA = not applicable.

Word Status	Stimulus	Length	Frequency French	Frequency English	Neighbors French	Neighbors English
cognate	bus	3	0.85	1.91	7	9
	cage	4	1.42	1.28	14	12
	cobra	5	0.00	0.48	1	1
	pigeon	6	1.09	1.04	1	0
	fanfare	7	0.56	0.30	0	0
	rutabaga	8	0.00	0.00	0	0
	escalator	9	0.00	0.30	0	0
	irritation	10	0.80	1.08	1	1
	destitution	11	0.00	0.00	1	1
	accentuation	12	0.39	0.00	0	0
	ranch	5	0.00	0.85	3	1
	menace	6	1.61	1.00	2	1
	forceps	7	0.00	0.00	0	0
	succinct	8	0.12	0.00	0	0
	chauffeur	9	1.42	0.78	0	0
	prohibition	11	0.61	0.85	0	0
	niche	5	0.80	0.70	6	0
	garage	6	1.14	1.40	3	0
	aquarium	8	0.55	0.00	0	1
	commerce	8	1.82	1.11	1	1
	antidote	8	0.13	0.30	0	0
	hostile	7	1.26	1.45	0	0
	humble	6	1.19	1.15	0	7
	convivial	9	0.00	0.30	0	0
	subterfuge	10	0.12	0.00	0	0
	trace	5	1.81	1.75	4	7
	vortex	6	0.00	0.00	2	2
	torture	7	1.02	1.38	3	0
	figurine	8	0.23	0.00	1	0
	pantomime	9	0.51	0.48	0	0
	MEAN	7.43	0.65	0.66	1.67	1.47
		(2.18)	(0.61)	(0.60)	(2.96)	(3.05)
French word	suc	3	0.79	NA	8	NA
	soie	4	1.50	NA	14	NA
	aplat	5	0.00	NA	1	NA
	pilule	6	0.82	NA	1	NA
	jubiler	7	0.51	NA	0	NA
	prévôtal	8	0.00	NA	0	NA
	sensorium	9	0.00	NA	0	NA
	ondulation	10	0.63	NA	0	NA
	pancréatine	11	0.00	NA	1	NA
	reconversion	12	0.42	NA	0	NA
	alise	5	0.00	NA	2	NA
	estime	6	1.42	NA	2	NA
	bouchon	7	1.02	NA	3	NA
	bougnoul	8	0.25	NA	0	NA
	sépulture	9	0.43	NA	0	NA
	ferroviaire	11	0.52	NA	0	NA
	ongle	5	1.41	NA	3	NA
	médité	6	0.29	NA	1	NA
	félicité	8	0.63	NA	1	NA
	franchir	8	1.68	NA	1	NA
	énervant	8	0.13	NA	0	NA
	horaire	7	1.21	NA	0	NA
	frémir	6	1.18	NA	0	NA
	cependant	9	2.33	NA	0	NA
	propulseur	10	0.11	NA	0	NA
	larme	5	1.88	NA	4	NA
	clapot	6	0.00	NA	2	NA
	bruiter	7	0.00	NA	2	NA

Appendix A continued.

Word Status	Stimulus	Length	Frequency French	Frequency English	Neighbors French	Neighbors English
French word	momifier	8	0.26	NA	1	NA
	glaciaire	9	0.19	NA	0	NA
	MEAN	7.43	0.65	NA	1.57	NA
		(2.18)	(0.65)		(2.90)	
English word	aim	3	NA	1.96	NA	10
	sour	4	NA	1.11	NA	12
	abort	5	NA	0.30	NA	1
	bodily	6	NA	1.00	NA	0
	brewery	7	NA	0.48	NA	0
	behemoth	8	NA	0.00	NA	0
	intricacy	9	NA	0.48	NA	0
	bitterness	10	NA	1.00	NA	0
	deferential	11	NA	0.00	NA	1
	exhilaration	12	NA	0.30	NA	0
	bliss	5	NA	0.95	NA	1
	stakes	6	NA	0.78	NA	2
	sunspot	7	NA	0.00	NA	0
	clearway	8	NA	0.00	NA	0
	bodyguard	9	NA	0.78	NA	0
	unthinkable	11	NA	0.85	NA	0
	macaw	5	NA	0.00	NA	0
	forego	6	NA	0.70	NA	0
	ruggedly	8	NA	0.00	NA	1
	basement	8	NA	1.15	NA	1
	foretell	8	NA	0.48	NA	0
	farming	7	NA	1.51	NA	0
	mumble	6	NA	1.26	NA	6
	blindfold	9	NA	0.30	NA	0
	unhallowed	10	NA	0.00	NA	0
	spite	5	NA	1.72	NA	7
	polity	6	NA	0.00	NA	2
	wedding	7	NA	1.57	NA	2
	ticklish	8	NA	0.00	NA	0
	enactment	9	NA	0.00	NA	0
	MEAN	7.43	NA	0.62	NA	1.53
		(2.18)		(0.60)		(3.08)
Nonword	rix	3	NA	NA	NA	NA
	gec	3	NA	NA	NA	NA
	huf	3	NA	NA	NA	NA
	poud	4	NA	NA	NA	NA
	olde	4	NA	NA	NA	NA
	gnut	4	NA	NA	NA	NA
	jasot	5	NA	NA	NA	NA
	duris	5	NA	NA	NA	NA
	murdi	5	NA	NA	NA	NA
	muyect	6	NA	NA	NA	NA
	panave	6	NA	NA	NA	NA
	onneth	6	NA	NA	NA	NA
	poertud	7	NA	NA	NA	NA
	gachand	7	NA	NA	NA	NA
	vodrane	7	NA	NA	NA	NA
	acemozol	8	NA	NA	NA	NA
	duarmavi	8	NA	NA	NA	NA
	bolalieu	8	NA	NA	NA	NA
	setaminti	9	NA	NA	NA	NA
	utandotul	9	NA	NA	NA	NA
	abogmecum	9	NA	NA	NA	NA
	iconcalmie	10	NA	NA	NA	NA
	isabortact	10	NA	NA	NA	NA
	pibebigroc	10	NA	NA	NA	NA
	gastebelbre	11	NA	NA	NA	NA
	slactemosoc	11	NA	NA	NA	NA
	melyrevoule	11	NA	NA	NA	NA

Appendix A Continued.

Word Status	Stimulus	Length	Frequency French	Frequency English	Neighbors French	Neighbors English
Nonword	joire	5	NA	NA	NA	NA
	voise	5	NA	NA	NA	NA
	loile	5	NA	NA	NA	NA
	rialme	6	NA	NA	NA	NA
	hiroud	6	NA	NA	NA	NA
	bierra	6	NA	NA	NA	NA
	cacirre	7	NA	NA	NA	NA
	samoche	7	NA	NA	NA	NA
	felmoel	7	NA	NA	NA	NA
	eurmoore	8	NA	NA	NA	NA
	glutarns	8	NA	NA	NA	NA
	jurnvril	8	NA	NA	NA	NA
	cuthrsmum	9	NA	NA	NA	NA
	thrumporc	9	NA	NA	NA	NA
	daubsifor	9	NA	NA	NA	NA
	cedravrefoc	11	NA	NA	NA	NA
	sedibromush	11	NA	NA	NA	NA
	appeeromila	11	NA	NA	NA	NA
	tinal	5	NA	NA	NA	NA
	nesul	5	NA	NA	NA	NA
	kanom	5	NA	NA	NA	NA
	caceon	6	NA	NA	NA	NA
	urupie	6	NA	NA	NA	NA
	ruvego	6	NA	NA	NA	NA
	apocurga	8	NA	NA	NA	NA
	aluspeti	8	NA	NA	NA	NA
	nobosabi	8	NA	NA	NA	NA
	unhainne	8	NA	NA	NA	NA
	thaintal	8	NA	NA	NA	NA
	jardafeu	8	NA	NA	NA	NA
	finharin	8	NA	NA	NA	NA
	joshabem	8	NA	NA	NA	NA
	felokist	8	NA	NA	NA	NA
	fuprnic	7	NA	NA	NA	NA
	lymmesh	7	NA	NA	NA	NA
	fuclors	7	NA	NA	NA	NA
	zibsta	6	NA	NA	NA	NA
	suddot	6	NA	NA	NA	NA
	gledol	6	NA	NA	NA	NA
	adrautros	9	NA	NA	NA	NA
	fudolatti	9	NA	NA	NA	NA
	naskimmer	9	NA	NA	NA	NA
	zissusmath	10	NA	NA	NA	NA
	dollvrysme	10	NA	NA	NA	NA
	fultrefloc	10	NA	NA	NA	NA
	dours	5	NA	NA	NA	NA
	sploc	5	NA	NA	NA	NA
	doufe	5	NA	NA	NA	NA
	glipne	6	NA	NA	NA	NA
	poghlo	6	NA	NA	NA	NA
	detsmi	6	NA	NA	NA	NA
	urfasse	7	NA	NA	NA	NA
	surmode	7	NA	NA	NA	NA
	drefuxe	7	NA	NA	NA	NA
	picrator	8	NA	NA	NA	NA
	frateron	8	NA	NA	NA	NA
	ralumbus	8	NA	NA	NA	NA
	laghunuck	9	NA	NA	NA	NA
	hylanfrah	9	NA	NA	NA	NA
	pavoceray	9	NA	NA	NA	NA

Appendix A Continued.

Word Status	Stimulus	Length	Frequency French	Frequency English	Neighbors French	Neighbors English
Nonword	gicerwisefac	12	NA	NA	NA	NA
	diuvalucinck	12	NA	NA	NA	NA
	asimoburcain	12	NA	NA	NA	NA
	MEAN	7.43 (2.15)	NA	NA	NA	NA

Appendix B

Stimuli and their characteristics for the French selective lexical decision task. Word characteristics are retrieved from Wordgen (Duyck, et al., 2004). NA = not applicable.

Word Status	Stimulus	Length	Frequency French	Frequency English	Neighbors French	Neighbors English
cognate	trot	4	0.81	1.26	4	3
	gnome	5	0.15	0.48	1	0
	bikini	6	0.25	0.30	0	0
	opossum	7	0.00	0.00	0	0
	flamenco	8	0.00	0.00	0	0
	moustache	9	1.39	1.30	1	0
	abominable	10	0.80	0.30	0	1
	agriculture	11	1.56	1.61	0	0
	accumulation	12	0.95	0.85	0	0
	olive	5	0.85	1.20	1	1
	jungle	6	0.70	1.26	1	5
	divorce	7	0.95	1.56	1	0
	corpulent	9	0.00	0.00	0	0
	alligator	9	0.00	0.30	0	0
	caricature	10	0.69	0.78	1	0
	ogre	4	0.71	0.30	1	1
	nadir	5	0.00	0.00	0	0
	dragon	6	1.04	1.00	0	0
	brigand	7	0.55	0.00	0	0
	fracture	8	0.45	0.78	1	0
	gestation	9	0.37	0.00	1	1
	marsupial	9	0.00	0.30	0	0
	rural	5	1.54	1.67	2	2
	suture	6	0.00	0.00	1	1
	missile	7	0.00	1.73	2	2
	magazine	8	0.96	1.81	0	0
	avalanche	9	0.57	0.48	0	0
	stipulation	11	0.15	0.00	1	1
	bison	5	0.43	0.48	6	0
	famine	6	0.77	0.90	1	0
	MEAN	7.43	0.55	0.69	0.87	0.60
		(2.19)	(0.48)	(0.62)	(1.31)	(1.13)
French word	buis	4	0.68	NA	4	NA
	plouc	5	0.20	NA	1	NA
	glissé	6	1.23	NA	3	NA
	suavité	7	0.04	NA	0	NA
	perlouse	8	0.00	NA	0	NA
	casquette	9	1.31	NA	1	NA
	tourbillon	10	1.10	NA	2	NA
	ferrailleur	11	0.00	NA	0	NA
	nouvellement	12	0.51	NA	0	NA
	gonze	5	0.53	NA	1	NA
	touffu	6	0.60	NA	1	NA
	plupart	7	1.98	NA	0	NA
	ascenseur	9	1.43	NA	0	NA
	bagagiste	9	0.00	NA	0	NA
	foudroyant	10	0.71	NA	1	NA
	émis	4	0.78	NA	2	NA
	cogne	5	0.80	NA	7	NA
	remous	6	0.97	NA	0	NA
	cocotte	7	0.54	NA	0	NA
	mansarde	8	0.55	NA	1	NA
	déchaîner	9	1.12	NA	1	NA
	couvercle	9	1.13	NA	0	NA
	affin	5	0.00	NA	0	NA
	poivre	6	0.83	NA	1	NA
	prunées	7	0.00	NA	0	NA
	centaine	8	1.58	NA	0	NA
	éréthisme	9	0.00	NA	0	NA
	inculpation	11	0.00	NA	1	NA

Appendix B continued.

Word Status	Stimulus	Length	Frequency French	Frequency English	Neighbors French	Neighbors English
French word	surin	5	0.46	NA	6	NA
	souris	6	1.42	NA	2	NA
	MEAN	7.43	0.68	NA	1.17	NA
		(2.19)	(0.56)		(1.76)	
English word	idle	4	NA	1.18	NA	2
	hazel	5	NA	0.48	NA	0
	burden	6	NA	1.54	NA	0
	dizzily	7	NA	0.00	NA	0
	bargeman	8	NA	0.00	NA	0
	allowance	9	NA	1.49	NA	0
	dependable	10	NA	0.30	NA	1
	achievement	11	NA	1.61	NA	0
	housekeeping	12	NA	0.60	NA	0
	array	5	NA	1.00	NA	1
	bullet	6	NA	1.40	NA	5
	exhaust	7	NA	1.60	NA	0
	smokiness	9	NA	0.00	NA	0
	recollect	9	NA	0.48	NA	0
	refinement	10	NA	0.70	NA	0
	trek	4	NA	0.60	NA	1
	ladle	5	NA	0.60	NA	2
	cradle	6	NA	1.00	NA	0
	moorhen	7	NA	0.00	NA	0
	chestnut	8	NA	0.78	NA	0
	contumacy	9	NA	0.00	NA	0
	quietness	9	NA	0.30	NA	0
	waist	5	NA	1.36	NA	2
	bygone	6	NA	0.00	NA	1
	unaware	7	NA	1.23	NA	0
	timeless	8	NA	0.48	NA	1
	cowardice	9	NA	0.48	NA	0
	valediction	11	NA	0.00	NA	1
	windy	5	NA	0.70	NA	0
	arctic	6	NA	0.85	NA	0
	MEAN	7.43	NA	0.69	NA	0.57
		(2.19)		(0.54)		(1.07)
Nonword	daux	4	NA	NA	NA	NA
	auch	4	NA	NA	NA	NA
	gnem	4	NA	NA	NA	NA
	preis	5	NA	NA	NA	NA
	shlan	5	NA	NA	NA	NA
	toune	5	NA	NA	NA	NA
	vurdil	6	NA	NA	NA	NA
	enovou	6	NA	NA	NA	NA
	bonama	6	NA	NA	NA	NA
	gegalop	7	NA	NA	NA	NA
	ralletu	7	NA	NA	NA	NA
	oberiss	7	NA	NA	NA	NA
	utternom	8	NA	NA	NA	NA
	glavunal	8	NA	NA	NA	NA
	gixteela	8	NA	NA	NA	NA
	toflctass	9	NA	NA	NA	NA
	fuisenble	9	NA	NA	NA	NA
	noughneix	9	NA	NA	NA	NA
	lyocuspeon	10	NA	NA	NA	NA
	agiatuvunt	10	NA	NA	NA	NA
	vaclatemio	10	NA	NA	NA	NA
	lagrirofois	11	NA	NA	NA	NA
	shahubravru	11	NA	NA	NA	NA
	ameufesitsh	11	NA	NA	NA	NA
	stazychlonun	12	NA	NA	NA	NA
	puditonkepto	12	NA	NA	NA	NA
	juvintobroto	12	NA	NA	NA	NA

Appendix B Continued.

Word Status	Stimulus	Length	Frequency French	Frequency English	Neighbors French	Neighbors English
Nonword	cinor	5	NA	NA	NA	NA
	fluro	5	NA	NA	NA	NA
	ussam	5	NA	NA	NA	NA
	galvec	6	NA	NA	NA	NA
	fobage	6	NA	NA	NA	NA
	vinhoc	6	NA	NA	NA	NA
	glebsil	7	NA	NA	NA	NA
	chrygot	7	NA	NA	NA	NA
	thaumbi	7	NA	NA	NA	NA
	vasoemlom	9	NA	NA	NA	NA
	lulpispar	9	NA	NA	NA	NA
	sanuflaul	9	NA	NA	NA	NA
	nirluveor	9	NA	NA	NA	NA
	girtamana	9	NA	NA	NA	NA
	tinsiggio	9	NA	NA	NA	NA
	tarebodach	10	NA	NA	NA	NA
	jepanzauri	10	NA	NA	NA	NA
	pripanozel	10	NA	NA	NA	NA
	walo	4	NA	NA	NA	NA
	puro	4	NA	NA	NA	NA
	avix	4	NA	NA	NA	NA
	zirss	5	NA	NA	NA	NA
	kobrt	5	NA	NA	NA	NA
	cheam	5	NA	NA	NA	NA
	polpau	6	NA	NA	NA	NA
	zolfux	6	NA	NA	NA	NA
	danvil	6	NA	NA	NA	NA
	wamnies	7	NA	NA	NA	NA
	kautent	7	NA	NA	NA	NA
	sympeet	7	NA	NA	NA	NA
	cesmorle	8	NA	NA	NA	NA
	haumnras	8	NA	NA	NA	NA
	greenran	8	NA	NA	NA	NA
	teroonvis	9	NA	NA	NA	NA
	tindrilga	9	NA	NA	NA	NA
	eufalshin	9	NA	NA	NA	NA
	polgelcot	9	NA	NA	NA	NA
	rufrecidi	9	NA	NA	NA	NA
	vepasarnu	9	NA	NA	NA	NA
	semon	5	NA	NA	NA	NA
	olbal	5	NA	NA	NA	NA
	achol	5	NA	NA	NA	NA
	soobet	6	NA	NA	NA	NA
	buflud	6	NA	NA	NA	NA
	fimeut	6	NA	NA	NA	NA
	spolmet	7	NA	NA	NA	NA
	hurclue	7	NA	NA	NA	NA
	roffoce	7	NA	NA	NA	NA
	mebitien	8	NA	NA	NA	NA
	gortacle	8	NA	NA	NA	NA
	footocan	8	NA	NA	NA	NA
	recuricth	9	NA	NA	NA	NA
	doypasfry	9	NA	NA	NA	NA
	lirverfic	9	NA	NA	NA	NA
	onparkidust	11	NA	NA	NA	NA
	shellpurpil	11	NA	NA	NA	NA
	obelperhubi	11	NA	NA	NA	NA
	norna	5	NA	NA	NA	NA
	tadro	5	NA	NA	NA	NA
	muvus	5	NA	NA	NA	NA

Appendix B Continued.

Word Status	Stimulus	Length	Frequency French	Frequency English	Neighbors French	Neighbors English
Nonword	lasblo	6	NA	NA	NA	NA
	afless	6	NA	NA	NA	NA
	molsot	6	NA	NA	NA	NA
	MEAN	7.43 (2.17)	NA	NA	NA	NA

Appendix C

Stimuli and their characteristics of the English selective lexical decision task. Word characteristics are retrieved from Wordgen (Duyck, et al., 2004). NA = not applicable.

Word Status	Stimulus	Length	Frequency French	Frequency English	Neighbors French	Neighbors English
cognate	mule	4	0.74	0.95	7	10
	vain	4	1.68	1.15	10	7
	mucus	5	0.00	0.48	1	0
	badge	5	0.00	1.00	2	4
	jaguar	6	0.29	0.70	0	0
	torrent	7	1.10	0.70	0	1
	sternum	7	0.00	0.00	0	0
	inaction	8	0.27	0.00	0	0
	pollution	9	0.16	1.52	0	0
	locomotive	10	1.24	0.30	0	0
	palpitation	11	0.41	0.00	0	0
	gravitation	11	0.72	0.70	0	0
	kitchenette	11	0.00	0.30	0	0
	prude	5	0.00	0.00	1	3
	potion	6	0.20	0.00	3	3
	absence	7	1.89	1.64	0	0
	blizzard	8	0.00	0.48	0	0
	mezzanine	9	0.00	0.00	0	0
	ligament	8	0.00	0.48	0	0
	bible	5	1.15	1.30	3	0
	carafe	6	0.49	0.00	2	0
	marina	6	0.33	0.70	3	1
	cottage	7	0.00	1.59	1	1
	crocodile	9	0.52	0.78	0	0
	explosion	9	1.40	1.42	0	0
	sermon	6	0.64	0.95	1	0
	bracelet	8	0.94	0.85	0	0
	prose	5	0.82	0.85	6	6
	pedigree	8	0.04	0.30	0	0
	cactus	6	0.18	0.47	0	0
	MEAN	7.20	0.51	0.65	1.33	1.20
		(2.04)	(0.55)	(0.52)	(2.43)	(2.48)
French word	cime	4	0.93	NA	7	NA
	soin	4	1.84	NA	10	NA
	acier	5	1.52	NA	2	NA
	étuve	5	0.37	NA	2	NA
	seguia	6	0.00	NA	0	NA
	minerai	7	0.90	NA	0	NA
	rancard	7	0.19	NA	2	NA
	épervier	8	0.27	NA	0	NA
	souillure	9	0.40	NA	2	NA
	filouterie	10	0.00	NA	0	NA
	ordonnateur	11	0.50	NA	0	NA
	péniblement	11	0.90	NA	0	NA
	mugissement	11	0.24	NA	1	NA
	gigot	5	0.39	NA	2	NA
	diseur	6	0.00	NA	3	NA
	endroit	7	1.93	NA	0	NA
	peignage	8	0.00	NA	0	NA
	mélangeur	9	0.00	NA	0	NA
	majorant	8	0.00	NA	0	NA
	piqué	5	1.15	NA	3	NA
	silice	6	0.50	NA	2	NA
	taurin	6	0.00	NA	3	NA
	rebiqué	7	0.00	NA	1	NA
	hardiesse	9	0.52	NA	0	NA
	faiblesse	9	1.46	NA	0	NA
	talion	6	0.21	NA	1	NA
	justesse	8	0.85	NA	0	NA
	duite	5	0.51	NA	6	NA

Appendix C continued.

Word Status	Stimulus	Length	Frequency French	Frequency English	Neighbors French	Neighbors English
French word	réemploi	8	0.00	NA	0	NA
	joujou	6	0.18	NA	0	NA
	MEAN	7.20	0.53	NA	1.57	NA
		(2.04)	(0.57)		(2.39)	
English word	soar	4	NA	1.04	NA	10
	stab	4	NA	1.00	NA	7
	hefty	5	NA	0.48	NA	0
	wedge	5	NA	0.90	NA	4
	cloudy	6	NA	0.60	NA	0
	lobster	7	NA	0.60	NA	1
	tracery	7	NA	0.30	NA	0
	deletion	8	NA	0.00	NA	0
	happiness	9	NA	1.46	NA	0
	editorship	10	NA	0.30	NA	0
	launderette	11	NA	0.00	NA	0
	patronizing	11	NA	0.48	NA	0
	comradeship	11	NA	0.30	NA	0
	mirth	5	NA	0.30	NA	3
	footer	6	NA	0.00	NA	3
	sixteen	7	NA	1.43	NA	0
	downfall	8	NA	0.48	NA	0
	sundowner	9	NA	0.00	NA	0
	sparsely	8	NA	0.30	NA	0
	token	5	NA	1.00	NA	0
	geezer	6	NA	0.00	NA	0
	inmate	6	NA	0.85	NA	1
	wealthy	7	NA	1.25	NA	1
	raspberry	9	NA	0.60	NA	0
	pregnancy	9	NA	1.32	NA	0
	oyster	6	NA	0.85	NA	0
	buttress	8	NA	0.60	NA	0
	brace	5	NA	0.90	NA	6
	spurious	8	NA	0.48	NA	0
	buzzer	6	NA	0.48	NA	0
	MEAN	7.20	NA	0.61	NA	1.20
		(2.04)		(0.44)		(2.48)
Nonword	hotursh	7	NA	NA	NA	NA
	galboux	7	NA	NA	NA	NA
	conlond	7	NA	NA	NA	NA
	slootruf	8	NA	NA	NA	NA
	fombrite	8	NA	NA	NA	NA
	trozysme	8	NA	NA	NA	NA
	cratorfer	9	NA	NA	NA	NA
	begrauval	9	NA	NA	NA	NA
	rodashron	9	NA	NA	NA	NA
	shatunfe	8	NA	NA	NA	NA
	bookifel	8	NA	NA	NA	NA
	lansovos	8	NA	NA	NA	NA
	fruck	5	NA	NA	NA	NA
	gnick	5	NA	NA	NA	NA
	isbal	5	NA	NA	NA	NA
	tadmon	6	NA	NA	NA	NA
	sliger	6	NA	NA	NA	NA
	koobem	6	NA	NA	NA	NA
	ommero	6	NA	NA	NA	NA
	cahora	6	NA	NA	NA	NA
	mesona	6	NA	NA	NA	NA
	ingolch	7	NA	NA	NA	NA
	cypsfon	7	NA	NA	NA	NA
	ochevem	7	NA	NA	NA	NA
	stityncry	9	NA	NA	NA	NA
	thipsauta	9	NA	NA	NA	NA
	cagapenst	9	NA	NA	NA	NA

Appendix C Continued.

Word Status	Stimulus	Length	Frequency French	Frequency English	Neighbors French	Neighbors English
Nonword	ongetiret	9	NA	NA	NA	NA
	fosfarcam	9	NA	NA	NA	NA
	sorausbit	9	NA	NA	NA	NA
	grodas	6	NA	NA	NA	NA
	aslife	6	NA	NA	NA	NA
	coggis	6	NA	NA	NA	NA
	tiemarnd	8	NA	NA	NA	NA
	vufflach	8	NA	NA	NA	NA
	tyrntist	8	NA	NA	NA	NA
	kilst	5	NA	NA	NA	NA
	ampst	5	NA	NA	NA	NA
	tygns	5	NA	NA	NA	NA
	jumpunah	8	NA	NA	NA	NA
	spemodas	8	NA	NA	NA	NA
	apniflux	8	NA	NA	NA	NA
	gegich	6	NA	NA	NA	NA
	jublud	6	NA	NA	NA	NA
	cantes	6	NA	NA	NA	NA
	moom	4	NA	NA	NA	NA
	lins	4	NA	NA	NA	NA
	utch	4	NA	NA	NA	NA
	vact	4	NA	NA	NA	NA
	olck	4	NA	NA	NA	NA
	plor	4	NA	NA	NA	NA
	unler	5	NA	NA	NA	NA
	synto	5	NA	NA	NA	NA
	ideor	5	NA	NA	NA	NA
	jagrt	5	NA	NA	NA	NA
	pnope	5	NA	NA	NA	NA
	sonck	5	NA	NA	NA	NA
	irofon	6	NA	NA	NA	NA
	unimus	6	NA	NA	NA	NA
	finoda	6	NA	NA	NA	NA
	moorfol	7	NA	NA	NA	NA
	slosaux	7	NA	NA	NA	NA
	penlair	7	NA	NA	NA	NA
	lonjech	7	NA	NA	NA	NA
	lolshan	7	NA	NA	NA	NA
	nogrish	7	NA	NA	NA	NA
	angrabse	8	NA	NA	NA	NA
	efegomps	8	NA	NA	NA	NA
	jobsotau	8	NA	NA	NA	NA
	suffaspil	9	NA	NA	NA	NA
	gutsherco	9	NA	NA	NA	NA
	tonshonux	9	NA	NA	NA	NA
	omunlophex	10	NA	NA	NA	NA
	catabolant	10	NA	NA	NA	NA
	nolfoxitif	10	NA	NA	NA	NA
	cluvunjegro	11	NA	NA	NA	NA
	vocaflupren	11	NA	NA	NA	NA
	molugmaline	11	NA	NA	NA	NA
	sturdostiss	11	NA	NA	NA	NA
	plepifaferd	11	NA	NA	NA	NA
	pubrupomita	11	NA	NA	NA	NA
	kochennette	11	NA	NA	NA	NA
	rhoenagotte	11	NA	NA	NA	NA
	gnypaizirnd	11	NA	NA	NA	NA
	husat	5	NA	NA	NA	NA
	danat	5	NA	NA	NA	NA
	noopi	5	NA	NA	NA	NA

Appendix C Continued.

Word Status	Stimulus	Length	Frequency French	Frequency English	Neighbors French	Neighbors English
Nonword	brosil	6	NA	NA	NA	NA
	tugmum	6	NA	NA	NA	NA
	gulpro	6	NA	NA	NA	NA
	MEAN	7.20 (2.02)	NA	NA	NA	NA