# Executive Control in Bilingual Language Processing

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Little is known in cognitive neuroscience about the brain mechanisms and brain representations involved in bilingual language processing. On the basis of previous studies on switching and bilingualism, it has been proposed that executive functions are engaged in the control and regulation of the languages in use. Here, we review the existing evidence regarding the implication of executive functions in bilingual processing using event-related brain potentials and functional magnetic resonance imaging. Several brain potential experiments have shown an increased negativity at frontocentral areas in bilinguals, probably related to the activation of medial prefrontal regions, for different tasks, languages, and populations. Enhanced cognitive control is required in bilinguals, which also involves the recruitment of the left dorso-lateral prefrontal cortex. The degree of activation of this mechanism is also discussed considering the similarity of languages in use at the lexical, grammatical, and phonological levels. We propose that the prefrontal cortex probably mediates cognitive control in bilingual speakers through the interplay between a top-down selection-suppression mechanism and a local inhibitory mechanism in charge of changing the degree of selection-suppression of the different lexicons.

An unresolved issue in bilingualism is how different languages are represented in the brain and which cognitive mechanisms are required to regulate their use. Although the level of performance achieved by an adult learner might be less than optimal, the cognitive mechanisms involved in language acquisition enable us to learn a second language (L2) throughout our life span. In learning (and sustaining) a second (or third) language, the brain has to build on a neural network that enables the segregation of the new language from the native one, the creation of its corresponding activation and inhibitory links at the lexical, morphological, and syntactic level, and, finally, the development of the ability to correctly select a word and its syntactic properties in the target language (i.e., the language currently in use). The creation and crystallization of a full new lexicon can be considered

a highly interesting natural experiment. The present article will deal with the cognitive mechanisms responsible for the regulation of two or more languages after they have been (partially) learned. We will argue at the end of the article that knowledge gained in the field is also important for the understanding of the acquisition of a new language.

Another goal of this article is to highlight how the cognitive neuroscience approach might prove helpful in understanding how an L2 is mastered and regulated in the brain. Building on a previous idea (Münte, Rodriguez-Fornells, & Kutas, 1999), we argue that brain imaging should not only be used to test predictions derived from psycholinguistic models, but that patterns of activations might be used to derive brain-inspired hypotheses about processing differences. We believe that this approach will be very fruitful in the future, as is attested to by the recent studies (e.g., de Diego Balaguer et al., in press) or brain-inspired models of language functions (Hagoort, 2005). The same idea has been raised recently by Poldrack and Wagner (2004): "knowledge of functional localization (i.e., the location of brain activations) can inform cognitive theories through the approach of reverse inference, wherein activation in a particular brain region (or regions) is taken as a marker of engagement of a particular cognitive process" (p. 177). In this article, we seek to apply this approach to the study of executive functions in bilinguals while recognizing the inherent limitations of this approach in terms of causality (see Poldrack & Wagner). Naturally, a data-driven brain-inspired interpretation of our data and a more adequate picture will emerge if this approach is applied to a set of studies addressing bilingual processing with varying paradigms.

## Neural Implementation of Various Languages in the Brain

The bilingual's ability when speaking to select a word in a target language without too much interference is puzzling in light of recent neuroimaging studies that demonstrate

overlapping neuroanatomical representation of languages at the macroscopic level (Chee, Caplan, et al., 1999, 2000; Chee, Hon, Lee, & Soon, 2001; Chee, Soon, & Lee, 2003; Chee, Tan, & Thiel, 1999b; Hasegawa, Carpenter, & Just, 2002; Hernandez, Dapretto, Mazziotta, & Bookheimer, 2001; Hernandez, Martinez, & Kohnert, 2000; Illes et al., 1999; Klein, Milner, Zatorre, Zhao, & Nikelski, 1999; Perani et al., 1998; Price, Green, & von Studnitz, 1999; for a recent review, see Franceschini, Zappatore, & Nitsch, 2003; Perani & Abutalebi, 2005). A critical issue with regard to this data is whether the spatial resolution of functional magnetic resonance (fMRI) (or positron-mission tomography [PET]) would allow us to demonstrate a separation of language representations in bilinguals.

In fact, noninvasive brain imaging studies do not agree completely with intraoperative electrocortical stimulation mapping and intraoperative optical imaging in bilingual populations. Early observations by Penfield and Roberts (1959) suggested that bilinguals have common language areas and pathways in the brain. However, Ojemann and Whitaker (1978) described two individuals who had brain regions that were shared by both of their languages along with other regions unique to each language. Similarly, Lucas, McKhann, and Ojemann (2004) reported that L1 and L2 have distinct and shared cortical representations. In 95% of the bilinguals (22 patients), stimulation produced deficits when naming pictures in only one of the languages and 43% of the patients showed specific language sites producing deficits in L1 or L2. Several restricted perisylvian areas were found in which L2 could not be mapped when compared to L1 representation in a large group of monolinguals. These areas were the inferior frontal and precentral gyrus, posterior temporal gyrus (extending to the supramarginal gyrus), and the posterior middle temporal gyrus. This pattern suggests that several language-related areas are exclusively dedicated to the processing of the native language. The acquisition and representation of an L2 might rely on neural assemblies, which are partially shared with L1 and partially specific (e.g., posterior temporal,

parietal, precentral, and prefrontal regions). It should be noted, however, that a case study of a Spanish (L1)/English (L2) bilingual using optical imaging (Pouratian et al., 2000) showed the inverse pattern to what would be expected from Lucas's analysis (see Roux & Trémoulet, 2002, for similar results, but see also Walker, Quinones-Hinojosa, & Berger, 2004). Although it is therefore important to consider the limitations of electrical and optical intraoperative brain mapping techniques,[1] these studies are clearly in favor of a partial functional separation of bilingual lexicons in the brain, as has been suggested by a minority of neuroimaging experiments (e.g., Dehaene et al., 1997; Kim, Relkin, Lee, & Hirsch, 1997). Such a view could also explain the clinical observations in aphasic bilinguals showing selective impairment or differential recovery of one language (Fabbro, 2001; Paradis, 1995).

Although definitive statements regarding language representation in bilinguals are premature at this stage, the brain regions sustaining the representation and processing of different languages appear to be partially overlapping and partially segregated. This leads to the question as to how access to the different languages is controlled and interference between the languages is prevented. Penfield and Roberts (1959) have argued for the existence of a "language switch" mechanism (see also Macnamara & Kushnir, 1971). As we show in the next sections, this "switch" appears to be instantiated by the brain's executive system.

## The Role of Executive Functions in Bilinguals

Switching and mixing languages are frequent in many bilingual speakers, especially when the interlocutor is able to understand both languages. On the other hand, fluent bilinguals switch from one language to the other and are able to separate both languages completely and without too much effort. Despite this ability, however, code-switching is also frequently observed, as bilinguals tend to introduce words from the other language into the language that they are currently using. It has been argued

that both switching proficiency and code-switching are related to the degree of activation of the target and nontarget languages at a given moment (Grosjean, 1997; Paradis, 1989). In addition to a bilingual's degree of proficiency in the L2, the bilingual status of the interlocutor and the communicative setting appear to be important for the degree of code-switching. At the other end of the continuum (i.e., in the "monolingual mode"; Grosjean, 1997), a smaller number of intrusions is observed, giving the appearance of complete independence of both languages, as if the nontarget language were switched off.

It is necessary to postulate a control mechanism that regulates the activation of the different languages in bilinguals and polyglots and what the neural mechanisms might be that implement this process. Cognitive control processes enable us to adapt our actions to the ever-changing environment and to shape them in relation to our current goals. Traditionally, cognitive control has been associated mainly with two properties: the ability to filter out irrelevant information in the environment (interference suppression) and the ability to inhibit inappropriate responses or thoughts (response inhibition). Cognitive control develops gradually in infants and is thought to be related to the slow maturation of the prefrontal cortex (PFC; see review in Diamond, 2002). Bialystok (1999) hypothesized that bilingual children might develop enhanced cognitive control mechanisms compared to monolingual children because they are faced with switching and attentional control demands from early on. In fact, she demonstrated that bilingual children might become exceptionally good at ignoring distractive information and at switching between different cognitive tasks.

There is common agreement that in producing a word in a particular language, the conceptual system of a bilingual activates the lexical representation of both languages (Costa, Miozzo, & Caramazza, 1999; De Bot, 1992; Hermans, Bongaerts, de Bot, & Schreuder, 1998; Poulisse, 1999). A second question concerns whether the activation of nontarget lexical representation is transmitted onward to the phonological properties of the word.

Several pieces of evidence suggest that this is the case (Colomé, 2001; Costa, Caramazza, & Sebastian-Galles, 2000). How, then, does the system control the production of the target word if the nontarget language candidates are interfering at the levels of lexical selection and phonological representation? Roelofs (1998) has proposed a checking procedure (based on Levelt, Roelofs, & Meyer, 1999) that discards the selected lexical representation whenever the language of the selected word does not match the intended language (and the intended conceptual representation).

Whereas some bilingual language production models have postulated inhibitory processes in order to control target lexical activation, such as the inhibitory control model (IC; Green 1986, 1998), other models achieve lexical selection by increasing the level of activation of the target language (De Bot, 1992; Grosjean, 1997; Paradis, 1989; Poulisse & Bongaerts, 1994). However, in order to activate a language without activating the nontarget language at the same time, it is necessary to correctly identify the relevant items of this language. Therefore, the selection mechanisms in use for the language production system have to be clearly specified; for example, in bilingual models that rely on differential activation of the items, the most activated item would be selected. In contrast, Green (1986), following Albert and Obler (1978), proposed that words in the lexicon possess a type of "language tag" and that language, therefore, is used as a feature for selection purposes. In a similar vein, Poulisse and Bongaerts proposed that each word possesses a "language tag" linking it to a particular language, and these language tags would enable only a limited set of lexical items to be activated, mostly from the target language.

In the IC model (Green, 1986, 1998), which is inspired by the supervisory attentional system (SAS) model (Norman & Shallice, 1986), control is achieved through three mechanisms: (a) a system similar to the SAS that is dedicated to establishing and maintaining goals; (b) control mechanisms acting at the level of "language task schemas"; and (c) control mechanisms operating at the bilingual lexico-semantic system (at the lemma level).[2] In order to begin an interaction in one language, speakers have to decide

and select a "specific language schema" (e.g., French) and inhibit alternative ones (e.g., English). However, selection of a word in the target language occurs at the lemma level using a type of "language tag" and is achieved by inhibiting lemmas of the other language. Thus, the selected "language task schema" is able to inhibit an activated lemma when a language "tag" does not correspond to the target language. In that case, control is executed via the inhibition of the inappropriate nontarget language items. In the Bilingual Interactive Activation (BIA) model (Dijkstra & Van Heuven, 1998), these tags are represented as language nodes, which have the role of reinforcing the lexical activation of the currently activated language and simultaneously decreasing lexical activation in the other lexicon. The competition that occurs both within and between languages is resolved via a local inhibitory mechanism (lateral inhibition). Adjacent language representations inhibit each other, and the selection of a particular response reduces the likelihood of selecting the neighboring response. Notice that the nature of the inhibitory mechanisms proposed differs between models, ranging from a general unspecific inhibitory mechanism, as in Green's model, to a local inhibitory one.

It should also be noted that in the IC model, the language task schemas are independent of the bilingual lexico-semantic system, and strong competition and conflict is predicted between them. The model considers that in order to select a language schema, speakers must first inhibit the nontarget language schema. Therefore, switching between languages will require changing the previous inhibitory status of the nontarget language, a process that will require time. In fact, a study by Meuter and Allport (1999) showed clear evidence of switching costs in naming numerals aloud. However, the switching costs were asymmetric: Speakers took longer to switch from the L2 to their L1 than the reverse switch to the nondominant language. The authors explained this finding by considering that because L1 inhibition is more demanding, it will also require more time to be reactivated. In the particular case of balanced bilinguals, in which

the inhibition applied to both languages is equal, Meuter (1994, cited in Meuter & Allport, 1999) provided evidence for an identical switching cost in a category-naming task.

In a recent study, Costa and Santesteban (2004) also reported that these asymmetric switching costs are related to the degree of proficiency of the bilingual speaker in the second language, and independent of other languages learned. In this study, non-proficient Spanish-Catalan L2 speakers (1.5 years second-language learning) showed clearly asymmetric costs that replicated the previous study of Meuter and Allport (1999). In contrast, highly proficient Spanish-Catalan speakers showed nonasymmetric costs (only general switching costs). The surprising result is that this bilingual group did show nonasymmetric costs when a nonfluent third language (L3; English) was evaluated. In order to reconcile this complex pattern of results, the authors suggested that when bilinguals become highly proficient in an L2, they develop specific language-selection mechanisms that allow them to process both L1 and L2 in a very flexible way (see Costa, 2005).

These results are consistent with Bialystok's (2001) proposal that a nonspecific control mechanism is naturally tuned and developed in highly proficient and probably *early* bilinguals, which gives them an advantage in general switching-inhibitory tasks. The existence of a highly flexible neural control mechanism in bilinguals (non-language-specific) could perfectly explain the previous pattern without the need for language-specific selection and an inhibitory mechanism. In a recent study, Bialystok, Craik, Klein, and Viswanathan (2004) provided some initial evidence for the advantage of bilinguals in executive function using the Simon task.[3]

Li (1998) argued against this notion of language tags, based on a series of studies in which no cost was associated to language switching in natural speech situations (Grosjean, 1988, 1997; Grosjean & Miller, 1994; Li, 1996). According to the IC model, language switching will require time, because the process of switching to another language involves the inhibition of

the previous language tags, a top-down regulated process. This idea is also contradicted by several experiments in which the two languages seem to be always activated, although their level of activation depends on the specific language situation and is modulated by several factors (e.g., proficiency level, speech mode, frequency of words; Grosjean, 1988; 1997). Li proposed an interesting alternative, in which there is no need for labels or language tags. Both lexicons become separated over time because a self-organizing network might develop localized patterns of activity in learning the different associations and mappings among phonology, orthography, morphology, and semantics. These localized patterns of activity are supposed to function as the learner's internalized representations of the two lexicons (see Li & Farkas, 2002).

Thus far, we have reviewed evidence that suggests that cognitive control is necessary to regulate bilingual language processing. However, more detailed bilingual cognitive control models are required in order to explain the previous behavioral studies and also the different clinical recovery patterns observed in bilingual aphasics, such as "alternate antagonism." In these patients (Paradis, 1995), one language is first recovered, and after a while, a switch is observed and the silent language comes back while the recovered one disappears. A specific lesion in the language control mechanisms might be able to explain this switching pattern. Additionally, several important issues are still open to controversy, such as (a) in which degree bilinguals use the same cognitive control mechanisms as monolinguals in bilingual language processing, (b) if bilinguals train specific executive functions in order to deal with language switching, inhibition, and interference or (c) if they develop a specific language control mechanism that is devoted to switching and inhibition of the different languages. In the following sections we will provide some evidence suggesting that different brain regions involved in cognitive control are active in bilinguals' language processing.

## Empirical Evidence for Control in Second Language Production

*The N2 noGo Component*

With the aim of evaluating the interference of the nontarget language at the syntactic and phonological levels during covert naming in bilinguals, we have used the N2 noGo component.[4] The same type of task has been used in a series of studies assessing the relative timing of the retrieval of conceptual/semantic, syntactic, and phonological information during language production and single-word reading and comprehension (for a review of the different studies, see Jansma, Rodriguez-Fornells, Möller, & Münte, 2004).

A number of electrophysiological studies have assessed the effects of response inhibition using event-related brain potentials (ERPs) and fMRI. These experiments showed that the stimulus-locked ERP in noGo trials is characterized by a large negativity of about 1–4 µV in size that occurs with task-dependent onset latencies over the frontocentral scalp (Gemba & Sasaki, 1989; Kok, 1986; Pfefferbaum, Ford, Weller, & Kopell, 1985; Sasaki, Gemba, Nambu, & Matsuzaki, 1993; Simson, Vaughan, & Ritter, 1977). In Figure 1a, the N2 noGo component is depicted in two different experimental conditions. In the semantic condition, participants decided whether to press a response button depending on whether the picture presented was an animal or an object (Go/noGo decision based on conceptual information). In contrast, in the phonological condition, participants had to covertly produce the name of the picture and decide whether the first letter was a consonant or a vowel (Rodriguez-Fornells, Schmitt, et al., 2002). The right panel shows the subtraction of noGo minus Go trials. As expected from both previous studies (see Schmitt, Münte, & Kutas, 2000; Van Turennout, Hagoort, & Brown, 1997) and language production models (Levelt et al., 1999), the onset and peak latencies of the N2 noGo-Go component was earlier for the semantic decision

**A. ERPs**
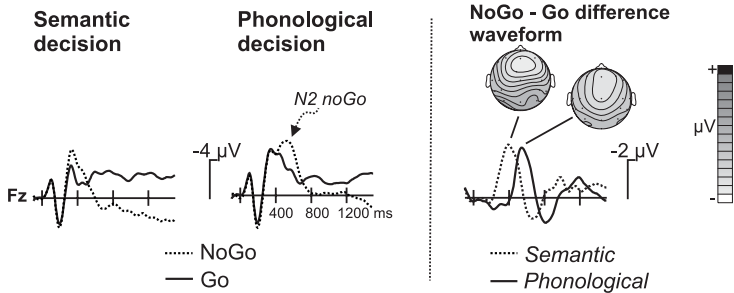


**B. Event-related fMRI**
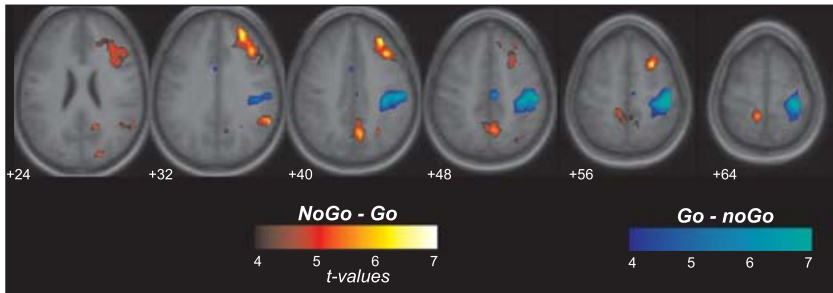


*Figure 1.* (a) Grand average ERPs at frontal recording locations showing the increased negativity for the noGo trials in the 250–450-ms range in the semantic condition and 450–650 ms in the phonological condition. This effect can be more clearly visualized in the noGo minus Go difference waveforms (right side). Also depicted are the isovoltage topographical maps (mean amplitude = 50 ms, centered at the latency peak; relative voltage scale) computed for both conditions. (Adapted from Rodriguez-Fornells, Schmitt, et al., 2002.) (b) Event-related fMRI activity from 22 participants (monolinguals and bilinguals responding with the left hand) for the contrast noGo–Go trials (hot-yellow colors) and Go minus noGo trials (winter-blue color). Notice the increased activation of the middle frontal gyrus (BA 9, 28/40/36) extending to the inferior frontal gyrus (BA 44, 36/16/20) for the noGo condition ($p < .0001$). (Data from Rodriguez-Fornells et al., 2005.)

than the phonological one. Notice also the standard right-central frontal distribution of this component.

Several lines of evidence link this frontal "N200" to lateral prefrontal inhibitory processes; for example, invasive studies in behaving monkeys have revealed activity related to response

inhibition in the prefrontal cortex in a Go/noGo paradigm that gives rise to an N200 in humans (Sasaki, Gemba, & Tsujimoto, 1989). Moreover, Sasaki et al. were able to suppress the overt response on Go trials by electrically stimulating the prefrontal cortex at the time that an N200 would normally have developed on a noGo trial. Sasaki and Gemba (1993) presented a convincing case for an "inhibition" account of the N200 by comparing data from humans and monkeys. Moreover, destruction of the prefrontal cortex in animals has been found to lead to a profound disturbance of performance on delayed response tasks (Fuster, 1989), and to an enhancement of disinhibition and impulsive behavior (Luria, 1973). A cortical inhibitory network including the dorsolateral and inferior frontal lobe has been suggested on the basis of various neuroimaging studies in humans (Garavan, Ross, & Stein, 1999; Konishi et al., 1998, 1999; Liddle, Kiehl, & Smith, 2001; Menon, Adleman, White, Glover, & Reiss, 2001; Rubia et al., 2001; for a recent review, see Aron, Robbins, & Poldrack, 2004; Buchsbaum, Greer, Chang, & Berman, 2005). Figure 1b shows the brain network activated in the noGo condition in an event-related fMRI study (Rodriguez-Fornells et al., 2005; Go/noGo phonological decisions, all 22 subjects pooled together). In the noGo-Go comparison, clear involvement of the right middle frontal regions, including part of the inferior frontal region, is observed. In this particular paradigm, the isovoltage maps for the N2 noGo-Go effects are consistent with the fMRI activation observed (compare Figures 1a and 1b).

Thus, it is likely that the N200 elicited by noGo trials is related to inhibition processes in the prefrontal cortex (but see Donkers & Van Boxtel, 2004; Nieuwenhuis, Yeung, Van den Wildenberg, & Ridderinkhof, 2003, for a conflict-monitoring account). The presence of an N200 implies that the information, which can be used to determine whether a response is to be given, must have been analyzed (Thorpe, Fize, & Marlot, 1996). The timing of the N200 might thus provide critical information about the timing of the availability of the information that is used to determine the Go/noGo decision. As it is usual in ERPs, the peak

latency of the N200 effect (i.e., the difference between Go and noGo ERPs) should be considered as an upper estimate of when the specific information must have been encoded.
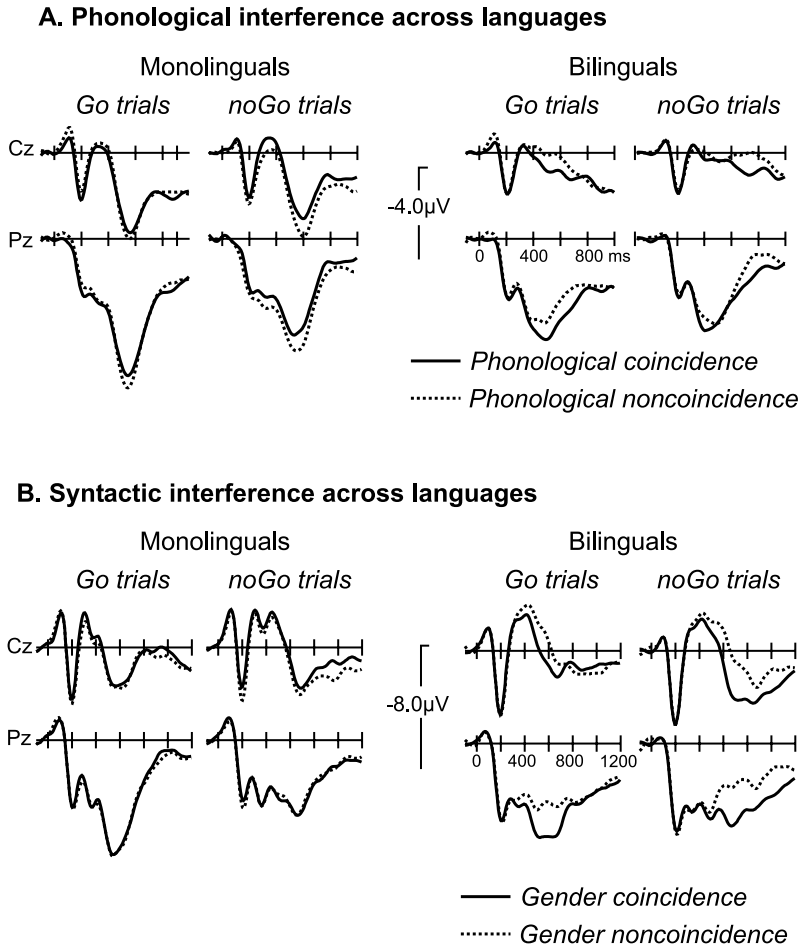
*The Phonological Level*

The main goal of our first study was to assess the degree to which highly proficient and early German-Spanish bilinguals experienced interference from the nontarget language when naming a picture in the target language (Rodriguez-Fornells et al., 2005). The combination of ERPs and fMRI enables us to observe both the time course of interference effects during language production and the implicated brain regions. In order to avoid vocalization artifacts during EEG and fMRI acquisition, a variant of the Go/noGo picture-naming task was employed.

The phonological Go/noGo task used required subjects to access the phonological representation of a picture, as they had to decide whether the name of the depicted picture began with a consonant or a vowel (see Wheeldon & Levelt, 1995). In alternate blocks, bilinguals were required to respond when the German (Spanish) name of the picture began with a consonant and to withhold a response for words starting with a vowel. The target language was changed every block, which lasted 100 trials. Critically, the stimuli were selected such that in half the trials the names in both languages (Spanish and German) would lead to the same response (e.g., vowel coincidence *Esel-asno* "donkey," or consonant coincidence *Spritze-jeringuilla* "syringe"), whereas in the other half, responses were different for the two languages (noncoincidence condition, *Erdbeere-fresa* "strawberry"). We hypothesized that if the language-selection mechanism acts at the lemma level, no phonological activation should be observed for the nontarget language. On the other hand, if selection is operating at a later stage, the phonological form belonging to the nontarget language word should be at least partially activated, giving rise to interference effects at behavioral, electrophysiological, and brain imaging levels.

The results indeed showed clear evidence for cross-language interference at the phonological level in bilinguals (see Figure 2). Phonological interference was revealed in the form of an increased negativity for noncoincidence trials during German and Spanish conditions in bilinguals only (see Figure 2a, left panel). This increased negativity is seen in the Go trials between 300 and 600 ms, and considerably later in the ERPs to the noGo responses (Figure 2a). The difference waveforms (see Figure 3),[5] which were created subtracting the noGo waveform minus the Go waveform, surprisingly revealed that the N200 component associated with noGo trials was clearly reduced in the bilingual group compared to German monolinguals. In this group, the difference waveform showed a standard N200 component with a right-frontal distribution (see Figure 3a, left panel), a peak latency at 450 ms for the monolinguals (see Rodriguez-Fornells, Schmitt, et al., 2002; Schmitt et al., 2000), and no differences related to the coincidence and noncoincidence conditions. In the bilinguals, noGo minus Go difference waves in the noncoincidence condition were characterized by an initial positivity followed by a negative increase. An interesting pattern emerged upon subtraction of the coincidence from the noncoincidence condition (for Go and noGo trials separately; see Figure 3a, right panel). These difference waveforms show an early negativity on Go trials and a surprising early positivity on noGo trials, followed by a later negativity on noGo trials. The biphasic nature of this latter effect provides support for the notion that participants had to override their initial nontarget language lexical activation (which provided information in favor of a Go response) in the noncoincidence noGo trials and, instead, withhold a response according to the instructions in the corresponding block. This pattern of Go/noGo incongruence has also been recently shown in the study of Van der Lugt, Banfield, Osinsky, and Münte (submitted) using a different type of task.

In sum, the covert Go/noGo phonological task showed partial inhibition of the Go response in the active language by the interfering noGo response required for the nontarget language word. In contrast, in the noGo trials, the increased negativity due to

**A. Phonological interference across languages**



**B. Syntactic interference across languages**



*Figure 2.* (a) Grand averages for monolinguals and German-Spanish bilinguals ($n = 12$) for the Go/noGo phonological interference experiment. Depicted are the waveforms for Go and noGo trials in the phonological coincidence and noncoincidence task (words that coincided or not with regard to the vowel/consonant decision across languages). The bilingual group showed an enhanced negativity for noncoincidence trials at frontal and central locations. This ERP effect was delayed in the noGo trials. (b) Grand averages for monolinguals and German-Spanish bilinguals ($n = 12$) for the Go/noGo gender interference experiment. In this experiment, noncoincidence trials had a different gender in both languages. As in the phonological experiment depicted above, bilingual participants showed a very similar effect in the interference condition.

noncoincidence started at about 600 ms. ERPs to noGo responses should have a reduced amplitude in the range 300–600 ms, because the nontarget language word would have required a Go response. An event-related fMRI in the same paradigm showed two regions associated with the noncoincidence effect in bilinguals when compared to monolinguals: the left dorso-lateral prefrontal cortex (DLPFC, BA 9/46) and the supplementary motor area (SMA) (Figure 4a). This result replicated previous studies in which the left middle prefrontal cortex has been found to be activated in Spanish-English bilinguals during mixed-language naming compared with blocks in which only one language was used (Hernandez et al., 2000, 2001; for a different pattern, see Price et al., 1999).

An interesting question here concerns the degree to which the previous ERP Go/noGo pattern and its interpretation could be partially supported by the fMRI study. According to our interpretation in the bilingual group, the incongruent condition has to elicit larger inhibitory activations (see Figure 1b) in Go noncoincidence trials compared to Go congruent trials. In fact, this is the case. As can be seen in Figure 4b, the comparison of noncoincidence minus coincidence in Go trials alone showed enhanced activation of the right middle frontal gyrus, anterior cingulate cortex (ACC), and SMA in the bilingual group. This pattern is clearly consistent with the ERP difference waveforms observed in Figure 3b for the Go trials in bilinguals.

The present study with alternating German and Spanish naming blocks created a rather unusual mixed-language situation, as subjects were required to name the same pictures either in Spanish or in German on alternating blocks. It is interesting to note that previous experiments (Colomé, 2001) supporting phonological interference in language production have used fluent Catalan-Spanish bilinguals who live in a strongly mixed-language context with about an equal presence of Catalan and Spanish in everyday life. In this study, Catalan-Spanish bilinguals were required to decide whether a specific phoneme (e.g., "m") was present in the Catalan name of a picture (e.g., *taula*

**A. Phonological interference across languages**
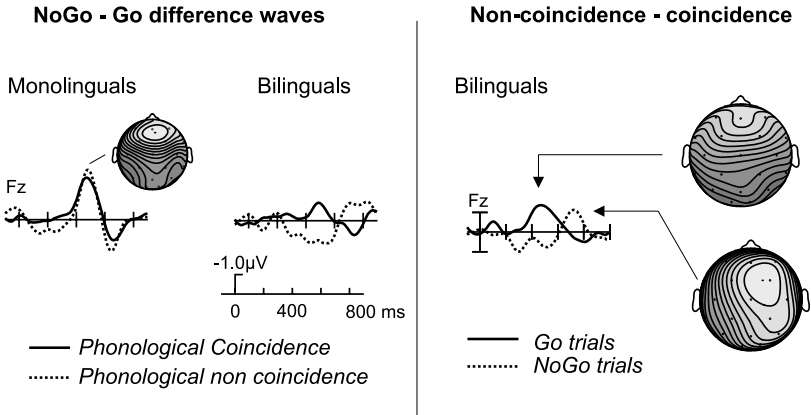


**B. Syntactic interference across languages**
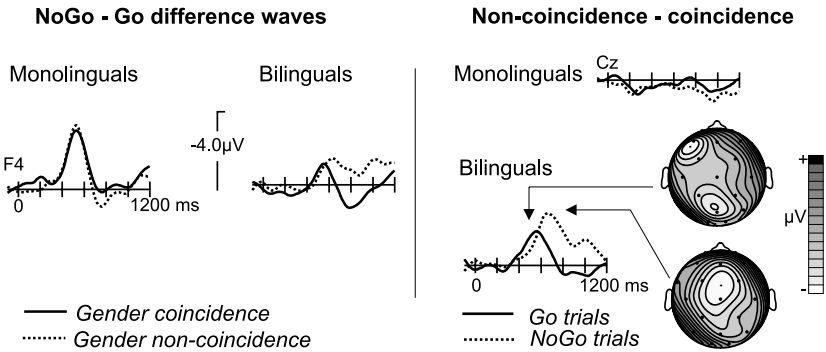


*Figure 3.* (a) Phonological interference task. Depicted is the difference wave-form (noGo minus Go trials) for both groups in the left panel. Notice the standard N2 noGo component in the monolingual group. The isovoltage map is also depicted showing the standard right-frontal central distribution of the component. In the bilingual group, the amplitude of this N2 noGo component is reduced. In the right panel, the difference waveform (noncoincidence trials minus coincidence) is depicted. It is interesting to observe that in the bilinguals, a similar N2 component is elicited, peaking earlier in the Go trials (see also the scalp distribution of the isovoltage maps). (b) Gender interference task. The same effects as described in Figure 3a are illustrated for this new task and for a different sample of monolinguals and bilinguals.

"table"). Participants were tested only in the Catalan language mode. Interestingly, subjects were slower to answer "no" when the phoneme to be monitored was part of the Spanish (i.e., nontarget language) word (e.g., "mesa" *table*) than if it was neither part of the Catalan nor the Spanish word. This implied that the phonological representation of the nontarget language word was active. It remains to be determined to what extent the results of this study can be generalized to monolingual environments, in which bilingual speakers are only required to produce words in one of their languages.

Clearly, only models that incorporate partial activation of the nontarget language items and, more specifically, their phonological representation are consistent with the present results. To reconcile the present data with serial models with discrete processing stages (Levelt et al. 1991, 1999), it has to be assumed that lemma selection and the subsequent activation of the phonological representation occur in parallel in the two languages. Cascade or spreading activation models (Dell, 1986; Peterson & Savoy, 1998; Stemberger, 1985) can also easily accommodate the present set of results. Because semantic features of the corresponding words in the two languages of bilinguals are identical,[6] a high degree of competition would be predicted for such words by spreading activation models. The degree to which the lemma and phonological representation in the nontarget language are activated might greatly depend on individual factors of the speaker (i.e., to what degree s/he uses both languages concurrently from day to day, and on situational factors, such as mixed language or monolingual environments).

As has been shown, bilinguals seem to cope with L2 interference during language production by recruiting generic "executive function" brain areas, such as the left DLPFC and ACC. Further evidence for the role of left DLPFC in switching comes from two different lines of research. A recent case report (Fabbro, Skrap, & Aglioti, 2000) described a patient (S.J.) with a lesion encompassing the left prefrontal cortex and part of the ACC who pathologically switched between his two languages: Friulian and

Italian. In this particular case, S.J. switched to Friulian when speaking to an Italian speaker with non-Friulian knowledge. The reverse switch, from Friulian to Italian, was also observed. From neuropsychological studies, pathological switching of languages is manifested by the pervasive tendency to switch from one language to the other during verbal production, and it seems to be related to a pragmatic disorder of communication and prefrontal lesions (Fabbro, 2001). In the particular case of S.J., the involvement of the ACC and PFC could be affecting either the ability to maintain the goal of the communication (e.g., which is the language in use?) or the ability to *suppress* the interference from the nontarget language.

Although fMRI cannot provide direct evidence of the necessary participation of a brain area in a cognitive process, the use of transcranial magnetic stimulation (TMS) can be very useful to test causal implications of a particular brain region in a specific process. In a recent case report, Holtzheimer, Fawaz, Wilson, and Avery (2005) provided evidence for the participation of the left DLPFC in the process of language switching in bilinguals. Two patients, who were undergoing a therapeutic protocol for treatment-resistant major depression, experienced an unexpected language switch after high-frequency repetitive TMS (rTMS) was applied to the left DLPFC. The unexpected switch and urge to speak in the other language (not in English) appeared only in one of the 15 rTMS sessions and lasted from several minutes to 2 hr. This particular study lends support to the idea that the left DLPFC is involved in language switching. It is noteworthy that the specific TMS protocol of Holtzheimer et al. is thought to activate rather than inhibit this region via depolarization of cortical interneurons with indirect effects on pyramidal cells (Strafella & Paus, 2001).

What is the specific role of the left DLPFC/ACC-SMA network in the regulation of existing languages in multilinguals? For example, it is essential to understand how this network is related to (a) the regulation and control of language communication in switching environments (switch control and monitoring or induction of language switch), (b) the selection/activation of the

target language in use ("language schema"), and (c) the inhibition of the nontarget language and, therefore, suppression of its interference. Previous imaging studies have revealed a role for these areas in different aspects of executive functioning (see Curtis & D'Esposito, 2003), such as (a) the selection of different response alternatives (D'Esposito, et al., 1995; Garavan, Ross, Li, & Stein, 2000; see also disruption of response selection with rTMS applied to the DLPFC, Hadland, Rushworth, Passingham, Jahanshahi, & Rothwell, 2001), (b) the switching between tasks (Dove, Pollmann, Schubert, Wiggins, & Von Cramon, 2000; Dreher, Koechlin, Ali, & Grafman, 2002; see also Rogers et al., 1998, who showed impairment in task switching for left-frontal patients), (c) the maintenance of a stable representation of the current task and prevention of interference (see Cohen, Botvinick, & Carter, 2000; Curtis & D'Esposito; Miller & Cohen, 2001), and (d) the inhibition of irrelevant items held in working memory (Baddeley, Emslie, Kolodny, & Duncan, 1998). In a Go/noGo lexical language decision task (Rodriguez-Fornells, Rotte, Heinze, Nösselt, & Münte, 2002), we found greater activation in the left anterior prefrontal region (BA 45/9, Figure 4) in bilingual subjects in response to Catalan words and pseudowords. This is a likely correlate of inhibition, as this region has recently been implicated in the selection of relevant information and interference resolution (Bunge, Ochsner, Desmond, Glover, & Gabrieli, 2001). The ACC has frequently been found to play a role in cognitive control and conflict tasks (Carter et al., 1998). The degree of activation of the DLPC might depend in part on the amount of conflict or interference detected, which is assumed to be signaled by the ACC (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Carter et al.; MacDonald, Cohen, Stenger, & Carter, 2000).

One potential and important criticism of our Spanish/German experiment concerns the extent to which the reported results would have also been obtained in a completely monolingual mode, where no language switch is present. Thus, a first cautious interpretation of the present data is that bilinguals recruit prefrontal executive brain regions in order to control the

A. Non-coincidence minus coincidence
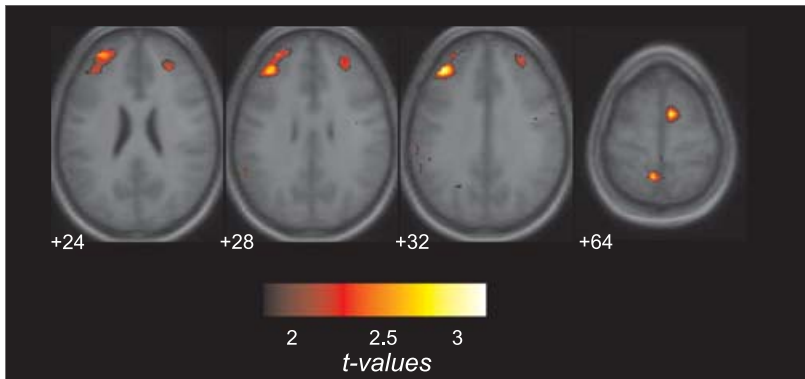


B. Go trials: non-coincidence minus coincidence
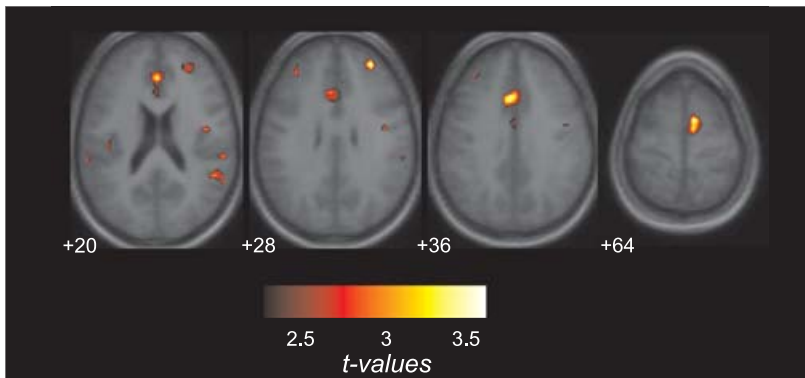


*Figure 4.* (a) Axial views of the group differences (German-Spanish bilinguals, $n = 11$; minus monolinguals, $n = 11$) in standard stereotactic space identified for the crucial contrast phonological noncoincidence minus coincidence condition in all trials. Values in the color scale refer to the $T$ values of the corresponding contrast. Notice the differential recruitment of the middle frontal gyrus (left BA 46/9) and SMA (BA 6) regions in this comparison. The axial views presented were superimposed on the mean anatomical image formed by averaging, for all 22 subjects, T1 structural MRI scans mapped into normalized MNI (Montreal Neurological Institute) space. (Adapted from Rodriguez-Fornells et al., 2005.) (b) Group differences in the same contrast (noncoincidence minus coincidence) for Go trials only. Notice the increased activation observed in the ACC (BA 32, −4, 20, 30, $T = 3.5$, $p < .001$), right middle frontal gyrus (BA 9/10, 34, 48, 28, $T = 3.8$, $p < .001$) and SMA (BA 6, 12, 0, 68, $T = 4.0$, $p < .001$).

interference produced in language production in multilingual environments, for example, by monitoring internal switches and language production errors and regulating the activation and suppression levels of the target and nontarget language, respectively. We will return to this issue below in order to propose a specific activation/inhibition language system.

*The Syntactic Level (Grammatical Gender)*

In a follow-up study (Rodriguez-Fornells, Lutz, & Münte, submitted), we evaluated the degree of interference when accessing syntactic information in both languages in a covert naming task in another group of fluent Spanish-German bilinguals. Grammatical gender does not, in many cases, match across languages. Thus, the word "table" is masculine in Italian (*il tavolo*) and German (*der Tisch*) and feminine in French (*la table*) and Catalan (*la taula*). This example illustrates that grammatical gender of entities other than human beings, to a large extent, is arbitrary.

In this study, the names of the pictures were selected considering gender agreement between Spanish and German: 60 names had the same gender (e.g., *der$_{masc}$ Speer–el$_{masc}$ dardo* "dart") and 60 names had different genders (*die$_{fem}$ Rakete– el$_{masc}$ cohete* "rocket"). Because gender in Romance languages takes only masculine and feminine forms, neuter gender in German was not considered. Speakers were required to perform a gender decision task using a Go/noGo covert picture naming procedure. This decision conveys different processes involved in gender-marked speech production, i.e., identifying a concept, selecting and retrieving the appropriate lemma and, finally, attaching its corresponding grammatical gender (see Jescheniak & Levelt, 1994; Levelt et al., 1999; Schriefers & Teruel, 2000). Using this type of task, the onset latency of the N200 noGo component for gender decisions is approximately 400 ms after picture presentation, normally 40 ms before the onset of phonological Go/noGo decisions, and between 70 and 90 ms after conceptual Go/noGo decisions

(Schmitt, Rodriguez-Fornells, et al., 2001; Schmitt, Schittz, et al., 2001; Van Turennout et al., 1998; see Jansma et al., 2004, for a review).

Syntactic interference is expected in bilinguals, given that lemma activation is produced in all languages in bilinguals at least to some degree (Colomé, 2001; Hermans et al., 1998; Rodriguez-Fornells et al., 2005). Several bilingual studies have already proposed that lemma activation is independent of the language in use, thus predicting that interference will appear when both languages do not agree in syntactic gender.

In order to allow evaluation of the differences between the effect of language switching, on the one hand, and the interference created by noncoincidence regarding syntactic gender between languages, on the other hand, the required target language switched every 18 trials in a predictable way (the target language was signaled by a red square surrounding the pictures in one of the languages). In addition, the structure of the first three trials after the switch was always identical, comprising a coincidence/noncoincidence/coincidence triplet. This structure was repeated in between each miniblock of 18 trials for the 12th, 13th, and 14th trials. This design, therefore, allowed direct comparison of the effects of language switching with the syntactic interference effect. German monolinguals were used as a control group in this study. By necessity, the paradigm in this group did not involve switching.

The behavioral results of this study showed interference in bilinguals when naming in the noncoincidence condition compared to the coincidence condition, as evidenced by the reaction time, percentage of hits, and percentage of false alarms (see Figure 5). Noncoincidence responses were significantly delayed (by ∼44 ms), with more false alarms and fewer hits when compared to the coincidence trials. Furthermore, a large language switch effect was found, especially for the first and second trial after a switch (Figure 5a). However, the interference effect of the gender noncoincidence was still visible; for example, the noncoincidence trial in the nonswitch triplet showed a delayed reaction time, fewer hits (see Figure 5a), and more false alarms. Notice

A.
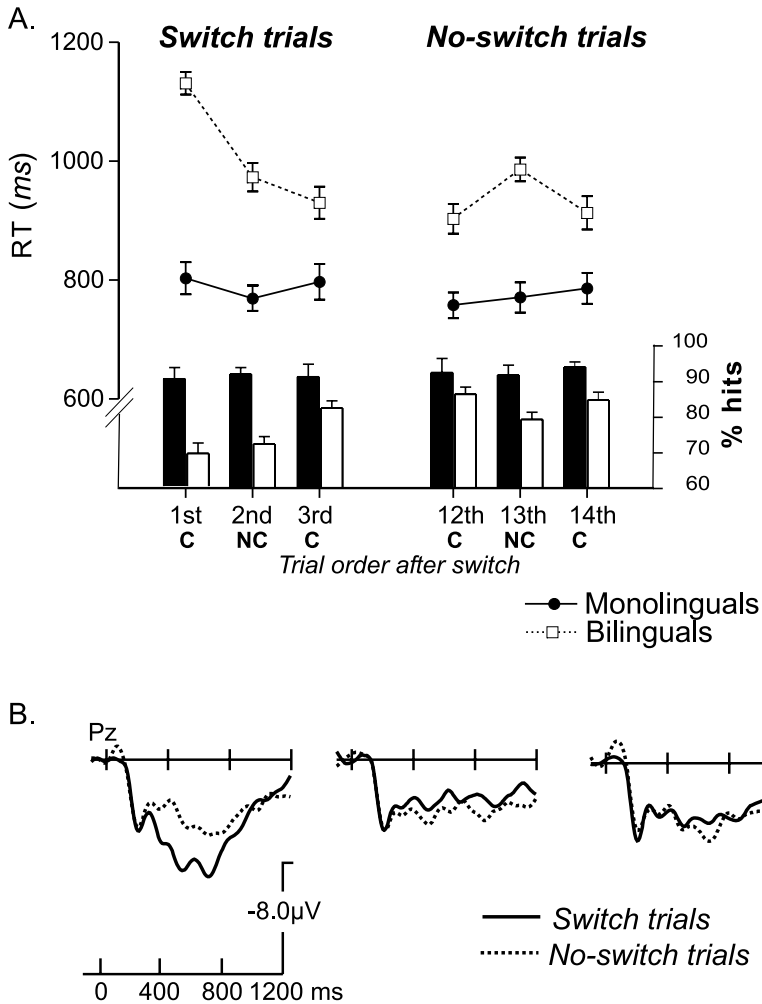


*Figure 5.* (a) Behavioral analysis (mean reaction time ± standard error of the mean [lines, left-side scale] and percentage of hits [bars, right-side scale]) for the three trials immediately following the language switch and the three trials in the middle of each miniblock (no-switch trials, 12th, 13th, and 14th) for monolinguals and bilinguals in the gender-interference experiment. C = Coincidence trial, NC = noncoincidence trial. (b) ERP waveforms in bilinguals comparing switch and no-switch trials. Comparisons show the averages considering the trial order of the switch and no-switch (1st trial with 12th, 2nd trial with 13th, and 3rd trials with 14th). Notice the increased late positive component (LPC) observed immediately after the language switch.

also that bilinguals showed a delayed reaction time independent of the switch or the gender-incongruence effect. Such a general delay in bilinguals had also been observed in the previous phonological interference experiment for both the ERP and fMRI parts.

The ERPs of monolinguals did not show an effect due to gender coincidence (Figures 2b and 3b, right panel), but a standard N200 noGo component was present (see Figure 3b, left panel). In contrast, and as in the previous experiment, bilinguals showed a marked incongruence effect across languages: Noncoincidence trials elicited a large negativity when compared to the coincidence condition (Figure 2b). In the noncoincidence minus coincidence difference waves (Figure 3b, right panel), a negativity can be observed for both Go and noGo trials, with a delay in the peak observed for the noGo trials. This pattern is similar to that observed in the previous phonological incongruence experiment. In addition, the N200 noGo component is attenuated for the bilinguals (see Figure 3b, left panel), who also show a different scalp distribution.

The ERP effects related to the language switch are shown in Figure 5b. An increased positivity is observed when the first trial after the switch is compared to the first nonswitch trial of the control triplet. This effect is reminiscent of similar positivities found in nonlinguistic switching tasks (Gehring, Bryck, Jonides, Albin, & Badre, 2003) and has been interpreted as an instance of the "P300." In fact, the "context updating" theory (Donchin, 1981; Donchin & Coles, 1988, 1998) would predict a larger P300 amplitude in the case of a language switch. This is because a language switch requires the participation of cognitive control for updating the contents of working memory, the participation of attention, and the decision to change the language in the present context of the performance.

Similar late positivities (in the range 400–800 ms) have also recently been found in a study of English-Spanish bilinguals, in which an unexpected language switch (code-switches) was presented while reading a sentence (Moreno, Federmeier, & Kutas, 2002; e.g., *He put a clean sheet on the cama* [Spanish for the

expected "bed"]). The peak amplitude and latency of the positivity to code-switches correlated negatively with the subjects' proficiency in Spanish as measured by the naming test.

Finally, Figure 6 compares ERPs for dominant and nondominant language trials for the phonological and syntactic interference experiments. As revealed by vocabulary scores in both languages, these particular groups of bilinguals showed greater fluency in German, although their native language was Spanish. In this comparison, and regardless of the different experimental conditions, the dominant language showed a larger negativity with an onset at about 400 ms, especially at frontal and central locations. Interestingly, reaction times for dominant and nondominant language trials were not different in the two studies. Nonetheless, it is tempting to speculate that this increased negativity reflects the enhanced control required for the dominant

A. Phonological decisions          B. Gender decisions

**Go**                                      **Go**

*Coincidence*    *Noncoincidence*      *Coincidence*    *Noncoincidence*

0          1000 ms                      0          1600 ms

-4.0 μV                                  -8.0 μV

**NoGo**                                    **NoGo**

*Coincidence*    *Noncoincidence*      *Coincidence*    *Noncoincidence*

—— *German (dominant)*
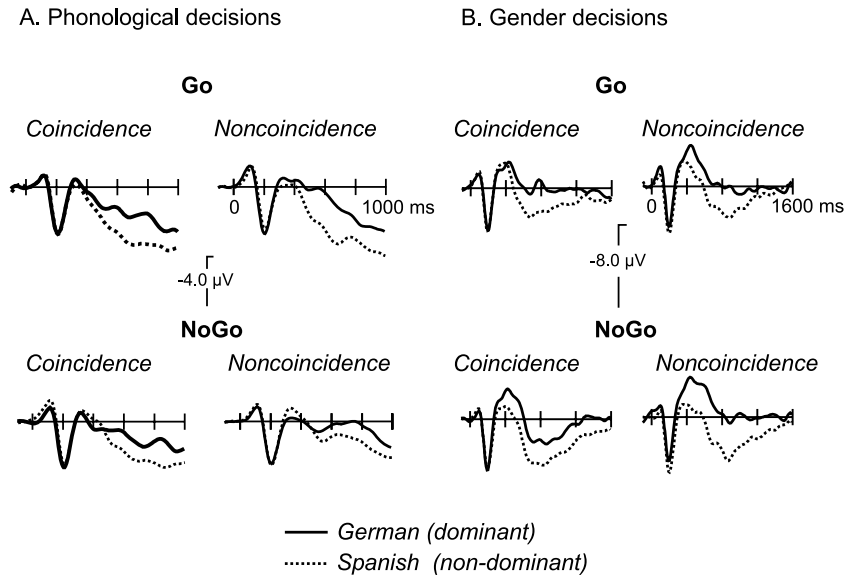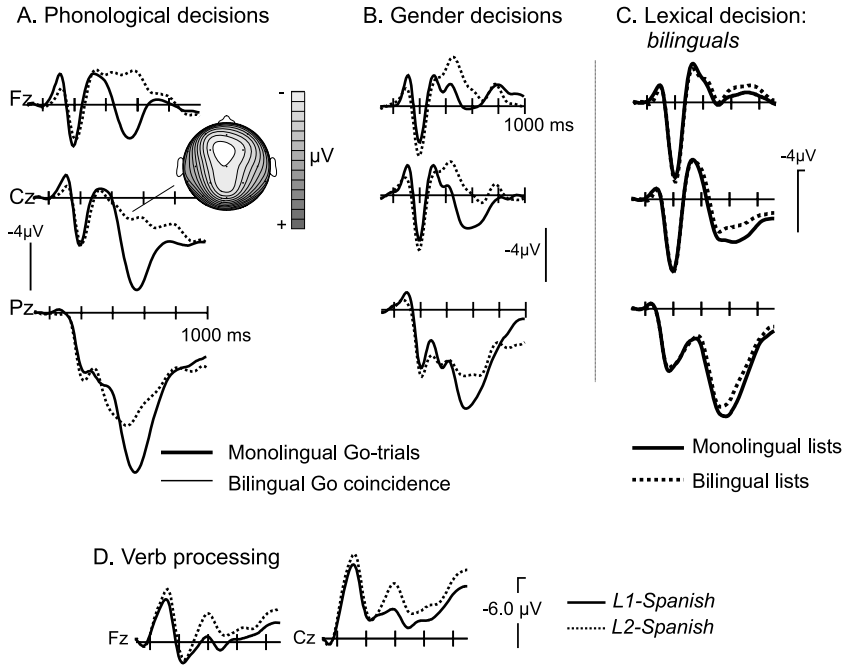········ *Spanish (non-dominant)*

*Figure 6.* Grand average for the German-Spanish bilinguals in two experiments: (a) phonological interference task and (b) gender-interference task. Notice that in all conditions, the dominant language elicited an increased negative component.

language. Thus, these results would support the idea that the selection of an active item in a lexicon has to be accomplished via inhibition of the task-irrelevant language. According to the IC model (Green, 1998), access to L2 representations involves greater suppression (or inhibition) of L1; therefore, enhanced control is required to overcome the applied inhibition when naming in the L1.

### Further Evidence of Enhanced Control in Bilinguals

The widespread negativity observed in bilinguals when naming in their L1 in both ERP studies has been interpreted as the existence of an enhanced control in bilinguals when engaged in L1 naming. The greater need for executive control should also show up in direct comparisons of the ERPs obtained in bilinguals with those recorded in monolingual controls. Indeed, we first observed an enhanced negativity in Catalan-Spanish bilinguals (relative to Spanish monolinguals) in a word-reading study that required them to inhibit nontarget words (see Figure 2 in Rodriguez-Fornells, Rotte, et al., 2002). We suggested that highly fluent bilinguals could strategically control the process of mapping spelling to sound in the target language when they are required to ignore words in the nontarget language. Enhanced engagement of executive control in bilinguals was also evident in the accompanying fMRI study, which showed greater activity (relative to monolinguals) in several regions, such as the left DLPFC, the anterior inferior frontal region, and the ACC.

In both of the above-discussed covert language production studies, bilinguals again show an overall enhanced negativity when compared to monolinguals (Figures 7a and7b; see Rodriguez-Fornells et al., 2005; Rodriguez-Fornells et al., submitted). These group differences had a medial frontal maximum pointing to medial frontal generators such as the ACC (see Figure 7a). Indeed, a brain area distinguishing bilingual from monolingual subjects in the accompanying fMRI study was the ACC. Various functional neuroimaging studies have shown that

A. Phonological decisions

B. Gender decisions

C. Lexical decision: *bilinguals*

Fz

Cz

Pz

μV

−4μV

1000 ms

1000 ms

−4μV

−4μV

Monolingual Go-trials

Bilingual Go coincidence

Monolingual lists

Bilingual lists

D. Verb processing

Fz

Cz

−6.0 μV

L1-Spanish

L2-Spanish

*Figure 7.* (a) Grand averages for monolingual ($n = 12$) and bilingual groups ($n = 12$) are plotted together for Go trials from the German naming task. For the bilinguals, only the phonological coincidence condition is presented. The topographical map for the difference wave was obtained by subtracting the monolinguals' ERPs from the bilinguals' waveforms using isovoltage mapping with spherical spline interpolation (min/max values −6.8/ −1 μV) (from Rodriguez-Fornells et al., 2005). (b) The same grand averages showing the same contrast in the gender covert naming task. Notice the similarities for a different group of bilinguals ($n = 12$) and on a different task (Rodriguez-Fornells, Lutz, & Münte, submitted). (c) Grand average for Spanish-Catalan bilinguals ($n = 20$) for Go trials in the monolingual list condition (including only target language words and pseudowords) and the bilingual list (including target language words, nontarget language words, and pseudowords) (Rodriguez-Fornells et al., unpublished data). (d) Grand average ERPs for Spanish-Catalan bilinguals in a study on verbal morphology in Spanish (De Diego Balaguer et al., 2005). The averages show all verb conditions pooled together. Notice the increased frontocentral negativity in the L2-Spanish group (L1 = Catalan, L2 = Spanish) when compared to the L1-Spanish group (L1 = Spanish, L2 = Catalan).

this region is active (a) when a prepotent response tendency has to be overcome, such as in the Stroop task (Pardo, Pardo, Janer, & Raichle, 1990), (b) when the response is undetermined, as in verb fluency tasks (Frith, Friston, Liddle, & Frackowiak, 1991), and (c) when committing errors and or experiencing response conflict (Carter et al., 1998). A recent model considers that this region evaluates the demand or need for cognitive control by monitoring for the occurrence of conflict or interference (Botvinick et al., 1999; Carter et al., 2000). It has to be kept in mind that the ACC is only part of a larger circuit that is involved in the detection of conflict and instantiation of further processing prior to response execution (Cohen et al., 2000; MacDonald et al., 2000; Miller & Cohen, 2001). A recent proposal considers that cognitive control is supported by a brain network involving the insular, prefrontal, and ACC, which resolves interference between competing responses (Wager et al., 2005).

This suggests that the frontocentral negativity observed in bilinguals relative to monolinguals should vary as a function of the need for cognitive control. To test this hypothesis, we required Catalan-Spanish bilinguals to make Go/noGo lexical decisions in monolingual lists (low-control condition) and bilingual lists (high-control condition; Rodriguez-Fornells et al., unpublished data). In the monolingual condition, only words from the target language (either Catalan or Spanish) and pseudowords (constructed on the basis of words from the target language) were presented. Participants had to make Go decisions for target words (inhibit pseudowords). In the bilingual condition, words from the target language (e.g., Spanish) were presented as well as nontarget words (e.g., Catalan) and pseudowords (half derived from the target and half derived from the nontarget language). Participants had to press only when a word in the target language was presented, inhibiting the other nontarget words and pseudowords. An increased negativity for words was observed in the bilingual condition (Figure 7c). Finally, in a recent study with Spanish-Catalan bilinguals (De Diego Balaguer et al., 2005; see explanation of this study below), the nondominant Spanish group showed

a similar enhanced negativity when doing the lexical decision task in their L2 (Figure 7d).

Another possible instance of this effect can be seen in the work of Moreno and Kutas (2005), who required participants to read sentences containing semantically congruent or anomalous final words. In alternating blocks, either their dominant or non-dominant language was used. The onset and peak latency of the N400 effect (i.e., a specific ERP component associated to semantic processing) was delayed in the less proficient language when compared to the dominant one. The authors also observed (see Figure 7 in Moreno & Kutas) a larger frontal negativity during nondominant language processing. Although the authors discussed this effect in terms of working memory (viewing it as an instance of the left anterior negativity [LAN] effect[7]) or as reflecting concreteness processing (because of its similarity with ERP differences between abstract and concrete words), we suggest that it might be related to the degree of cognitive control involved in processing a language in a specific context.

A preliminary conclusion regarding these effects could be that they reflect brain mechanisms for interference resolution and conflict detection and are common to monolingual and bilingual subjects. Speakers or comprehenders might recruit them to different degrees in different tasks depending on individual differences in ability (e.g., language proficiency and the level of interference of the nontarget language). Further research is required in which individual differences in language proficiency and other relevant biographical variables could be correlated with the degree of activation of this cognitive control network.

### The Role of Similarity Between Languages With Respect to the Recruitment of Control Mechanisms

One relevant issue with respect to the control mechanisms needed by the bilingual brain is the similarity between the languages spoken. Particularly in languages from the same linguistic family (e.g. Romance languages such as Spanish, Catalan, or

Italian), some commonalities at the lexical, phonological, or grammatical levels are evident. Indeed, many languages contain similar, dissimilar, and, in some cases, even identical representations. Consider, for example, so-called cognate words (e.g., *casa*, for "house" in Spanish, Italian, and Catalan) and noncognate words (e.g., *perro-cane-gos* for "dog" in Spanish, Italian, and Catalan, respectively) or, at the grammatical level, the order of arguments in the sentence (e.g., Subject-Verb-Object, Object-Subject-Verb), the number of conjugation classes, and so forth. With respect to this diversity, two possibilities are available to the system: either to consider each language independently of these similarities and differences or to take advantage of the similarities between languages. If the first strategy is adopted, then we should not see differences between those representations that are similar and dissimilar between the L1 and L2. If the latter strategy is adopted, then the control system should be flexible enough to adapt and control interference from dissimilar representations while allowing a beneficial effect of similar representations of the L2 in L1 representations.

In the following section we will comment on how the similarity at the lexical, grammatical, and phonological levels can help or interfere in the processing of the L2, and we will then discuss how the control system is able to deal with the lexical, grammatical, and phonological components when both similar and distinct representation might occur in the two languages of a bilingual.

## Similarity of Lexical Items Across Both Languages (Cognate Words)

Some languages, such as Spanish and Catalan or Italian and Catalan, share many cognate words (words that have a very similar phonological structure in both languages [e.g., in Spanish-Catalan: *coche-cotxe* "car"; in Catalan-Italian: *parlar-parlare* "speak"]). Costa et al. (2000) presented pictures with cognate and noncognate words and asked Catalan-Spanish bilinguals to name them in Spanish. Bilinguals naming latencies were

faster for pictures with cognate words than those with noncognate words, whereas no differences were found for monolinguals. This result is in favor of the activation of lexical items of the nontarget language and supports the idea that this activation flows to the phonological level (see also Kroll, Dijkstra, Janssen, & Schriefers, 2000).

The question addressed here is whether covert production of cognate words is facilitated, and if so, then the cognitive control required to produce these words might be reduced. Let us consider this issue with our gender-interference experiment (Rodriguez-Fornells et al., submitted). In a further condition, 20 Spanish-German cognate words were introduced (congruent gender in all cases). As expected, we observed reaction-time facilitation for the gender decisions of these cognate words (in bilinguals: noncognate words, 969 ms, and cognate words 875 ms; in monolinguals: noncognate, 785 ms, and cognate words, 816 ms). Furthermore, the ERP pattern for cognate and noncognate words was very different in the bilingual group (see Figure 8a). In a similar fMRI study performed in another group of Spanish-German bilinguals, comparison of cognate words minus noncognates revealed a clearly reduced activation in bilinguals in two critical areas: left DLPFC (BA 46/9) and ACC (BA 32). These data are thus consistent with the idea that cognitive control is reduced in the case of cognate processing in bilinguals.

It remains to be determined whether reduced cognitive control would also appear in the case of interlingual homographs such as *angel*, meaning "sting" in Dutch. Whereas cognate words share both formal and semantic information, interlingual homographs are indistinguishable in terms of form but completely different in terms of meaning. Thus, if parallel activation is produced when processing homographs, then a greater need for cognitive control will be required depending on the linguistic context (see Dijkstra & Van Heuven, 1998, 2002). In several studies, parallel activation of both languages appears to lead to facilitation effects when subjects have to decide whether the word exists in either language, whereas interference appears when the subjects have to make a

lexical decision in one of the languages (Dijkstra, Van Jaarsveld, & Brinke, 1998). This parallel activation was not present in the interlingual homograph study when the material included exclusively words in one language (Dijkstra et al. 1998; see Gerard & Scarbourough, 1989), indicating that cognitive control might be even easier when semantic information is not shared, as long as no activation of the other language is forced by the material.

## Learning Similar Morphological Systems

One view of the architecture of the language system distinguishes a "lexicon," storing the idiosyncratic forms of words, from a "grammatical component," which stores the information about how those lexical forms are combined to form morphologically complex forms and sentences. This distinction is crucial when it comes to adult L2 acquisition. Studies and everyday experience show that whereas lexical acquisition can be achieved at a native or near-native level, syntactic and phonological performance is generally much worse in the L2 (Birdsong, this volume; Birdsong & Molis, 2001; Flege, Yeni-Komshian, & Liu, 1999; Johnson & Newport, 1991; Weber-Fox & Neville, 1996), despite extensive practice. Thus, at the level of morphosyntactic acquisition, we should be able to observe clear similarity effects, either in the form of interference or facilitation.

The case of morphological processing in morphologically complex but similar languages poses the challenging question of how the system is able to manage lexical items that are both similar and dissimilar according to the level of processing. A direct evaluation of progressive learning on the acquisition of similar and distinct morphosyntactic rules between languages has recently been reported (Osterhout, McLaughlin, Kim, Greenwald, & Inoue, 2004). In this longitudinal study, a sample of American students who were enrolled in a formal French course was evaluated using ERPs after 1, 4, and 8 months of training. An N400 effect to semantic anomalies was already present after the first

month of learning. In addition, two syntactic violations were evaluated: (a) subject-verb agreement, which is present in English as well as in French, and (b) number agreement between the article and the noun, rarely present in English. Whereas a P600 component was elicited at the fourth month of training for the subject-verb agreement violation, no P600 effect was elicited for the second type of grammatical violation, even at the last evaluation point. The P600 component, peaking over central-parietal recording sites, is elicited by syntactic violations and unexpected (complex) syntactic constructions (such as sentences with noncanonical word order, Matzke, Mai, Nager, Rüsseler, & Münte, 2002) and has been associated with syntactic reanalysis (Kaan, Harris, Gibson, & Holcomb, 2000). The results of Osterhout et al. support the hypothesis that morphosyntactic rules shared by the L1 and L2 are qualitatively different from the ones that are not common to the two languages.

A further study by Portin and Laine (2001) corroborates the idea that the limitation in L2 grammatical (morphological) learning might actually depend on the similarity between the L1 and L2 with respect to this dimension. Portin and Laine studied fluent early Swedish-Finnish bilinguals. Finnish has a very rich morphological system and native-Finnish monolinguals appear to process words in a compositional manner (in combinations of stems and affixes). Swedish, in contrast, is a Germanic language and has a much more limited morphological system. In this study, Swedish monolinguals processed monomorphemic and inflected Swedish nouns approximately equally fast. In contrast, Finnish-Swedish bilinguals processed inflected Swedish items significantly more slowly than monomorphemic words. This suggests that Finnish-Swedish bilinguals transferred the process of decomposing inflected words in their L1 (Finnish) to Swedish. A direct effect of similar compared to dissimilar structures can be found in Hahne, Mueller, and Clahsen (2006). They explored how L2 learners (L2 German, L1 Russian) process inflected words by means of two offline tasks (acceptability judgment and elicited production) and ERP recordings during the processing of

morphological violations (noun plurals and past participles). Error rates for the noun plurals were higher in the L1-Russian group for the acceptability judgment task. With regard to the ERP, similar studies in monolinguals have shown a P600 following possibly a LAN peaking around 350–400 ms (Coulson, King, & Kutas, 1998; Weyerts, Penke, Dohrn, Clahsen, & Münte, 1997). In the L1-Russian group, violations of regular noun plural suffixation elicited a P600 but no LAN, whereas both components were present in a control group of native speakers of German. By contrast, a surprising result was obtained for past participle processing. In this case, the bilingual group was identical to the group of native-German speakers for the processing of regular and irregular violations in performance, as well as on the ERP measures. Interestingly, Russian and German share the same regular suffix (*-t*). Although in Russian, the selection of the *-n* and *-en* suffix participle is phonologically determined by certain stem endings, whereas in German, the *-n* suffix is determined by class membership and only applies to the subclass of strong (irregular) verbs, the similarity between the languages might have been crucial and probably facilitated the learning of this inflectional pattern in German.

In order to further explore this idea, we conducted an ERP study of Spanish morphology with two groups of highly proficient Catalan-Spanish early bilinguals with inverse profiles (de Diego Balaguer et al., 2005). One group (L1-Spanish) had learned Spanish as their primary language and Catalan as their L2. In contrast, the L2-Spanish group had learned Catalan first. Importantly, the regular suffix (*-o*) is common to both languages[8] (e.g., *menj-ar*/*menj-o* "to eat/I eat" in Catalan, *cant-ar*/*cant-o* "to sing/I sing" in Spanish), whereas the irregular alternations are totally different. Spanish and Catalan, unlike the language pairs studied by Portin and Laine (2001) or Hahne et al. (2006) have very similar morphological structures; that is, they both have the same number of conjugation classes, tenses, and persons. Therefore, learners can easily exploit the structures already available in their L1 in the process of learning the morphological system of the

L2. Regular Spanish verbs showed the same centro-parietal N400 priming effect in the second language speakers (L2) as in primary language (L1) speakers. However, ERP differences between groups were observed for irregular morphology.[9] In L1 speakers, an N400 effect appeared for both regular and irregular verbs (see Figure 8b) and had about the same size. In contrast, L2 speakers showed a reduced N400 priming effect in the irregular contrast. The size of the N400 effect in this particular study (computed by subtracting the primed from an unrelated condition) reflects the effect of morphological priming. Thus, again, similar structural properties might promote processing in L2, whereas dissimilar structures appear to cause interference.

## The Phonological Level

The proverbial difficulty of native speakers of Chinese to perceive and produce the differences between /r/ and /l/ illustrates that phonological (dis)similarity between L1 and L2 is a major factor in the processing of L2. Take Spanish and Catalan for
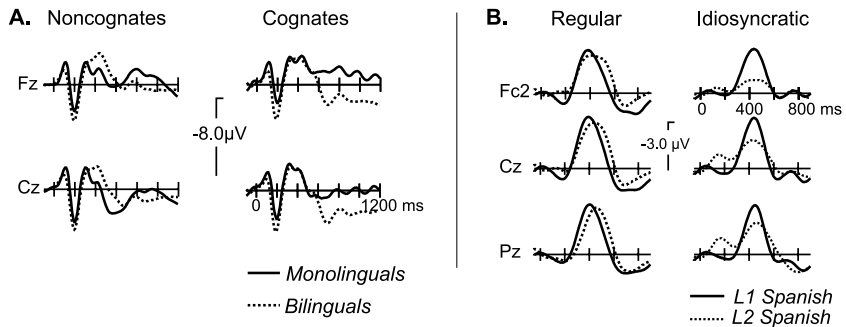


*Figure 8.* Similarity effects across languages. (a) ERP averages for cognate and coincidence noncognate words in monolinguals and bilinguals (from the gender-interference experiment). (b) ERP averages for regular (similar) and irregular (dissimilar) verbs in Spanish dominant (L1-Spanish) and Catalan dominant (L2-Spanish) bilinguals showing the N4 repetition priming effect (difference waveforms, unrelated minus related items). (Adapted from De Diego Balaguer et al., 2005.)

example, which differ in the number of vowels. Whereas Spanish has five vowels (/a, e, i, o, u/), Catalan has eight (/a, e, ε, i, o, ɔ, u, ə/). Thus, both languages have the phoneme /e/, but /ε/ is contrastive only in Catalan; the sound /ε/ is perceived as a particular instance of the category /e/ by Spanish monolinguals (Sebastian-Galles, Echevarria, & Bosch, 2005). The ambiguity of the phoneme /ε/ is reflected in the Spanish dominant bilingual speakers of Catalan in a particular difficulty in the perception and production of this phoneme. A previous study by Bosch, Costa, and Sebastian-Galles (2000) has shown that even highly proficient and early Spanish dominant bilinguals (before 4 years old) have trouble perceiving the /e-ε/ contrast. These problems have consequences also at the lexical level (Pallier, Colomé, & Sebastian-Galles, 2001). The results of a recent electrophysiological study (Sebastian-Galles, Rodriguez-Fornells, De Diego Balaguer, & Diaz, in press) show that although Spanish-dominant bilinguals have no problems in rejecting nonwords made by changing a common vowel contrast (e.g., *finestra* "window," changed to the pseudoword *finostra*), they had substantial difficulty when the change involved a Catalan-specific contrast (e.g., *finestra* changed to the pseudoword *finεstra*). Moreover, although the Catalan group showed a clear error-related negativity (ERN) when producing an error in pseudoword decisions involving a Catalan contrast (e.g., in the case of *finεstra*), no ERN trace was observed in the Spanish dominant bilingual group. The ERN component is obtained time-locked to erroneous decisions (Gehring, Gross, Coles, Meyer, & Donchin, 1993) and has been clearly related to the activation of the ACC and other prefrontal regions (see Carter et al., 1998; Ullsperger & Von Cramon, 2001). Although the specific relation to the ERN component and response conflict and error detection is under debate (see Botvinick, Braver, Barch, Carter, & Cohen, 2001; Holroyd & Coles, 2002; Yeung, Botvinick, & Cohen, 2004), we favored the interpretation that in this particular case, Spanish bilinguals did not experience any conflict or uncertainty when processing the incorrect Catalan pseudoword. Interestingly, the ERN might be

a very useful component for evaluating the degree of response conflict in bilinguals when processing languages in different contexts (see following section).

## How the Language Production System in Bilinguals Implements Inhibition

Several different bilingual models briefly discussed above posit the existence of inhibitory mechanisms that enable the deactivation or partial suppression of the language not in use. Although we have provided evidence for the involvement of fronto-central "executive" brain areas in bilingual language processing, there is, as yet, no clear or direct evidence of inhibition at the behavioral, brain region, or neuron levels involved in the regulation of both languages. How exactly does the prefrontal cortex regulate the selection and activation of the target lexicon and the corresponding grammatical rules? Inspired by findings in other domains of cognitive neuroscience we will propose how two interrelated control/inhibitory mechanisms might regulate bilingual speech production: (a) A top-down control inhibitory mechanism could be implemented by the prefrontal cortex when language schemas are activated and (b) this prefrontal selection/inhibition mechanism could interact with a more local and bottom-up inhibitory mechanism that regulates the level of activation of the nontarget language. Depending on the communicative situation (monolingual vs. mixed-language contexts), the top-down modulation could regulate the local-inhibitory system in order to control for the degree of access to nontarget representations when speaking. This control mechanism is possible due to the rich interconnectivity of the prefrontal cortex with other regions of the brain (Pandya & Barnes 1987; Pandya & Yeterian 1990).

Using single-cell recordings, functional neuroimaging, and electroencephalography, an influence of the prefrontal cortex on the selective activation and suppression of different specialized posterior regions of the brain has been observed (Barcelo, Suwazono, & Knight, 2000; Corbetta, Miezin, Dobmeyer,

Shulman, & Petersen, 1990; Hillyard, Hink, Schwent, & Picton, 1973; Moran & Desimone, 1985; Pessoa, Kastner, & Ungerleider, 2003). For example, ERP studies in patients with focal prefrontal cortex lesions have shown that primary auditory- and somatosensory-evoked responses are enhanced (Chao & Knight, 1998; Knight, Scabini, & Woods, 1989; Yamaguchi & Knight, 1990). These results suggest a disinhibition of sensory flow to primary cortical regions. In addition, damage to the lateral prefrontal cortex has been associated to marked decrements in the top-down signal accompanied by behavioral evidence of impaired detection ability (Barcelo et al., 2000). Using fMRI and ERPs, Gazzaley, Cooney, McEvoy, Knight, and D'Esposito (2005) have recently shown that the magnitude of neural activity and the speed of neural processing were clearly modulated by top-down influences. In this study, activation in the visual association cortex for faces and scenes were dependent on the instructions to attend to or ignore one or the other type of stimuli. Whereas attending to faces, for example, increased the activation of the ventral temporal lobe (fusiform gyrus, face area), decreased activation (or suppression) was simultaneously observed in the corresponding scene visual processing area (parahippocampal cortex, place area).[10] This study clearly demonstrated that top-down modulations from the prefrontal cortex can directly facilitate stimulus processing at posterior regions of the cortex and suppress activity in nonrelevant regions (for a review, see Knight & Stuss, 2002; for a similar proposal in visual attention, see Desimone & Duncan, 1995).

Invasive electrophysiological studies in patients with implanted electrodes have revealed a large face-selective N200 component, which is generated in small regions on the inferior surface of the occipito-temporal cortex (Allison, Puce, Spencer, & McCarthy, 1999). This component reflects excitatory depolarizing potentials in pyramidal neurons in these regions and has been related to face perception per se rather than later recognition stages. In other small regions of the occipito-temporal cortex, a similar N200 response has been elicited by other types of stimulus, such as letter strings (words and nonwords), numbers,

complex objects, and gratings. More recently, it has been shown (Allison, Puce, & McCarthy, 2002) that the presentation of a face elicited a N200 negativity in the face-selective region, whereas it induced a positivity in word-selective regions. Letter strings led to the reverse pattern. The positivity might reflect hyperpolarizing inhibition of apical dendrites, providing strong evidence that assemblies of neurons that are activated or responsive to one stimulus category (such as faces) inhibit cell responsiveness to another category (such as letter strings), probably by a type of lateral inhibition. The authors proposed a simple model in which the mechanism of inhibition consisted in a recurrent collateral inhibition. Because the P200/N200 peaks were highly correlated, this suggests a local inhibitory process driven bottom-up by the input signal.

With regard to bilingual language processing, such a type of local inhibitory mechanisms could be the neural instantiation of the proposed inhibitory links between languages. Furthermore, top-down mechanisms might be able to influence the degree of tuning of these specific language-selective regions to the language context; for example, this top-down modulation of the prefrontal cortex in other parts of the brain will increase for weak stimulus-response mappings when they are in competition with stronger ones, specially when flexibility is required.

## Future Issues in the Cognitive Neuroscience of Neural Control in Bilingualism and L2 Learning

Bilinguals seem to cope with L2 interference by recruiting typical "executive function" brain areas that have been observed in many other experimental contexts. These areas might be crucial in suppressing and inhibiting the production of the nontarget language word. Future studies should more closely examine the interplay between control and executive brain mechanisms and the selection or suppression (inhibition) of language lexicons in bilinguals. In this section we will briefly highlight several possible lines of research related to topics of discussion.

One important remaining question is how neural control is implemented in the course of learning a new language. Although several recent studies have examined the neural mechanisms involved in word learning (Cornelissen et al., 2004; Friederici, Steinhauer, & Pfeifer, 2002; Grönholm, Rinne, Vorobyev, & Laine, 2005; Laine, 2000; McLaughlin, Osterhout, & Kim, 2004; Mestres, Rodriguez-Fornells, Münte, submitted; Mueller, 2005; Sakai, 2005), the role of cognitive control in learning a L2 has been neglected so far. For example, the revised hierarchical model of bilingual memory (Kroll & Stewart, 1994) makes specific predictions about how new words (L2) are learned. This model proposes that at the early stages of word learning, the lexical link between the new (L2) word and the corresponding L1 word is stronger than the link between the concept and the new word. With the repeated use of the new word, the conceptual link is reinforced and speakers are able to use this path freely in order to comprehend and produce words without having to rely on the lexical link (new word–L1 word). Although this model provides an interesting framework to study the word-learning problem, no studies have yet addressed the brain correlates of, for example, the consolidation of the lexical and semantic links, their brain representation, and the control mechanism that regulates the differential strengths and levels of activation of the different representations during the acquisition process.

From a different perspective, Gaskell and Dumay (2003) studied behaviorally the influence of newly learned words (nonassociated to any meaning) on the processing of an existing lexical item. Using repeated exposures of new words (e.g., *cathedruke*) over the course of 5 days, these authors studied the delay in recognizing similar existing words (e.g., *cathedral*). An interesting inhibitory effect was found on the fourth and fifth day. This study demonstrated that new words gradually develop lexical representations, which subsequently lead to lexical competition during word recognition. This type of study will prove very interesting in understanding the learning of an L2 at the lexico-semantic, morphological, and syntactical levels.

A host of other interesting issues remain to be explored. An incomplete and subjective selection might include the following: (a) the impact of implicit and explicit processes in language learning and the differential involvement of memory mechanisms (Ullman, 2001), (b) assessment of the early stages of adult language acquisition using artificial languages (Friederici et al., 2002; Gomez & Gerken, 2000; Sanders, Newport, & Neville, 2002), (c) delineation of the exact contribution of the left DLPFC in cognitive control in bilinguals (selection, switching, inhibition/suppression of the nontarget language), (d) relation of activity in the DLPFC to proficiency; (e) search for the existence of two proposed selection/inhibitory mechanisms in bilinguals (e.g., using functional connectivity measures or intracortical stimulation and recording), and (f) assessment of the relation between individual differences in executive functions and mastery of an L2.

A long-term goal of such a research program would be to understand how different learning and tutoring methods, biographical circumstances, and language attitudes impact on the process of learning an L2 (Franceschini et al., 2003; Grosjean, 1998; Klein, 1996) in order to improve the acquisition of new languages.

## Notes

[1]Examples are as follows: (a) access restricted to the regions of craniotomy, (b) heterogeneity of the patient samples and limited number of patients, (c) mapping mainly reflects the disruptions on the gyral surface rather than the sulcus, which is more easily mapped using fMRI (Pouratian et al., 2000), and (d) bias in the type of patients studied (i.e., problems in generalizing to functional localizations in healthy populations).

[2]In the model of language production proposed by Levelt et al. (1999), lemmas are considered to be abstract lexical entries that mediate between the conceptual and phonological/phonetic levels and are supposed to contain all syntactically relevant properties of the word to be produced. Therefore, lemmas are defined as an entry in the mental lexicon specifying a word's syntactic properties.

[3]The *Simon task* is a well-known paradigm in experimental psychology used to examine stimulus-response interference. This task is similar to other

well-known interference paradigms, like the *Stroop* and the Eriksen flanker tasks. In the Simon paradigm, the irrelevant spatial location of an object conflicts with the response required for that object (e.g., making a left-hand response to a triangle presented in the left side of a monitor).

[4]Response inhibition, which is integrated in the executive system, is frequently evaluated using the Go/noGo paradigm. This function is necessary to suppress response tendencies that could be contextually inappropriate. The Go/noGo task always involves a type of stimuli for which the volunteer has to respond as quickly as possible (Go trials) and another type that requires a withholding of the response (noGo trials). For example, in a Go/noGo visual categorization task, participants could be instructed to make a motor response if the picture presented is an animal and to inhibit their responses if it is not an animal. With the utilization of neuroimaging techniques, it is relatively easy to analyze the brain signatures and activation related to inhibition (noGo trials) and to compare it with noninhibited trials.

[5]Difference waveforms are usually computed in order to isolate a specific ERP component (in this particular case, the N2 noGo). The underlying assumption is that only one component varies between both experimental conditions and that this component could be isolated using the subtractive procedure and performing the statistical analysis on the resulting "difference waveform" (for the limitations of this approach, see Fabiani, Gratton, & Coles, 2000).

[6]The claim that semantic representations are shared across the bilingual's two languages is still a matter of debate. Support for a shared semantic system comes basically from a large number of studies showing cross-language semantic priming. However, one of the problems is that much of the research devoted to this topic has been based on materials that refer to concrete objects (as the ones used in our study). Some authors have stated that more abstract or more ambiguous types of concept might not be sharing the same meaning representation (see Kroll & Tokowicz, 2001; Van Hell & De Groot, 1998). A word in a language could be associated with a distinct pattern of semantic features or primitives and, therefore, the resulting meaning could be slightly different across languages. In a recent study, Dong, Gui, and MacWhinney (2005) proposed a new model of the semantic bilingual memory, which tries to unify different perspectives. This model proposes the coexistence of shared and separate conceptual representations in bilinguals.

[7]The LAN is an ERP component characterized by a left frontal negativity observed between 300 and 450 ms after word onset and that has been frequently encountered in morphosyntactic violations (e.g., violations of tense, number, or gender agreement; Weyerts et al., 1997; Coulson et al., 1998). However, similar LAN-like components have been associated with verbal working memory processes (King & Kutas, 1995).

[8]Although the so-called *central* variant of Catalan pronounces the -o suffix as /u/, the remaining varieties pronounce it as /o/ and the written form is also -o.

[9]Two types of irregular verb were studied (semiregular verbs with a systematic diphthong alternation, *sentir-siento*, and verbs with idiosyncratic changes, *venir-vengo*). For the sake of simplicity, we only discuss here the results for fully irregular idiosyncratic verbs.

[10]The parahippocampal cortex is a structure in the medial temporal lobe adjacent to the hippocampus. The fusiform gyrus lies lateral to the parahippocampal and lingual gyrus and is separated from these structures by the collateral sulcus.

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