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Review

Event-related potentials (ERPs) in the study of bilingual language processing

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Abstract

The present review focuses on event-related potential (ERP) studies that have addressed two fundamental issues in bilingualism research, namely the processing of a first *versus* a second language in the bilingual brain and the issue of control of two languages. A major advantage of the ERP technique is its high temporal resolution that enables the study of task-related neural activity at the millisecond level. For example, ERP studies of bilingualism have shown that developmental changes in the ability to discriminate native and foreign speech sounds can experimentally be traced by the presence or absence of a specific ERP component (the mismatch negativity). They have also revealed latency delays in a semantic-related ERP component (the N400) in bilinguals compared to monolinguals, as well as in bilinguals reading in their L1 or L2 language. These studies have also highlighted the importance of L2 proficiency level and age of acquisition on bilingual language processing. Moreover, ERP studies have pointed out potential mechanisms of avoidance of interference between languages (the NoGo N200 effect). The present review aims to describe and integrate the main results of the selected ERP studies on bilingualism and to provide an overview of how different ERP components can be used to address important theoretical questions in this field. Finally, we suggest potential research directions to clarify unresolved issues and to advance this emerging field of research.

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Keywords: Event-related potentials; Bilingualism; Mismatch negativity; N400; NoGo N200; Language switching; Cognitive control

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Contents

| | |
|--|----|
| 1. Introduction | 2 |
| 2. First vs. second language processing in the brain | 3 |
| 2.1. Phonetic/phonological level: phoneme discrimination in a second vs. a first language | 3 |
| 2.1.1. Automatic auditory change detection as measured by the mismatch negativity evoked potential | 3 |
| 2.1.2. Phoneme discrimination in infants | 4 |
| 2.1.3. Phoneme discrimination in adults learning a second language | 5 |
| 2.2. Semantics: semantic violations in a second vs. a first language | 7 |
| 2.2.1. The N400 event-related potential | 8 |
| 2.2.2. The N400 component in between-groups comparisons | 8 |
| 2.2.3. The N400 component in within-group comparisons | 10 |
| 2.3. Syntactic level: syntactic violations in a second vs. a first language | 12 |
| 3. Control of two languages in one brain | 13 |
| 3.1. Executive control in bilingual language processing | 13 |
| 3.2. Cognitive control and inhibitory effects in bilinguals | 15 |
| 3.2.1. Inhibitory effects: the N200 Go/noGo component | 15 |
| 3.2.2. Controlling languages: zooming effects | 18 |
| 3.3. Language switching in bilinguals: event-related brain potential studies | 19 |
| 3.3.1. ERP components associated to task-switching | 19 |
| 3.3.2. Switching languages for single words | 20 |
| 3.3.3. Switching languages while reading sentences | 23 |
| 4. Summary and conclusions | 25 |
| Acknowledgements | 27 |
| References | 27 |

1. Introduction

Our scientific knowledge on bilingual language processing such as bilingual lexical memory structure, language acquisition in bilingual children, adults' ability to switch languages or to avoid cross-language interference, and cerebral language lateralization in bilinguals, is mostly based on behavioural measures. In recent years, we have witnessed an increase in the use of the event-related potentials (ERPs) in neurocognitive research on bilingualism. An important advantage of the ERP technique is that it provides a direct measure of real time brain activity at the millisecond level even without the need of an additional task from the participant other than e.g. reading for comprehension (this is also true for the magnetoencephalography method that taps the magnetic field created by synchronous activity of a large number of neurons). The ERP technique has thus the potential to highlight the temporal unfolding of neural events associated with different subprocesses of language reception or production. It is also worth noting that while psycholinguistic models of language remain silent about the cerebral localization of specific functions, they do make predictions about the composition and temporal order of subprocesses needed for language tasks such as naming, reading, or repetition. Such predictions can be tested with the ERPs thanks to their high temporal resolution.

In the current paper, we will review selected ERP studies that have addressed one of the two following issues. The first issue concerns the processing of first (L1) vs. second (L2)

language in the brain. Do the neural correlates of L1 vs. L2 processing differ from each other? We examine this issue with studies that have focused at receptive language processing at the phonetic/phonological, semantic, or syntactic level. The second major issue involves the control of two languages in one brain. How does the bilingual brain manage to avoid interference from the non-target language? Which neurophysiological changes accompany switching between languages?

2. First vs. second language processing in the brain

Language is a multifaceted phenomenon that can be experimentally studied via different linguistic domains. In the following section, we will describe some of the studies that have used the ERP methodology to study phonetic, semantic, and syntactic aspects of bilingual language processing. Some of these studies address a specific question of a specific language process while others test diverse linguistic domains within the same bilingual population (e.g., semantic and syntactic processing in L2 vs. L1). A good example of the latter is the cross-sectional study by [Weber-Fox and Neville \(1996\)](#). They tested groups of L2 learners exposed to their second language at five different points in development (from 1 to 3 years to after 16 years of age) and compared their ERP responses to semantic and syntactic violations in L2 with those obtained from native speakers of the language. Although we will describe their findings in more detail later on, we would like to start off by mentioning that according to the authors of this study, semantic processing is less vulnerable to delays in second language exposure than syntactic processing, indicating that subsystems specialized for different linguistic domains display different sensitivity periods ([Weber-Fox & Neville, 1996](#)). In what follows, we review the current literature on each linguistic domain separately.

2.1. *Phonetic/phonological level: phoneme discrimination in a second vs. a first language*

In this section we will first describe the ERP component that has been used to study speech sound discrimination, i.e., the mismatch negativity or MMN. Then we deal separately with bilingual ERP studies carried out in infants and those focused on adults learning to discriminate sounds in a second language.

2.1.1. *Automatic auditory change detection as measured by the mismatch negativity evoked potential*

A particularly important component for preattentive information processing in the auditory modality is the MMN ([Näätänen et al., 1978](#)). It consists of a negative deflection in the auditory ERP at around 150–200 ms in response to stimuli that are “deviant” with respect to the context in which they appear (see illustration in [Fig. 1](#)). The major source of MMN is located in the auditory cortices (for review, see [Alho, 1995](#)). It has been proposed that there are additional frontal MMN sources that might be related to the involuntary switching of attention due to the deviant stimulus ([Alho, 1995](#)), but the evidence is inconsistent (e.g., [Edwards et al., 2005](#)). In a typical MMN study, subjects are exposed to a stream of auditory stimuli while being engaged in some other task (e.g., reading). The auditory stream consists of repetitions of the same sound (standard) interspersed with occasional deviant auditory stimulus to which the MMN is elicited.

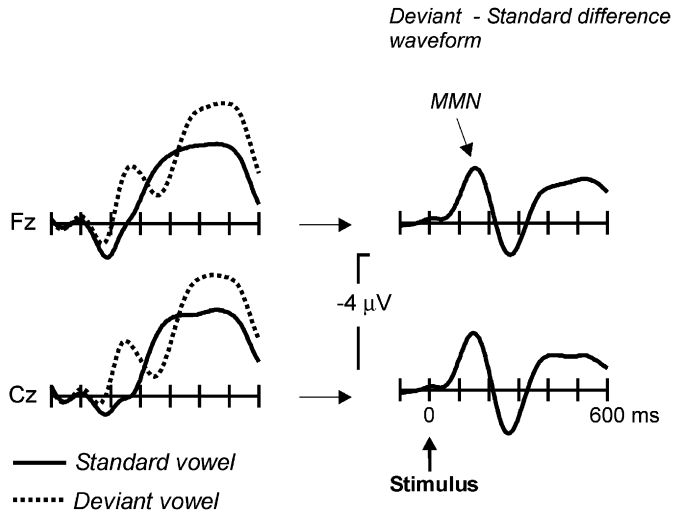


Fig. 1. On the left side are shown the event-related stimulus-locked brain components associated to the processing of simple vowels in a passive listening task while subjects were reading a newspaper. Notice that for the most infrequent vowel (deviant vowel), an increase of negativity is observed over the range of the 100–250 ms. When both ERP waveforms are subtracted (right side), a clear mismatch negative component (MMN) is observed showing a standard frontocentral distribution.

The MMN has been considered to reflect automatic change detection (Cheour et al., 2000). Whether MMN responses go beyond detecting an acoustic difference between standards and deviants has important implications for research on spoken language processing. Interestingly, deviants of a speech sound in the subject's native language have been found to elicit considerably larger amplitude MMN responses than could have been expected on the basis of the mere acoustic distance from the standard phoneme alone (Näätänen et al., 1997). Thus, the MMN amplitude highlights the relevance of particular acoustic distinctions over others. Furthermore, if the deviant stimulus is a phoneme prototype in a particular language (e.g., the Estonian vowel prototype / δ / that is acoustically and phonetically situated in-between the Finnish-language prototypes /o/ and / δ /), the MMN amplitude enhancement for that deviant occurs in speakers of that particular language (Estonian) but not in speakers of another language that lacks this phoneme category (Finnish) (Näätänen et al., 1997). MMN amplitude to speech sound stimuli appears to be experience-dependent and therefore provides valuable information on acquisition of phonetic categories in infants as well as in children and adults learning a second language. Since no conscious attention to the critical auditory stimuli is required, the MMN paradigm is particularly suitable to study infants.

2.1.2. Phoneme discrimination in infants

The ability of young infants to discriminate phonemes even if they are not used in their native language has been claimed to regress during the first year of life (Dehaene-Lambertz & Dehaene, 1994). Based on the modulations of MMN amplitude, Cheour et al. (1998) showed that by 1 year of age, the children's ability to perceive non-native vowels diminishes, whereas perception of native vowels improves. It seems that beyond a certain age, enhanced MMNs are elicited to phonemic deviations only as long as these are

meaningful distinctions in the subject's native language. This line of research therefore supports the claim that infants can discriminate non-native speech contrasts without relevant experience, and that there is a decline in this ability during ontogeny (Werker & Tees, 1984). It has also been claimed that related to this decline, a phonemic process appears around 10–12 months that assimilates speech sounds to native categories whenever possible; otherwise they are perceived in auditory or phonetic (articulatory) terms (Best et al., 1988). Below we will discuss how the ERP literature from adults learning an L2 fits in with the proposal of an “assimilation” process.

Returning to infants, some researchers have claimed that the ability to distinguish non-native speech sounds still remains at 11 months of age although the neural correlates of speech discrimination are sometimes different from typical MMN effects (Rivera-Gaxiola et al., 2005). These authors recorded ERPs in 7- and 11-month-old infants in response to native and non-native speech sounds. In agreement with previous behavioural data, infants' discriminatory ERP responses to the non-native contrast were present at 7 months of age, but disappeared by 11 months of age. Further, the authors divided the sample in two subgroups on the basis of individual ERP components and found two subgroups of infants that remained sensitive to the non-native contrast at 11 months. One group showed an early positive component at 150–250 ms (mismatch positivity) in response to the deviant stimuli while the other group showed a larger later negativity (at 250–550 ms). Thus, this analysis revealed that infants may be able to accomplish phonemic discrimination of non-native contrasts in different ways since subgroups of individuals showed distinct ERP patterns (Rivera-Gaxiola et al., 2005). The authors suggest that the N250–550 differences index a more mature pattern of response, whereas the earlier P150–250 responses reflect the employment of a more acoustic form of analysis. Thus, the initial finding that the ability to discriminate non-native speech sounds decreased by the age of 1 year, has been challenged by this ERP study. According to the authors, the infant brain remains capable of discriminating non-native phonetic contrasts at 11 months of age (Rivera-Gaxiola et al., 2005). With regard to the MMN polarity changes (positive or negative) in studies on infants, Weber et al. (2004) suggest that this depends on data filtering settings. Further research is needed to clarify this methodological issue.

In contrast to the difficulties adults encounter while learning to discriminate sounds in L2 (which we will address in the following section), researchers have found a fortunate scenario for children. Using the amplitude of the MMN as an index of the ability to detect speech contrasts in a non-native language, it has been shown that in just a couple of months, 3–6-year-old children learn to discriminate non-native speech sounds without any special training (Cheour et al., 2002). In fact, besides MMN changes, 3–6-year-old children learning an L2 also show changes in other ERP components such as the P3a that reflects the involuntary attention switching toward deviant stimuli, and late difference negativity (LDN), which has been suggested to index reorienting processes following distraction (Shestakova et al., 2003).

2.1.3. Phoneme discrimination in adults learning a second language

When learning a second language in adulthood, one should somehow retrace the “lost ability” to tell the difference between speech sounds in a foreign language. An MMN study by Winkler et al. (1999) with Finnish monolinguals, Hungarian monolinguals, and Hungarian–Finnish bilinguals is relevant to this issue. They used two vowel contrasts: one that is relevant for Finnish and another that is relevant for both Finnish and Hungarian.

All groups showed MMN for the latter contrast but only the Finnish monolinguals and the Hungarian–Finnish bilinguals who had spent a considerable time in Finland (2–13 years), showed native-like MMN effects for the Finnish-language contrast. However, learning an L2 in a classroom environment may not lead to the formation of new long-term native-like memory traces. Thus, MMNs from advanced Finnish students of English were significantly smaller than native-like MMNs to vowel contrasts (Peltola et al., 2003). Taken together, these two studies would suggest that immersion with authentic speech input is required for the early cortical processing of foreign speech sounds to become native-like.

As we mentioned earlier, the difficulty in adult L2 learners might be due to the fact that certain degree of assimilation of the foreign language acoustic input into the native language phonemic space seems to take place. Dehaene-Lambertz et al. (2000) showed that the input signal presented to Japanese and French speakers was directly parsed into the native language phonological format. In their study, MMN responses recorded from French participants were either absent or significantly weaker for Japanese participants. Phonetic combinations foreign to Japanese such as having no vowels between consonants were apparently resolved by the Japanese listeners by means of assimilating the acoustic input to their native language phonetic rules. By not detecting a mismatch between a sequence that includes a vowel sound and a sequence that does not, the Japanese listeners behaved as if they had perceived a vowel between consonants even in stimuli that contained no acoustic correlate of vowels. The fact that the phenomenon does not occur in French listeners (they do instead react to the contrast between having vs. not having a vowel) suggests that speech perception in an L2 is deeply affected by the phonemic structure of the native language.

A similar influence of native-language phonemic distinctions has been found with regard to vowel length. In some languages such as Finnish the distinction between long and short vowels is often crucial for meaning, i.e., a word can convey a completely different meaning based on the duration of an intervening vowel (compare /tuli/ “fire” and /tu:li/ “wind”). In the study by Nenonen et al., native and L2 speakers were equally sensitive to deviant pure pitch tones. However, while native speakers of Finnish also showed an increased MMN response when the deviant consonant–vowel syllable had a shorter vowel duration than the standard stimulus, L2 learners did not (Nenonen et al., 2003). Again, a phonemic feature present in L2 but absent in L1 may be hard to discriminate by second language learners. Moreover, a review of the literature by Mueller (2005) points out that the degree of learnability of different phonetic features may vary in L2 acquisition.

More recently, the so-called error-related negativity (ERN) component was used to evaluate in which degree phonological errors were discovered by L2 learners (Sebastian-Galles et al., 2006). The ERN component is obtained immediately after the commission of an erroneous response (Gehring et al., 1993) and has been related to the activation of the anterior cingulate and other prefrontal regions (see Carter et al., 1998; Ullsperger & von Cramon, 2001). Although the specific relation of the ERN component to response conflict and error detection is still under debate (see Yeung et al., 2004), this component can be very useful in evaluating the degree of conflict or uncertainty in bilinguals when processing in L2 (e.g., lexical decision tasks, covert production, etc.). Sebastian-Galles et al. (2006) showed that although Spanish-dominant bilinguals performing a lexical decision task had no problems in rejecting non-words such as “finostra” (from “finestra” *window*), they had substantial difficulty when the change involved a Catalan-specific contrast (e.g., *finestra*

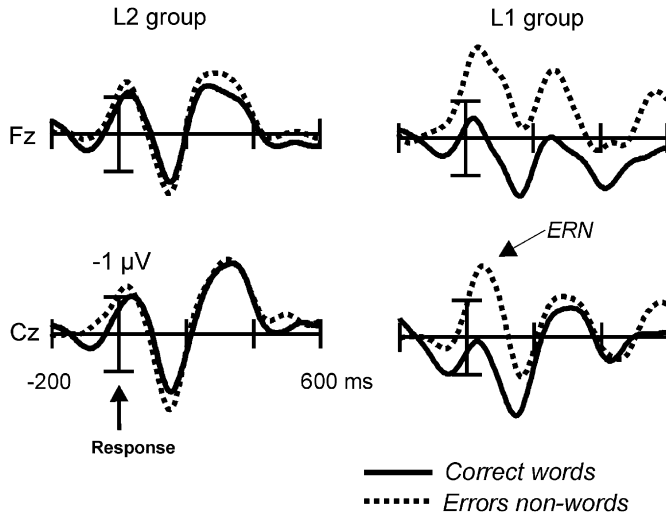


Fig. 2. Response-locked event-related brain activity (frontocentral electrodes) associated to the processing of correct Catalan words and erroneous responses to non-words which included a difficult phonological contrast. Participants were performing an auditory lexical decision task in Catalan. Catalan was the second language acquired in the L2 group (Spanish–Catalan bilinguals). In contrast, the other group (L1 group or Catalan–Spanish bilinguals) was raised in Catalan. Notice that the L2 group did not show the classic error-related negativity (ERN component) associated to the commission of erroneous responses which is convergent with previous behavioural data showing the lack of discrimination of this phonological contrast in this bilingual group. ERP averages were time-locked to the response of the participant and not the moment in time at which the stimulus was presented (adapted from Sebastian-Galles et al., 2006).

changed to the pseudoword *finestra*). Spanish-dominant bilinguals have marked problems perceiving this /e–ɛ/ Catalan contrast (Bosch et al., 2000). Interestingly, 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 *finestra*). In contrast, no ERN trace was observed in the Spanish-dominant bilingual group (see Fig. 2).

In conclusion, the studies reviewed above show that the ERP technique provides researchers with a very useful tool to explore what critical linguistic contrasts listeners' brains are sensitive to even when their behavioural responses do not evidence any difference between contrasting speech-sounds. ERPs allow exploring how sensitivity to speech contrasts develops in infants vs. older children, or in adults learning a second language. Besides purely theoretical interest for understanding speech perception and to test the sensitivity period hypothesis, future research in this field can provide more information on the acquisition of critical phonetic contrasts in an L2 as a function of training and therefore guide the development of L2 teaching methods. An interesting study of phonetic training shows that amplitudes of the P1, N1, and N200 ERP components can reflect learning at an earlier phase than corresponding behavioural measures do (Tremblay et al., 1998).

2.2. Semantics: semantic violations in a second vs. a first language

In the following section, we address the semantic domain of language in bilingualism, focusing on ERP studies of semantic anomaly detection at the sentence level. We will first

introduce the N400 ERP component utilized in these studies, and then proceed to review the results of N400 studies contrasting bilinguals to monolinguals (between-groups comparisons), as well as bilinguals in their L1 vs. L2 language (within-subjects comparisons).

2.2.1. *The N400 event-related potential*

A widely studied ERP response, the N400 component, is a negative deflection peaking at around 400 ms after stimulus onset. Although it was first described in an experiment contrasting semantically predictable vs. semantically nonsensical sentence completions (Kutas & Hillyard, 1980a, 1980b), the N400 is not simply an index of semantic anomaly, but rather a part of the brain's normal response to potentially meaningful events (Kutas & Federmeier, 2000; Kutas et al., 2000). The amplitude of the N400 is the parameter that is most sensitive to lexical–semantic manipulations. Thus, its magnitude varies with semantic congruity (as originally described), cloze probability of words in a context, word repetition, word frequency, and semantic category, among others. Its distribution across the scalp has been found to vary depending on the type of eliciting stimulus (auditory vs. visual; pictures and faces vs. words). Finally, and perhaps more critical for the bilingual studies that we will be covering in this section, certain N400 parameters such as its onset and peak latency, although typically rather stable, have also proven to be susceptible to biological and cognitive influences. Thus, for example, increasing age of the participants and increased stimulus presentation rate are both accompanied by a delay in N400 latency (Kutas & Kluender, 1994). The fact that the N400 amplitude is maximal when input consists of sentences with semantic violations vs. expected sentence endings, has contributed to the use of an overt semantic violation sentence paradigm in bilingualism studies. This paradigm can be used to examine how bilinguals process their L2 vs. L1 in a within-group design, or to contrast bilingual speakers with native speakers of the L2 language in a between-groups design. It is important to bear in mind that ERP differences arising from between-groups comparisons need to be handled with caution as ERPs can differ between groups in many ways. Between-groups differences may emerge in amplitudes, in latencies, and in scalp topography, and group effects may interact with experimental manipulations (Picton et al., 2000). On the other hand, within-subject comparisons (e.g., bilinguals in L1 vs. L2) call for a careful matching of L1 and L2 stimuli so that any observed effects are not merely reflecting intrinsic differences in stimulus difficulty/complexity. In the following sections we will review separately results from studies that have used between-groups comparisons and studies that have employed a within-group setup exclusively or in combination with between-groups comparisons.

2.2.2. *The N400 component in between-groups comparisons*

As compared to native speakers of L2, bilinguals are sometimes reported as being slower in their lexical decisions (e.g., Lehtonen & Laine, 2003; Portin & Laine, 2001). This has been hypothesized by some researchers to be due to an “extended lexical search” in bilinguals, whereas others have argued for less “automatization” in an L2 vs. a native language (Ardal et al., 1990). Ardal et al. used a classical N400 semantic violation paradigm to examine the potential reasons behind the slowing of lexical decision responses in L2. A significant delay in the N400 peak latency (approximately 40 ms) was found for bilinguals in their L2 compared to monolinguals. In addition, N400 latency differences were also reported between bilinguals in their L1 and monolinguals. Thus, according to

this study, bilinguals show a reduced processing speed in both languages (L1 and L2) when compared to monolinguals. The establishment of a link between slowed lexical decision times and a latency shift in the cortical response to semantic violations while reading for comprehension, is however delicate. There were no overt lexical decisions to be made in the ERP experiment and the N400 delays occur with words in a context rather than in processing of single words and nonwords. The authors of the study suggest that the N400 latency shift indexes a shift in the timing of an automatic word-identification process which precedes generation of N400. Moreover, they also reported a frontal negativity with reduced amplitude in L2 compared to L1 in bilinguals (a within-group comparison), claimed to be modulated by language proficiency. Neither the N400 nor this frontal negativity varied as a function of age of acquisition of L2. Finally, the study reports a tendency of N400 to peak on the left side of scalp in bilinguals, and on the right side in monolinguals, suggesting that different neural generators might be involved in the response to semantic errors in monolinguals and bilinguals.

The study by Weber-Fox and Neville (1996) mentioned above also found N400 delays (of approximately 20 ms) to semantically incongruent sentence endings in English in groups of Chinese speakers who were exposed to English as an L2 after 11–13 or 16 years of age. Bilinguals exposed to L2 before 11 years of age did not show significant delays in their N400 response compared to monolingual English speakers. A similar shift in the N400 peak latency was observed between these two late-L2-exposed groups, but only the very late exposed group (those exposed to L2 after 16 years of age) performed less accurately than the monolinguals in behavioural semantic anomaly detection. This made the authors suggest that the latency shift in N400 is not closely tied to level of accuracy but may rather reflect a slight slowing in processing (Weber-Fox & Neville, 1996). Although the authors of this study focused on age of acquisition as a critical factor, they acknowledged that age of acquisition and years of experience with the language were of similar predictive value for the N400 latency. Moreover, those exposed to English after 11–13 or 16 years of age reported reduced proficiency in speaking English compared to their L1, i.e., Chinese. This was in contrast to the participants exposed to L2 earlier (before 11 years of age) who rated themselves actually more proficient in their L2 (English) than in their native Chinese language. In contrast to previous studies, other N400 parameters such as amplitude or distribution did not significantly differ between bilinguals and monolinguals.

Hahne and Friederici (2001) studied native Japanese speakers who had learned German as an L2 after puberty by using an auditory sentence comprehension task rather than written language input. The study included semantic, syntactic, and combined semantic–syntactic violations in contrast to correct sentence endings. With regard to the ERPs to semantic anomalies, they found that the bilinguals showed an N400 effect similar to the one observed in native speakers of German. However, the N400 effect lasted about 400 ms longer in the L2 than in the L1 group, which the authors interpret as longer engagement in trying to integrate the word into the prior context. It is important to point out that they also found differences between bilinguals and monolinguals with regard to the processing of correct sentences. Correct sentences elicited a more positive ERP in the L2 learners than in the native listeners (between 500–1000 and 700–1100 ms) which could in turn be the reason why the N400 effect appears to last longer for them. In addition, the semantic violation condition elicited an additional right anterior-central negative effect in the 700–1100 ms time-window compared to correct sentences. That effect was present in

the bilinguals only. The key issue might be again the differences in the processing of correct sentences between their groups. The authors interpret these results as suggesting that late learners may, at their early learning stage, activate additional conceptual processes not necessarily active in native speakers.

An additional auditory study was carried out by [Hahne \(2001\)](#). In this study, Russian-speaking late learners of German (after the age of 10) were compared to German native speakers on the processing of correct, semantically violated and syntactically violated sentence endings. With regard to the semantic violations, an N400 effect was elicited for both groups although it showed reduced amplitude and longer peak latency (about 200 ms later) in the L2 group compared to the native speakers. Again, group comparisons revealed differences in the processing of correct sentences, too. Between 400 and 700 ms, correct sentences elicited a larger negativity in the L2 group than in the native speakers. Both the study with Japanese participants described previously ([Hahne & Friederici, 2001](#)) and the present one with Russians ([Hahne, 2001](#)) included correctness judgements on the sentences. The participants of the latter study had a better behavioural performance (lower error rate) compared to the Japanese. Based on the overall behavioural performance difference between these two studies, Hahne suggests that the ERP responses vary systematically with the proficiency level in L2.

2.2.3. The N400 component in within-group comparisons

When comparing the results from their bilinguals' two languages, [Kutas and Kluender \(1994\)](#) found N400 timing effects. Specifically, they found that the N400 in the less proficient language of a bilingual peaked later and also lasted longer than that in the more proficient language. In addition, on average the N400 amplitudes were also smaller for the less proficient language of a bilingual. Thus, other parameters of the N400 besides latency, such as its duration and amplitude, seem to be altered in bilinguals, and the proficiency in a language is considered to be a critical factor in driving this variation.

[Proverbio et al. \(2002\)](#) recorded ERPs from Italian monolinguals as well as from early highly fluent Italian–Slovenian bilinguals as they read sentences where the last word rendered the sentence either correct, semantically incorrect, or syntactically incorrect. The task was to decide whether or not the sentences were well-formed. The bilinguals were highly proficient with early exposure to both languages (compound bilinguals). Since the main focus was on the potential differences in brain representation for L1 vs. L2, they studied the scalp distribution differences on the ERP patterns for the monolinguals vs. bilinguals in Italian, as well as for the bilinguals in Italian vs. Slovenian. For the processing of semantic errors, the authors report a reversed pattern of N400 lateralization for the bilinguals compared to the monolinguals. Semantic incongruence resulted in greater response over the left hemisphere than over the right in the bilinguals, while the pattern was reversed in the monolinguals. Moreover, they found N400 amplitude differences when they performed within-group comparisons in the bilinguals processing Italian vs. Slovenian sentences. They observed that the N400 was much greater for semantic errors than for syntactic errors in Slovenian but not in Italian. Also, the N400 was more negative for Italian than for Slovenian target words for both the semantic and the syntactic errors. The authors do not provide a N400 latency analysis to semantic anomalies between groups nor between languages within the bilingual group.

[Moreno and Kutas \(2005\)](#) examined the N400 effect in English–Spanish bilinguals of varying proficiency across languages while the subjects read semantically incongruent vs.

congruent sentence endings in each of their languages. A subgroup of bilinguals had both a late exposure and a lower vocabulary proficiency in L2 (English) compared to L1 (Spanish). Another subset of bilinguals had an early exposure to both languages but had later on acquired a better vocabulary in one of their languages (English). In both subgroups, the N400 effect peaked significantly later in the non-dominant than in the dominant language target words by approximately 27 ms. Both age of exposure and vocabulary proficiency independently accounted for a small but statistically significant amount of the variance of the N400 latency after the contribution of the other factor had been partialled out. The N400 onset measures, albeit not as robust as the peak latency measures, also revealed that the N400 congruity effect began about 10 ms earlier for the dominant than for the non-dominant language. No reliable differences were found in the size of the N400 effects across languages. Moreover, when collapsed across congruity, ERPs were more positive to endings in the dominant than in the non-dominant language from 300 to 900 ms. As the language dominance effect had a frontal distribution in the 300–400 ms time-window and it resembled abstractness/concreteness effects found at about the same time range within a single language (a larger anterior negativity for concrete than for abstract words), the authors suggested that the overall “style” of processing a language, being it more literal or metaphorical, may depend on the degree of proficiency in the language. There might however be alternative explanations for the different ERP patterns between languages in bilinguals, and these issues need to be explored further.

In summary, most of the studies that have used a semantic violation paradigm to examine the N400 event-related response have found a significant delay in its peak latency for L2 relative to L1 (Ardal et al., 1990; Hahne, 2001; Kutas & Kluender, 1994; Moreno & Kutas, 2005; Weber-Fox & Neville, 1996). With regard to the factors that may contribute to delays in the peak latency of the N400 response to semantic incongruities, both a late age of exposure and a lower proficiency in the language seem to play a role. An early age of exposure, however, does not always guarantee a fast response to semantic incongruity in a language (Moreno & Kutas, 2005). The functional interpretation of the slowing of the N400 response in bilinguals in their L2 vs. L1, or between bilinguals vs. monolinguals is yet unclear and demands further investigation. Other modulations of N400 parameters such as amplitude, onset latency, and scalp distribution are not equally consistent across studies and future studies should aim to determine what crucial factors drive such variations. Finally, some of the reviewed studies reported a different ERP pattern not only to semantic anomalies but even to semantically *correct* sentences in a native vs. an L2 language across groups (Hahne, 2001; Hahne & Friederici, 2001). It has also been argued that regardless of semantic congruity, the ERP pattern to a target word in a more vs. less proficient language differs within subjects (Moreno & Kutas, 2005). In conclusion, the ERP studies suggest that semantic processing in L1 and L2 may not only have a different time-course but may also be conducted in a different fashion regardless of whether the auditory/written language input makes sense. What these putative qualitative differences exactly mean in information processing terms needs to be clarified in future studies. Thus far, the semantic violation sentence paradigm used in bilingualism research has been used as a tool to maximize the size of an effect (N400) that in general terms is considered to be an index of semantic integration difficulty or facilitation. Perhaps bilingualism research with ERPs will evolve to study other aspects of semantic processing not necessarily linked to the brain reaction to overt semantic violations, in a similar way to what has happened in the monolingual semantic processing literature.

2.3. Syntactic level: syntactic violations in a second vs. a first language

Mirroring the ERP literature on semantic processing reviewed above, the electrophysiological research on bilinguals' syntactic processes has mainly focused on the ERP responses to overt syntactic violations in L2 compared to the ones obtained from monolingual speakers of the language. In monolinguals, the ERP components commonly altered by syntactic violations include left anterior negativities (LAN), earlier left anterior negativities (ELAN), and/or syntactic positive shifts (SPS) that are also coined as P600 effects. The interpretation of some of these components as syntactic error detectors has been questioned as some researchers argue that they may instead reflect overall working memory processes (LAN) or, for the P600, be part of P300-like effects (Coulson et al., 1998a, 1998b; Kluender & Kutas, 1993; Münte et al., 1998). For example, P600 effects have lately been reported to index grammatical complexity or an encounter with uncanonical less preferred syntactic structures, and not necessarily calling for the existence of an overt syntactic violation. In spite of their controversial functional interpretation, P600 and sometimes concurrent earlier ELAN/LAN effects are typically elicited when overt syntactic violations are processed by monolingual speakers.

The results by Weber-Fox and Neville (1996) on semantic violations in bilinguals were reviewed above, but their study included also three types of syntactic violations, namely phrase structure (e.g., The scientist criticized Max's *of*¹ proof the theorem), specificity constraint (e.g., What did the scientist criticize Max's *proof* of?), and subadjacency constraint (e.g., What was a proof of *criticized* by the scientist?) violations within whole-sentence contexts. With regard to phrase structure violations, their results revealed that even short delays in the onset of language exposure (1–3 years) altered ERPs when compared to monolingual native speakers. They found reduced asymmetry on the N125 and N300–500 components and an absence of the 500–700 ms P600 for some of their bilingual subgroups. The reduced asymmetry in earlier components was interpreted as a reduced left hemisphere specialization in these participants. The reduction of the P600 amplitude under L2 exposure later than 10 years of age was attributed to either a lack or a slowing of the attempt to recover the meaning of the sentence. With regard to syntactic violations of specificity constraint rules, bilinguals seemed to be less affected by late exposure. Among the late bilinguals, those exposed at 11–13 years of age showed less ERP asymmetry than monolinguals (similar to their ERP findings for phrase structure violations), while the ones exposed after 16 years of age did not show any ERP effect for violations of specificity constraint rules (Weber-Fox & Neville, 1996). The main conclusion from the authors of this study is that whereas semantic ERP responses are only slightly affected by a late age of L2 exposure, syntactic ERP correlates are clearly altered in bilinguals with respect to monolingual speakers of the language and those alterations are observed even with short delays in the exposure to the L2. It is however important to point out again that the age at initial exposure to L2 was a good predictor of self-rated L2 skills in the bilinguals. Therefore, L2 proficiency appears to be confounded with age of exposure in these results.

In Hahne's (2001) study, Russian speakers who had learned German after the age of 10 were compared to native speakers of German on the processing of sentences containing a phrase structure violation (a participle immediately following a preposition that yields a

¹Italicized words indicate points at which ERP responses to syntactic violation were compared to correct control sentences.

phrase structure error in German, e.g., Das Geschäft wurde am *geschlossen*; The shop was being on *closed*). Sentences were presented auditorily to participants and they were asked to judge their correctness by pressing one of two buttons. While native speakers showed an ELAN around 170 ms followed by a broad centro-parietal positivity (P600) peaking at 800 ms, late German learners lacked the earlier effect and showed a slightly delayed late positivity peaking at 950 ms (Hahne, 2001). As we mentioned in the previous section, this study also found differences between L2 learners and natives for the processing of correct sentences.

A similar set of auditory sentences containing phrase structure violations was presented to Japanese late learners of German by Hahne and Friederici (2001). These participants showed hardly any ERP differences between sentences containing syntactic violations and correct sentences, in contrast to native German listeners who displayed an ELAN followed by a P600 effect for syntactic errors. The authors put forth two alternative explanations for the lack of P600 effects in their second language learners. First, it could be indexing an absence of late syntactic repair processes for the syntactically incorrect sentences. Second, it could be due to the fact that correct sentences themselves showed late positivities in the late learners compared to the native speakers. As regards the latter account, the authors suggested that the demands of syntactic integration in correct sentences possibly induce a similar processing load as the repair processes in syntactically incorrect sentences for L2 learners (Hahne & Friederici, 2001). They also suggest that syntactic rules in their native language might have affected the ERP responses of the Japanese subjects. Since prepositions do not exist in Japanese, they might have not expected a noun after a preposition—which the authors assume was the case for German listeners. A comparison across studies reveals that the Japanese-speaking late learners of German had more errors than the Russian-speaking late learners of German (Hahne, 2001). Hahne suggests that ERP responses vary systematically with the proficiency level in L2 and that late syntactic processes reflected in the P600 seem to come into play with increasing proficiency. However, early negativities, which may reflect rather highly automatic processes in native speakers, might not be achieved by late language learners maybe due to developmental constraints in neural plasticity.

The studies reviewed in this section indicate attenuated or even absent ERP effects on syntactic anomalies in late L2 learners as compared to monolingual speakers of that language. Again, age at onset of language exposure and proficiency appear to play an important role in the ERP results obtained. It has also been suggested that for late learners, “native-like” ERP patterns in syntactic anomaly processing might only be obtainable for the late, less automatic components (Diaz et al., 2006; Hahne et al., 2006; Mueller, 2006).

3. Control of two languages in one brain

3.1. Executive control in bilingual language processing

Which are the cognitive mechanisms required to regulate and control the use of different languages and to prevent interference between them? This question was early formulated by Penfield and Roberts (1959), who argued for the existence of a “language switch” mechanism (see also Macnamara & Kushnir, 1971). Penfield and Roberts note that “Although the cortico-thalamic speech mechanism serves all three languages and there is

no evidence of anatomical separation, nevertheless, there is a curiously effective automatic switch that allows each individual to turn from one language to another. What I have referred to as a ‘switch’ would be called, by experimental physiologists, a conditioned reflex. When a child or adult turns to an individual who speaks [...] only French words [...] this conditioned signal turns the switch over and only French words come to mind.” (Penfield & Roberts, 1959, p. 253). In this citation, the authors referred to the surprising capacity, observed already in small children, to switch languages depending on the language characteristics of the interlocutor. In order to do that, bilingual infants need to selectively attend to interpersonal cues in order to choose the target language for proper communication in that situation.

The need to switch back and forth between languages and to inhibit or filter out intrusion words from the non-target language may improve certain executive/cognitive control functions implemented by the prefrontal and frontal-striatal loops in the early years of development in bilingual children. In general, executive or cognitive control functions are important in overcoming prepotent automatic behaviours (e.g., the dominant language), increasing selective attention and concentration in a particular task or context, adjusting the choices to the current goal, facilitating new learning, and in adapting ourselves to new or unexpected situations (Baddeley, 1986; Mesulam, 2002; Norman & Shallice, 1986). The relation between development of executive functions and bilingualism was postulated and tested by Bialystok (see Bialystok & Martin, 2004). The behavioural studies on bilingual vs. monolingual children conducted by Bialystok et al. (2005, 2006, 2007) have indicated a bilingual advantage particularly in one aspect of executive function, namely inhibitory control, and this line of research has currently been extended also to the latter part of the lifespan.

Similar to the “language switch” proposal of Penfield and Roberts, Macnamara and Kushnir (1971) proposed a theory of the “input switch” in order to explain why bilinguals took longer to read mixed-language text passages when compared to single-language passages, even though the passages were otherwise equivalent in length and complexity (see Dalrymple-Alford, 1967; Kolers, 1966). According to this theory, when a bilingual encounters a switch in the language, the comprehension mechanisms for the ongoing language need to be switched off and the ones appropriate for the alternative language need to be switched on. Although the process is automatic during language comprehension tasks (in contrast to voluntary control needed during language production tasks) it nonetheless taxes cognitive resources. This “input switch” model was criticized for it assumed that the languages a bilingual masters could never be to some degree simultaneously active.

Another model, coined as the “monolingual–bilingual mode continuum” model, was put forth by Grosjean (1995, 1997). Grosjean proposes that depending on the situation, bilinguals move along a continuum where one extreme represents a completely monolingual mode while the other end depicts a fully bilingual mode. It is nevertheless unclear how bilinguals move from one mode to the other. Besides, the full independence of the languages at the monolingual extreme could still be questioned.

Regarding the nature of the cognitive control mechanisms used by bilinguals in order to select the target language to use, it is still unresolved if they are supported by the general executive system or by specific language control mechanisms implemented to control and avoid interference when processing a language (for review, see Rodriguez-Fornells et al., 2006). Several studies have provided evidence for the involvement of the frontocentral

“executive” brain areas in bilinguals (Fabbro et al., 2000), using functional magnetic resonance imaging (Abutalebi et al., 2007a, 2007b; Crinion et al., 2006; Hernandez et al., 2001; Hernandez & Reyes, 2002; Price et al., 1999; Rodriguez-Fornells et al., 2002, 2005; Wang et al., 2007) and transcortical magnetic stimulation (Holtzheimer et al., 2005). These data seem to agree with Bialystok’s (2001) proposal, i.e., a non-specific control mechanism is naturally tuned and developed in highly proficient (and probably early) bilinguals, giving them an advantage in various switching/inhibitory tasks.

Other psycholinguistic models on bilingual language processing argue for the existence of a top-down or more local inhibitory mechanisms that enable the deactivation or partial suppression of the language not in use (Dijkstra & van Heuven, 1998, 2002; Green, 1986, 1998). In that case, control is executed via the inhibition of the inappropriate non-target language items. According to Abutalebi and Green, language production in bilinguals is a dynamic process involving cortical and subcortical structures that make use of inhibition to resolve lexical competition and to select the intended language (Abutalebi & Green, 2007). However, this inhibitory mechanism is not postulated in all bilingual models. In some of them the only requirement for lexical selection is the regulation of the level of activation of the target language (de Bot, 1992; Grosjean, 1997; Paradis, 1989; Poulisse & Bongaerts, 1994): the most activated item would be the one finally selected. It is however necessary for the system to identify to which language each word belongs, which is normally resolved in cognitive and computational models by postulating a “language tag” (Green, 1986; Poulisse & Bongaerts, 1994) or “language node” (Dijkstra & van Heuven, 1998, 2002) that is attached to each word of a lexicon (but see Li for criticism against this concept, Li, 1998).

In the following sections, we will see how the ERP technique provides researchers with a valuable online brain measure to explore potential mechanisms of non-target language inhibition, as well as the neural correlates of the processing of language switches.

3.2. Cognitive control and inhibitory effects in bilinguals

3.2.1. Inhibitory effects: the N200 Go/noGo component

Before reviewing several ERP studies related to cognitive control/inhibition and bilingualism, we should shortly describe the rationale of the so-called Go/noGo paradigm used to study response suppression or inhibition in ERP experiments (see also reviews in Jansma et al., 2004; Rodriguez-Fornells et al., 2006). In a Go/noGo task participants are asked to make a response when a given stimulus-related condition is fulfilled (Go trials) and otherwise withhold their response (noGo trials). Using ERPs (and other neuroimaging techniques), one can analyse the brain responses related to the inhibitory commands (noGo trials) and compare it directly with the non-inhibited or Go trials (see Fig. 3A). The difference waveforms are computed by subtracting the Go condition from the noGo condition. As Fig. 3A shows, the No-Go trials are typically associated with a middle-right frontal N200 effect (see also the difference waveform). It is worth mentioning that the NoGo N200 is not a language-specific ERP effect: it is rather functionally linked to response inhibition in general, particularly in non-linguistic domains (see Nieuwenhuis et al., 2003; see Donkers & van Boxtel, 2004, for an alternative response conflict-monitoring account). Notice also that there is no possibility of using overt behaviour to investigate noGo brain responses or inhibitory commands, as there is no observable behavioural correlate (except indirect ones such as percentage of false alarms and their reaction times).

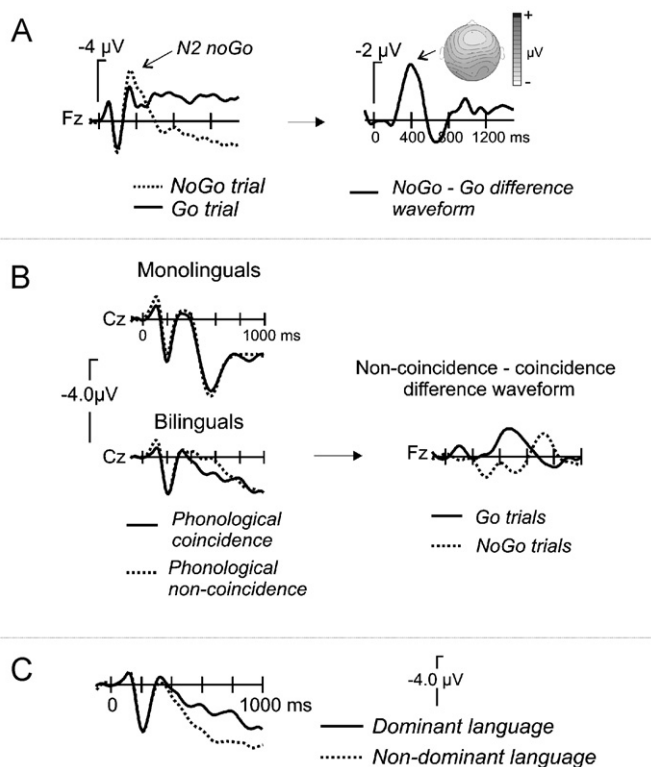


Fig. 3. (A) Grand average ERPs at a frontal electrode (left side) showing the increased negativity usually observed for noGo trials in the 200–400 ms time-range. Participants were performing a semantic Go/noGo picture naming (covert) task. This noGo component is easily observed when the Go waveform is directly subtracted from the noGo condition (right side). Depicted also is the scalp distribution of the N2 component (isovoltage map, mean amplitude of 50 ms, centred at the latency peak of the N2 noGo minus Go component; relative voltage scale) (adapted from [Rodríguez-Fornells et al., 2002](#)). (B) Grand averages at central electrode location for monolinguals and German–Spanish bilinguals ($n = 12$) in a Go/noGo phonological interference picture naming (covert) task. Depicted are the waveforms only for Go trials in the phonological coincidence and non-coincidence conditions (words that coincided or not with regard to the vowel/consonant decision across languages). The bilingual group showed an enhanced negativity for non-coincidence trials at frontal and central locations. On the right side, we depicted the difference waveform (non-coincidence minus coincidence condition) for bilinguals at a frontal electrode and for Go and noGo trials. Notice that a different time-course was observed for this enhanced frontal component in the Go and noGo trials. The corresponding difference waveforms for monolinguals were almost flat (adapted from [Rodríguez-Fornells et al., 2005](#)). (C) Grand average in the bilingual group for Go trials and the coincidence condition in the previous experiment. Blocks in which the dominant (German) language was used to perform the task showed an increased negativity over frontocentral locations when compared to the non-dominant language blocks (adapted from [Rodríguez-Fornells et al., 2005](#)).

In one ERP study on language control and bilingualism ([Rodríguez-Fornells et al., 2002](#)), the N200 noGo/Go component was used to investigate if items in the non-target language produced interference in a lexical decision task. The rationale underlying this study was that as long as items from the non-target language were processed as possible lexical entries (non-target words), more intense response suppression might be needed and

therefore differences in the N200 noGo component were expected between pseudowords and words and also between monolingual and bilingual participants. No differences were observed in the onset latency of the N200 noGo component across conditions or groups (see Fig. 2C in the cited article). These results lead to the proposal that bilinguals have a very flexible cognitive control system that helps them to filter out the non-target language (see comments to this study in Grosjean et al., 2003).

Using the same N200 Go/noGo experimental strategy, two ERP studies have recently evaluated the effect of interference of the non-target language in covert language production using a language switching setup. In the first experiment (Rodríguez-Fornells et al., 2005), German–Spanish bilinguals performed a phonological Go/noGo picture-naming task. In alternating 100-trial blocks, bilinguals were required to respond if the German or Spanish name (depending on the block) began with a vowel or a consonant (depending on the experimental condition). Half of the pictures had names in both languages that elicited the same type of response (coincidence in the vowel or in the consonant; e.g., “esel” and “asno”, *donkey*) and half of the stimuli were different for the two languages (e.g., “erdbeere” and “fresa”, *strawberry*). The ERP results indicated cross-language interference at the phonological level in this group of bilinguals. A frontocentral negativity between 300 and 600 ms (see Fig. 3B) was observed for the non-coincidence trials during German and Spanish conditions in the bilinguals. By contrast, this effect was absent in a German monolingual control group. Interestingly, in the Go trials, the difference waveforms between non-coincidence minus coincidence conditions elicited an early negativity. This effect could easily be interpreted considering that in the non-coincidence condition, the participants had to inhibit their initial non-target language lexical activation, which provided erroneous information in favour of a noGo response (larger N200 noGo). The inverted pattern was evidenced in the noGo trials, based on non-coincidence minus coincidence subtraction.

A similar pattern was obtained in a follow-up study (Rodríguez-Fornells et al., unpublished results) in which the amount of interference was studied when a similar group of German–Spanish bilinguals accessed conflicting syntactic information across languages. Since grammatical gender does not often match across languages (e.g., “the table” is masculine in German, “*der Tisch*” and feminine in Spanish, “*la mesa*”), a Go/noGo covert grammatical gender task was studied (see also Rodríguez-Fornells et al., 2006). The difference between the design of the previous study and the current one is that here a language switch was introduced every 18 trials. In addition, the structure of the first three trials after the switch was always identical, comprising coincidence, non-coincidence, and coincidence trials. This triad was compared to the 12th, 13th, and 14th non-switch trials in the middle of the mini-block. German monolinguals were also used as a control group. Again, the behavioural and the ERP results clearly showed a large degree of interference in the syntactic non-coincidence condition (a different grammatical gender in both languages). In this condition, the frontal negativity observed between 300 and 800 ms was replicated and a pattern similar to the one obtained in the previous study was observed for the non-coincidence minus coincidence difference waveforms. Moreover, the present study introduced the analysis of the switch trials. Immediately after the switch, an increased positivity was observed when this trial was compared to the corresponding non-switch trial.

An evaluation of the two above mentioned studies in a recent review (Rodríguez-Fornells et al., 2006) revealed that when the dominant and non-dominant languages were

compared, bilinguals showed a larger negativity with an onset at about 400 ms in both studies, specially at frontal and central locations (see Fig. 3C). This larger negativity was interpreted as evidence of the amount of cognitive control required when naming in the dominant language. According to Green's model (Green, 1998), access to the non-dominant language representation involves greater suppression or inhibition of the dominant language, and therefore, enhanced control might be required to overcome the applied inhibition when naming in the dominant language.

In order to further corroborate the idea that this negative component is related to enhanced control, the results of five studies were pulled together (see Rodriguez-Fornells et al., 2006 for a review). In three of these studies using bilinguals of varying proficiency (Catalan–Spanish highly proficient bilinguals: Rodriguez-Fornells et al., 2002; German–Spanish bilinguals: Rodriguez-Fornells et al., 2005, 2006), bilinguals showed larger medial frontal negativities (between 400 and 800 ms) across all the studies. This effect can also be observed in Fig. 3B (left side) comparing the ERP waveforms of the monolingual and bilingual groups. This was corroborated also in two additional studies in which a larger negativity was observed in bilinguals when reading mixed-language lists as compared to monolingual lists (Rodriguez-Fornells et al., unpublished data), as well as in bilinguals when processing their less fluent language (De Diego Balaguer et al., 2005). This systematic enhancement of the midfrontal negativity observed in different studies was interpreted as an index of the amount of executive control required to process the current task in a specific language. Based on this interpretation, several predictions could be made. For example, if bilinguals are required to perform a task in one language, and the amount of non-target language distractors is very high in the surroundings (noise, people talking, etc.), the increased control required to filter out the non-relevant information might be reflected in this frontocentral negative component.

In summary, the studies reviewed above have shown that the use of a Go/noGo ERP paradigm can be very valuable in the study of cross-language interference effects. First, non-coincidence conditions showed an increase in the frontal negativity which might be related to the trade-off between inhibition and activation of the non-target and target lexical candidates. Besides, a long-lasting midfrontal component appearing after 400 ms might reflect the amount of cognitive control required to process a specific task in one language. In switching settings, this midfrontal negative component is larger for the dominant than for the non-dominant language, and in comparison to monolinguals, bilinguals should show a larger midfrontal negativity related to the degree of cognitive control required to process a specific language. Finally, these studies also showed the importance of considering the role of general cognitive control mechanisms in language production and perception. In fact, although the studies were not designed with this purpose in mind, they clearly showed that conflicting cross-language situations (co-activation of different phonological or grammatical representations) engaged cognitive control mechanisms.

3.2.2. *Controlling languages: zooming effects*

To which degree can bilinguals completely deactivate one language when processing another and avoid interference from the non-target or blocked language? A familiar experience to any bilingual is the process which is required to set and to restore a language that has not been used during several months. A similar and interesting experience occurs when in another country somebody begins to speak to you in a language that you know

but would not expect to encounter in that country or situation. Sometimes, a brief period of conversation may even be lost until the non-target language is reset. These adjustment processes highlight that languages can be at different levels of activation and inhibition across time, reminiscent of the “monolingual–bilingual mode continuum” model initially proposed by Grosjean (1995, 1997). A recent study (Elston-Güttler & Friederici, 2005) addressed this issue and investigated the amount of activation of L1 and L2 depending on the processing language context or setting of the experiment. The idea was to understand the zooming process that people experience when adjusting or recalibrating from one language context to another, for example, when changing the country and the corresponding languages. This process might be considered different from the one studied in the bilingual switching paradigms, in which languages alternate constantly and the objective is to study how both languages are kept activated and regulated, avoiding intrusions and interferences.

Elston-Güttler et al. (2005) investigated the processing of German–English interlingual homographs, words that have identical form but completely different meanings (e.g., “gift”, meaning “poison” in German and “present” in English). German–English bilinguals (English was the L2) were required to read sentences in English ending with a homograph. Semantically related (e.g., “poison”) or unrelated (e.g., “shell”) target words in English were presented immediately after the last word of the sentence. The rationale of the design was that if the processing of the interlingual homograph word activated the corresponding meaning in L1 (gift in German), the presentation of a semantically related word might induce a reduction of the N400 component (and faster reaction times) when compared to the processing of a control or semantically unrelated word. The interesting manipulation was that half of the participants saw a 20-min film in German before the experiment while the other half saw the same film entirely in English instead. However, the entire task for both groups was performed in English and no exclusively German words were present. The experiment revealed a semantic N400 priming effect when subjects had viewed the German film (non-target language). In contrast, when the context (the film) was entirely in English, no semantic priming effect was observed. A further analysis was performed dividing the ERP session in two halves (15 min each). While the semantic priming effect observed in the German-film group was present during the first half of the experiment, this effect clearly disappeared in the second half. The reaction time results followed a pattern similar to the N400 semantic priming effects. These results favour the idea that the degree of language activation (or inhibition) is very sensitive to the global language context of processing. They also indicate a very fast zooming into a monolingual mode, as the semantic priming effect in the German-film group abolished after 15 min of exposition.

An interesting point that could be made is that zooming effects arising from language specific contexts might potentially be comparable to more general habituation phenomena such as those observed in repetition priming paradigms.

3.3. *Language switching in bilinguals: event-related brain potential studies*

3.3.1. *ERP components associated to task-switching*

Before turning to ERP studies on language switching, a few words on task-switching and its neurophysiological correlates in general are in order (for a review, see Monsell, 2003). While specific studies vary, e.g., in terms of predictability of task-switching and overlap in

stimulus–response contingencies, switch trials typically elicit longer responses and more errors. This effect is known as *switch cost* and it affects particularly the initial trials of a new task. A preparatory cue informing about the upcoming switch greatly diminishes the switch cost but does not wipe it out entirely. Finally, even though responses recover very fast after the switch, a response delay on subsequent non-switch trials is present as compared to a single-task setup. For a cognitive account of these effects, the reader is referred to Rogers and Monsell (1995) and Monsell (2003).

In recent years, several studies have tried to identify the main electrophysiological correlates of task-switching (Barcelo et al., 2000, 2002; Gehring et al., 2003; Karayanidis et al., 2003; Miniussi et al., 2005; Nicholson et al., 2005, 2006; Rushworth et al., 2002; Wylie et al., 2003). The results are not easy to summarize as different components with different latencies, polarity, and topography have been identified across studies, associated either to the response–stimulus preparation interval, to the processing of the cue, or to processing of the target task-switching stimulus. Nevertheless, at least two clear ERP effects have been encountered systematically across studies. The first one is a positive parietal component associated to a preparatory cue and related to the next switch. It has been related to task-set reconfiguration (inhibiting the currently irrelevant task set and activating the new one), and in case no anticipatory cue is available, it appears after the processing of the switch stimulus (Nicholson et al., 2005, 2006). The second commonly observed evoked response is a long-lasting medial negative component appearing after the presentation of the target stimuli that require the switch. It is thought to index the differences in stimulus–response priming and stimulus-triggered response interference associated with the previously relevant task set.

3.3.2. *Switching languages for single words*

In this section we will review some studies that have taken advantage of the ERP technique to examine the brain correlates of language switching. Bilingualism could be viewed as a natural experiment on switching where different mappings exist between a concept (meaning) and a language sign (lexical representation in L1, L2, etc.). In order to investigate how bilinguals regulate the level of activation of the different languages, select the target language and switch between languages, we need to create paradigms which induce language switches and examine the behavioural and functional brain information during switching and non-switching periods. Studies in bilingualism need to disentangle the dynamics and neural correlates of the main effects associated to task-switching. These entail characterization of (i) the transient *language switching costs*, (ii) the factors that might help to prepare a language switch (*preparatory effects*), (iii) the *residual costs* in situations where anticipatory cues were available, and (iv) the *long-term or mixing switching costs* as compared to monolingual tasks. Other important questions regarding bilingual switching relate to the degree of similarity between the languages (e.g., amount of cognates, phonological similarities) and how language proficiency at each language affects switching costs.

With regard to the last questions, a series of behavioural studies have reported asymmetric language switch “costs” in naming in L1 and L2 (Meuter & Allport, 1999). Surprisingly, bilingual subjects named digits more slowly in their first language (L1) on switch trials albeit on non-switch trials their L2 naming was slower overall. These results suggest that bilinguals take longer to reset their L1 than their L2 in switch trials. The authors argued that this additional time is needed mainly because (i) more inhibition

should be applied to the stronger (more habitual) language, and (ii) inhibition is carried over to the next trial. This hypothesis is based on the interpretation of Allport et al. (1994, *Task-Set Inertia Hypothesis*) about the amount of time required to reconfigure the more familiar schema or task-set. It is still at issue whether and how inhibition carried from the previous trial might affect the processing on the next switch trial (Meiran et al., 2000; Ruthruff et al., 2001; Sohn & Anderson, 2001). It has been argued that carry-over inhibition might delay the onset of response selection stages. According to another view, the effect reflects an additional control process (e.g., response conflict detection). Finally, it should be noted that in a recent follow-up study, Costa and Santesteban (2004) did not encounter this asymmetric switching cost for high proficiency bilinguals.

Regarding ERP studies on language switching, Jackson et al. have conducted two ERP studies where language switching either in production (Jackson et al., 2001) or in comprehension (Jackson et al., 2004) were examined. The language production study examined ERPs elicited in 20 English native speakers as they saw coloured digits on a screen with the colour prompting them to name the digits either in English (L1) or in their second language (French, German, Spanish, Mandarin, or Urdu). Digits of a particular colour alternated in a fully predictable sequence (every two trials). It is important to point out that the ERP language production studies bear some technical difficulties since the ongoing EEG is highly contaminated by facial muscle movements. In order to be able to analyse uncontaminated ERPs, Jackson et al. presented digits to the subjects for a long duration (1000 ms) and asked them to name the digits as quickly as possible only after they disappeared from the screen. In a parallel version they used a short duration time (250 ms) and speeded naming from the stimulus onset to be able to analyse the participants' reaction times as well.

As expected, reaction times showed that naming digits took longer in L2 than in L1, and digit naming requiring language switching also took longer than naming without switching. However, the authors did not encounter the asymmetric cost previously reported by Meuter and Allport (1999). They found that the latencies for naming in L1 vs. in L2 differed for the non-switching trials but not for the switching trials, i.e., the direction of the switch (from L1 to L2 vs. from L2 to L1) did not exert an effect on reaction times. This result is in contrast to the ERP pattern encountered. Although a larger left fronto-central negativity was obtained in the switch trials compared to the non-switch trials, this effect was observed only for the L2→L1 switch trials. The authors speculate on the resemblance of this negativity with a N200 noGo inhibitory component. They also performed an independent component analysis (ICA) in order to isolate a component having a similar distribution to an ICA component observed in their prior Go/noGo study. Based on the similarities in scalp distribution, the authors suggest that the response suppression needed in the noGo trials in non-linguistic tasks (the frontal N200) and the response to language switching (N320) may in fact stem from the same neural substrate. According to Jackson et al., the result in the language study might indicate that a greater inhibition of L1 (the dominant-habitual language) is required when accessing L2 language lexicon. This idea is therefore in agreement with the asymmetric cost observed in the study of Meuter and Allport (1999) although no similar behavioural effects were observed in Jackson et al.'s study.

In addition, Jackson et al. observed a later switching effect (independent of the direction of the switch) in a parietal late positivity component (LPC, 385–700 ms). The authors suggested that the LPC switching effect is indexing the reconfiguration of

stimulus–response linkages to regain access to the previously suppressed lexicon (Jackson et al., 2001). This positivity might correspond to a similar positive switching component isolated in other ERP studies and be related to task-set reconfiguration processes when processing cues index an incoming switch.

There are, however, several caveats which call for caution when interpreting the results of Jackson et al.: (i) their bilinguals were not highly proficient in their L2 (proficiency in L2 was scored as 3.3 in a 1–7-point scale) and the L2 group seemed to be quite heterogeneous; (ii) overlap in the digit names across the different L2 languages tested was not controlled for; (iii) their ERP analysis was prone to false positive results (multiple *t*-test comparisons in 128 channels were applied at each time-point); (iv) the possible interaction between language and switching was not verified by inferential statistics (the ERP analysis was limited to pairwise comparisons with *t*-tests).

A follow-up study from the same group (Jackson et al., 2004) used digits written in one language or another (again presented in a fully predictable sequence) while asking participants to make even/odd speeded decisions by pressing one of two response buttons (e.g., two-one-*cinq-sept*-four-eight). Here the task thus tapped only receptive language abilities. The previously found frontal negativity (N200) effect for switching trials was absent in this study, and the same was true for the parietal LPC effects. Authors explain the absence of LPC effects by arguing that the even/odd button-press response was here irrelevant to the language of the digit that was presented. Moreover, based on the absence of an N200 effect, they conclude that there was no need to suppress the alternative language for a lexical input entry as opposed to a lexical output response in their prior language production study. Finally, one should note that switches were fully predictable in both of these studies. Further research could aim to examine whether the predictability of the language switch affects the frontal negativity and the later positive components.

Finally, Alvarez et al. (2003) recorded ERP responses to words in L1 (English) and in L2 (Spanish) that consisted of either within- or across-language repetition (exactly same word following one another vs. translation equivalents following one another). Twenty-eight English native speakers, enrolled in introductory/intermediate Spanish classes, participated in the study. Earlier ERP studies have shown that there is a decrease in the amplitude of the N400 component when a word is repeated (Bentin & Peled, 1990; Besson et al., 1992). Alvarez et al. mainly aimed to explore the within- vs. between-language repetition effects and specifically whether the repetition-related attenuation of the N400 response is larger for the within-language repetition than for the between-language repetition. Although that was in fact the case, we will focus here on the language switching effects obtained in their study. An increase in the N400 amplitude for L2 words is reported when they followed their translation equivalent in L1 (L1→L2 language switches). Moreover, after 500 ms a negative deflection was observed in the conditions where the preceding word was from the other language, regardless of the direction of the switch. In this study, any switch of language involved an explicit prior presentation of the target word translation equivalent. This contrasts with other studies in which the corresponding target word in the alternative language could have been thought of but was not physically present. In addition, rather than just reading for comprehension, the participants of Alvarez et al. performed a semantic categorization task (pressing a button for a body part word in either language) which very likely made them to focus their attention on the lexical–semantic aspects of each individual word and on the potential benefits of having previously seen either an L1 or an L2 word equivalent. One should note here that some

psycholinguistic models suggest the existence of stronger lexical links in the L2→L1 direction than in the L1→L2 direction (see the Revised Hierarchical Model by Kroll & Stewart, 1994). Alvarez et al. claim that their results are consistent with such a model since a larger response for L2 after L1 could potentially indicate that an L1 word does not automatically activate its L2 equivalent while there could be an automatic activation of an L1 entry after seeing its L2 translation equivalent.

3.3.3. Switching languages while reading sentences

The different studies on bilingual control and language switching that we reviewed so far used simple stimuli like words, digits, or pictures, and participants were required to perform covert naming decisions or other types of psycholinguistic tasks. We will now describe some language switching studies using whole sentences as stimuli.

The study by Moreno et al. (2002) presented 34 English–Spanish bilinguals with sentences in English (e.g., “He put a clean sheet on the...”) that could unpredictably end up with (1) the most expected word ending for that sentential context in English (“*bed*”); (2) a synonym of that expected word in English (“*mattress*”); or (3) a translation equivalent of the expected word in Spanish (“*cama*”, meaning “bed” in Spanish). The general aim was to examine whether switching costs during reading for comprehension could incur at lexico-semantic processing stages or later on at decision-making stages. It is well known that the N400 component amplitude is sensitive to semantic aspects and particularly to the cloze probability² of a word in its preceding context (Kutas & Federmeier, 2000; Kutas & Hillyard, 1984). Thus, within the language (English), a larger N400 response was expected to the synonyms (“*mattress*”) than to the expected sentence-final words (“*bed*”).

An important question in the study by Moreno et al. was whether switching into Spanish to convey the same meaning (“*cama*”) will also cause lexico-semantic integration difficulties in the context of another language (English). Perhaps an even larger N400 effect could be found when the expected lexical item is replaced with a corresponding word in another language. Linguists have argued that translation equivalents are often not exact equivalents. The encyclopaedic knowledge that a speaker possesses about a certain word will seldom exactly match the connotations he or she has with the translation equivalent (Backus, 1996). A word in English might have a special semantic relationship with its preceding English context that the Spanish translation equivalent lacks in the mind of the reader. However, in this study language switches into Spanish did not elicit typical semantic N400 effects. Instead, language switches elicited a large posteriorly distributed LPC in the 450–850 ms time-window. Likewise, changes in font (capital vs. lower case letters) in monolinguals elicit positive ERPs in contrast to the negative ERPs (N400) elicited by semantic mismatch (Kutas & Hillyard, 1980a, 1980b). The LPC effects found in the Moreno et al.’s (2002) study suggested that switches in language had been treated more like unexpected events at the physical level rather than challenges for integration at the lexical–semantic level. In addition, ERP features such as the amplitude and the latency of the LPC were correlated with the vocabulary proficiency in the language of the switch. In general, a greater proficiency in a language was predictive of an earlier and smaller LPC response for switches into that language.

²“Cloze probability” is defined as the proportion of subjects that will fill in a particular word as being the most likely completion of a sentence fragment.

An alternative interpretation regarding the appearance of this positive component after the language switch is that it might reflect the involvement of a task- or language-set reconfiguration process. As we have previously reviewed, a parietal positive component is usually observed after the presentation of a cue that informs about the following switch. This positivity has been interpreted as a task-set reconfiguration which allows for the active preparation of a switch. Similarly, the appearance of a positive component after a language switch has also been reported in two ERP studies on bilinguals (Jackson et al., 2001; Rodriguez-Fornells et al., 2006). If one agrees with this interpretation, the increased positive component observed for a language switch when reading sentences might be reflecting the same task-set reconfiguration process needed to perform a language switch, inhibiting the current language in use and reactivating the target language. Notice also that in this paradigm, the switch is unpredictable and therefore the previous positive and negative ERP components observed for cue and stimulus processing, respectively, might appear overlapped at stimulus onset.

A recent study also used a whole sentence reading task to examine ERP responses to switches of language (Proverbio et al., 2004). Eight Italian native speakers and eight Italian–English professional interpreters served as subjects. In addition to different samples, this study differs from the previously reviewed one (Moreno et al., 2002) in several respects. The most critical difference with the previous study is the fact that Proverbio et al. used a blocked design and participants knew at the beginning of each block what type of sentences they would be reading (i.e., entirely in English, entirely in Italian, switching from English to Italian, switching from Italian to English). Moreover, in contrast to the prior study, half of the time the stimulus sentences ended with a semantic incongruity and subjects were not just reading for comprehension but were asked to decide about the adequacy of the final word with respect to the prior context as fast and accurately as possible. Although the sentence-final words were matched across experimental conditions for critical variables such as length, frequency and imageability, it is important to bear in mind that the pools of sentences in English and in Italian as well as the ones mixed or unmixed were completely different in this study (in the Moreno et al., 2002 the context leading up to the target word was kept constant). Moreover, the cloze probability of congruent word endings was not reported across languages (Italian vs. English) and sentences had a high degree of complexity and technicality since they had been extracted from the European Parliament archive.

Given all the differences in experimental design listed above, it is difficult to compare the two studies to each other. Based on the reaction time results from Proverbio et al., interpreters showed switching costs (the unmixed sentences received shorter reaction times than the mixed ones) even when the switches of language were entirely predictable. Regarding ERP responses, the authors focused on an early (130–200 ms) and a later (300–500) time-window. In the early time-window which authors refer to as N1, a language switch by hemisphere interaction was found. At left hemispheric sites N1 was larger to unmixed than to mixed sentences, whereas right hemisphere regions were not sensitive to language switching. In addition, a significant language by semantic congruity by language switch interaction is reported, apparently stemming from a language switch effect only in the semantic incongruity condition, with larger N1 potential to sentences preceded by English rather than by Italian contexts. Regarding the later time-window of analysis (300–500 ms), authors report larger N400s for interpreters in the mixed than in the unmixed conditions. This effect was, however, much larger when going from the more

dominant to the less dominant language than in the opposite order. It is unclear from the report whether this comparison of mixed vs. unmixed conditions collapses semantic congruity and incongruity. The enhancement of N400 elicited by semantic incongruity may overlap with a possible late LPC switching effect. The lack of LPC effects for language switching may be due to the predictability of a switch and the introduction of semantic incongruities. Future studies directly contrasting the processing of predictable and unpredictable switches of language are needed to clarify whether LPCs are found only for unpredictable switches.

In summary, only a handful of studies have examined the ERPs related to switches of language either in reception (Alvarez et al., 2003; Jackson et al., 2004; Moreno et al., 2002; Proverbio et al., 2004; Rodriguez-Fornells et al., 2002) or in production (Jackson et al., 2001; Rodriguez-Fornells et al., 2005, 2006). The ERP correlates of language switching in production appear to be similar to those observed during inhibition of overt responses in NoGo tasks (Jackson et al., 2001). This finding favours bilingual psycholinguistic models that incorporate some form of inhibition of non-target language in bilingual word production. Moreover, suppression of a non-target language seems to be asymmetrical given the fact that its neural correlate (a frontal negativity around 320 ms) is only present when switching to the L1 language right after a trial in which L1 had supposedly been inhibited. With regard to the processing of language switches in whole sentence paradigms, ERP results seem to be sensitive to the details of each experimental design. A study using reading for comprehension with unpredictable language switches found a posteriorly distributed LPC effect during language switching (Moreno et al., 2002). Other studies that either included decisions on semantic adequacy of sentence-final words (Proverbio et al., 2004) or semantic categorization of word-pairs (Alvarez et al., 2003) observed increases in the N400 amplitude to language switches. The latter study obtained N400 increases specifically for switches from L1 to L2, suggesting that L2 verbal items are not automatically activated following presentation of their L1 equivalents, whereas automatic activation of L1 items following their L2 equivalents might in fact occur (Alvarez et al., 2003). The study by Proverbio et al. (2004) made language switches predictable by presenting each sentence type in an independent experimental block.

In conclusion, the study of language switching using ERP measures is still at its early stages but the results are promising. This line of research can be used to test psycholinguistic models of language control in bilinguals. One of the important advantages of the ERP technique over previous behavioural measures is that it allows looking at how language processing takes place in the brain without a need to rely on manual/oral overt responses.

4. Summary and conclusions

In this paper, we have reviewed selected ERP studies that have addressed bilingual language processing. Due to its excellent time resolution, the ERP technique can provide independent (neural) evidence that bears on the mental architecture of language processing in bilinguals. With regard to our first theme, the processing of first vs. second language in the bilingual brain, ERP research on bilingualism can draw direct benefit from the extensive literature on the psychophysiology of monolingual language processing. Our review of studies addressing phonetic/phonological, semantic, or syntactic processing in bilinguals indicate that the ERP components characteristic of these processing stages are

modulated by age of acquisition and language proficiency of the bilingual person. In other words, the “native-likeness” of a bilingual in any of these domains hinges upon the onset and extent of exposure. Some indications for possible sensitivity periods have been obtained, e.g., in ERP studies on syntactic anomaly detection where ERP results suggest that late bilinguals may fail to develop automatic short-latency syntactic processing systems for their L2. Thus far, the studies on semantic and syntactic processing have relied heavily on the use of rather unusual stimuli, namely overt violations (semantically or syntactically illegal constructions). In the future, this approach will hopefully be complemented by other paradigms that do not rely on the processing of linguistic anomalies.

The other topic in our review was a uniquely bilingual skill, namely language switching in reception or production. It seems natural to assume that language switching must load higher-order cognitive control processes. Indeed, earlier behavioural studies have revealed that there is a cognitive cost related to language switching, albeit the cost may vary depending on, e.g., the direction of the switch. The ERP research in this area is still at its beginning stages, and the few available studies are difficult to compare due to widely different experimental setups and participant groups. Spatiotemporal similarities between some ERP components during language switching while withholding a response in a Go/noGo task suggest that language switching calls for active inhibition of the non-target language. This in turn has implications for the psycholinguistic models of bilingual language control.

It is important to highlight that the use of the ERP technique to study bilingual populations is at its very early stages and many unresolved issues remain. For example, elucidating whether bilinguals use different strategies when dealing with one language or another beyond those specific instances in which the linguistic input is either semantically or syntactically anomalous may become an important research topic in the future. In addition, changes in ERP responses that are concomitant to the increase of linguistic experience need to be further explored. They could potentially become a very useful tool for the evaluation and development of L2 learning/training programs. In the future, we should be able to tell what changes are expected to occur in the brain as individuals gain proficiency in a second language, which limitations are set by maturational factors, and how compensatory learning strategies might work.

With this purpose in mind, several studies have begun to address these issues focussing on the initial stages of language learning. The advantage of language learning studies compared to classical bilingualism research is that the amount of exposure to the new L2 is very well controlled, and therefore, the electrophysiological changes observed can more confidentially be associated to the specific information learned through training. Moreover, they permit to use longitudinal designs in order to investigate the evolution of the different language learning processes and its electrophysiological correlates (see [Osterhout et al., 2006](#)). These types of research paradigms will allow investigating bilingualism issues without the heterogeneity typically present in bilingual samples (differences in age of acquisition on L2, amount of exposure, mixing vs. non-mixing language environments, proficiency, etc.). For example, several studies have already investigated the electrophysiological changes associated to speech segmentation and initial word recognition ([Cunillera et al., 2006](#); [De Diego Balaguer et al., 2007](#); [Sanders et al., 2002](#)). In a similar vein, the neurophysiological signatures associated to learning new words has been investigated ([Cornelissen et al., 2003, 2004](#); [Friederici et al., 2006, 2002](#); [McLaughlin et al., 2004](#); [Mestres-Misse et al., 2007](#); [Mueller et al., 2005](#); [Opitz & Friederici, 2004](#)).

Moreover, the issue of interference between languages is particularly relevant not only for theoretical reasons but also for real life situations. Consider for example professional interpreters dealing with input in one language while conveying the message in another language. Understanding what cognitive abilities (such as those indexed by ERP effects) need to be trained in order to perform fast and accurately this particularly demanding bilingual language task is a crucial issue. The more we know about how and when interference takes place in the mind/brain, the nearer will be the applications from the laboratory to real life situations. We can learn a lot more about bilinguals by looking into their brains and exploring how they process information in L1 and L2 in real time.

Through our selective review, we hope to set some ground for future studies that address bilingual language processing using ERPs and/or other measures of brain function. In the future, converging evidence from multiple measures of brain function are called for in order to better understand how bilinguals are able to handle two (or more) languages with a single but powerful brain.

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References

- Abutalebi, J., Annoni, J.M., Zimine, I., Pegna, A.J., Seghier, M.L., Lee-Jahnke, H., et al. (2007a). Language control and lexical competition in bilinguals: an event-related fMRI study. *Cerebral Cortex*, doi:10.1093/cercor/bhm182.
- Abutalebi, J., Brambati, S. M., Annoni, J. M., Moro, A., Cappa, S. F., & Perani, D. (2007b). The neural cost of the auditory perception of language switches: An event-related functional magnetic resonance imaging study in bilinguals. *Journal of Neuroscience*, 27(50), 13762–13769.
- Abutalebi, J., & Green, D. (2007). Bilingual language production: The neurocognition of language representation and control. *Journal of Neurolinguistics*, 20(3), 242–275.
- Alho, K. (1995). Cerebral generators of mismatch negativity (MMN) and its magnetic counterpart (MMNM) elicited by sound changes. *Ear and Hearing*, 16(1), 38–51.
- Alvarez, R. P., Holcomb, P. J., & Grainger, J. (2003). Accessing word meaning in two languages: An event-related brain potential study of beginning bilinguals. *Brain and Language*, 87(2), 290–304.
- Allport, A., Styles, E. A., & Hsieh, S. L. (1994). Shifting intentional set—Exploring the dynamic control of tasks. *Attention and Performance Xv*, 15, 421–452.
- Ardal, S., Donald, M. W., Meuter, R., Muldrew, S., & Luce, M. (1990). Brain responses to semantic incongruity in bilinguals. *Brain and Language*, 39(2), 187–205.
- Backus, A. (1996). *Two in one*. Tilburg: Tilburg University Press.
- Baddeley, A. D. (1986). *Working memory*. Oxford: Oxford University Press.
- Barcelo, F., Perianez, J. A., & Knight, R. T. (2002). Think differently: A brain orienting response to task novelty. *Neuroreport*, 13(15), 1887–1892.
- Barcelo, F., Suwazono, S., & Knight, R. T. (2000). Prefrontal modulation of visual processing in humans. *Nature Neuroscience*, 3(4), 399–403.
- Bentin, S., & Peled, B. S. (1990). The contribution of task-related factors to ERP repetition effects at short and long lags. *Memory & Cognition*, 18(4), 359–366.
- Besson, M., Kutas, M., & Vanpetten, C. (1992). An event-related potential (ERP) analysis of semantic congruity and repetition effects in sentences. *Journal of Cognitive Neuroscience*, 4(2), 132–149.

- Best, C. T., McRoberts, G. W., & Sithole, N. M. (1988). Examination of perceptual reorganization for nonnative speech contrasts: Zulu click discrimination by English-speaking adults and infants. *Journal of Experimental Psychology: Human Perception and Performance*, 14(3), 345–360.
- Bialystok, E. (2001). *Bilingualism in development: Language, literacy, and cognition*. New York: Cambridge University Press.
- Bialystok, E., Craik, F. I., & Freedman, M. (2007). Bilingualism as a protection against the onset of symptoms of dementia. *Neuropsychologia*, 45(2), 459–464.
- Bialystok, E., Craik, F. I., Grady, C., Chau, W., Ishii, R., Gunji, A., et al. (2005). Effect of bilingualism on cognitive control in the Simon task: Evidence from MEG. *Neuroimage*, 24(1), 40–49.
- Bialystok, E., Craik, F. I. M., & Ryan, J. (2006). Executive control in a modified antisaccade task: Effects of aging and bilingualism. *Journal of Experimental Psychology-Learning Memory and Cognition*, 32(6), 1341–1354.
- Bialystok, E., & Martin, M. M. (2004). Attention and inhibition in bilingual children: Evidence from the dimensional change card sort task. *Developmental Science*, 7(3), 325–339.
- Bosch, L., Costa, A., & Sebastian-Galles, N. (2000). First and second language vowel perception in early bilinguals. *European Journal of Cognitive Psychology*, 12(2), 189–221.
- Carter, C. S., Braver, T. S., Barch, D. M., Botvinick, M. M., Noll, D., & Cohen, J. D. (1998). Anterior cingulate cortex, error detection, and the online monitoring of performance. *Science*, 280(5364), 747–749.
- Cornelissen, K., Laine, M., Renvall, K., Saarinen, T., Martin, N., & Salmelin, R. (2004). Learning new names for new objects: Cortical effects as measured by magnetoencephalography. *Brain and Language*, 89(3), 617–622.
- Cornelissen, K., Laine, M., Tarkiainen, A., Jarvensivu, T., Martin, N., & Salmelin, R. (2003). Adult brain plasticity elicited by anomia treatment. *Journal of Cognitive Neuroscience*, 15(3), 444–461.
- Costa, A., & Santesteban, M. (2004). Lexical access in bilingual speech production: Evidence from language switching in highly proficient bilinguals and L2 learners. *Journal of Memory and Language*, 50(4), 491–511.
- Coulson, S., King, J. W., & Kutas, M. (1998a). ERPs and domain specificity: Beating a straw horse. *Language and Cognitive Processes*, 13(6), 653–672.
- Coulson, S., King, J. W., & Kutas, M. (1998b). Expect the unexpected: Event-related brain response to morphosyntactic violations. *Language and Cognitive Processes*, 13(1), 21–58.
- Crinion, J., Turner, R., Grogan, A., Hanakawa, T., Noppeney, U., Devlin, J. T., et al. (2006). Language control in the bilingual brain. *Science*, 312(5779), 1537–1540.
- Cunillera, T., Toro, J. M., Sebastian-Galles, N., & Rodriguez-Fornells, A. (2006). The effects of stress and statistical cues on continuous speech segmentation: An event-related brain potential study. *Brain Research*, 1123(1), 168–178.
- Cheour, M., Ceponiene, R., Lehtokoski, A., Luuk, A., Allik, J., Alho, K., et al. (1998). Development of language-specific phoneme representations in the infant brain. *Nature Neuroscience*, 1(5), 351–353.
- Cheour, M., Leppänen, P. H., & Kraus, N. (2000). Mismatch negativity (MMN) as a tool for investigating auditory discrimination and sensory memory in infants and children. *Clinical Neurophysiology*, 111(1), 4–16.
- Cheour, M., Shestakova, A., Alku, P., Ceponiene, R., & Näätänen, R. (2002). Mismatch negativity shows that 3–6-year-old children can learn to discriminate non-native speech sounds within two months. *Neuroscience Letters*, 325(3), 187–190.
- Dalrymple-Alford, E. C. (1967). Prestimulus language cueing and speed of identifying Arabic and English words. *Psychological Reports*, 21(1), 27–28.
- de Bot, K. (1992). A bilingual production model: Levelt’s “speaking” model adapted. *Applied Linguistics*, 13, 1–24.
- De Diego Balaguer, R., Sebastian-Galles, N., Diaz, B., & Rodriguez-Fornells, A. (2005). Morphological processing in early bilinguals: An ERP study of regular and irregular verb processing. *Brain Research Cognitive Brain Research*, 25(1), 312–327.
- De Diego Balaguer, R., Toro, J. M., Rodriguez-Fornells, A., & Bachoud-Lévy, A. C. (2007). Different neurophysiological mechanisms underlying word and rule extraction from speech. *PLOS One*, 2(11), e1175.
- Dehaene-Lambertz, G., & Dehaene, S. (1994). Speed and cerebral correlates of syllable discrimination in infants. *Nature*, 370(6487), 292–295.
- Dehaene-Lambertz, G., Dupoux, E., & Gout, A. (2000). Electrophysiological correlates of phonological processing: A cross-linguistic study. *Journal of Cognitive Neuroscience*, 12(4), 635–647.
- Diaz, B., Erdozia, K., Mueller, J. L., Sebastian-Galles, N., & Laka, I. (2006). Individual differences in syntactic processing of a second language: Electrophysiological evidence. *Journal of Psychophysiology*, 20(3), 228.
- Dijkstra, T., & van Heuven, W. J. B. (1998). The BIA model and bilingual word recognition. In J. Grainger, & A. M. Jacobs (Eds.), *Localist connectionist approaches to human cognition* (pp. 189–225). Mahwah, NJ: Erlbaum.

- Dijkstra, T., & Van Heuven, W. J. B. (2002). The architecture of the bilingual word recognition system: From identification to decision. *Bilingualism: Language and Cognition*, 5, 175–197.
- Donkers, F. C., & van Boxtel, G. J. (2004). The N2 in go/no-go tasks reflects conflict monitoring not response inhibition. *Brain and Cognition*, 56(2), 165–176.
- Edwards, E., Soltani, M., Deouell, L. Y., Berger, M. S., & Knight, R. T. (2005). High gamma activity in response to deviant auditory stimuli recorded directly from human cortex. *Journal of Neurophysiology*, 94(6), 4269–4280.
- Elston-Güttler, K. E., & Friederici, A. D. (2005). Native and L2 processing of homonyms in sentential context. *Journal of Memory and Language*, 52, 256–283.
- Elston-Güttler, K. E., Gunter, T. C., & Kotz, S. A. (2005). Zooming into L2: Global language context and adjustment affect processing of interlingual homographs in sentences. *Cognitive Brain Research*, 25(1), 57–70.
- Fabbro, F., Skrap, M., & Aglioti, S. (2000). Pathological switching between languages after frontal lesions in a bilingual patient. *Journal of Neurology, Neurosurgery and Psychiatry*, 68(5), 650–652.
- Friederici, A. D., Bahlmann, J., Heim, S., Schubotz, R. I., & Anwander, A. (2006). The brain differentiates human and non-human grammars: Functional localization and structural connectivity. *Proceedings of the National Academy of Sciences of the United States of America*, 103(7), 2458–2463.
- Friederici, A. D., Steinhauer, K., & Pfeifer, E. (2002). Brain signatures of artificial language processing: Evidence challenging the critical period hypothesis. *Proceedings of the National Academy of Sciences of the United States of America*, 99(1), 529–534.
- Gehring, W. J., Bryck, R. L., Jonides, J., Albin, R. L., & Badre, D. (2003). The mind's eye, looking inward? In search of executive control in internal attention shifting. *Psychophysiology*, 40(4), 572–585.
- Gehring, W. J., Goss, B., Coles, M. G. H., Meyer, D. E., & Donchin, E. (1993). A neural system for error-detection and compensation. *Psychological Science*, 4(6), 385–390.
- Green, D. W. (1986). Control, activation, and resource: A framework and a model for the control of speech in bilinguals. *Brain and Language*, 27(2), 210–223.
- Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and Cognition*, 1(2), 67–81.
- Grosjean, F. (1995). A psycholinguistic approach to code-switching: The recognition of guest words in bilinguals. In L. Milroy, & P. Muysken (Eds.), *One speaker, two languages. Cross-disciplinary perspectives on code-switching* (pp. 259–275). Cambridge: Cambridge University Press.
- Grosjean, F. (1997). Processing mixed language: Issues, findings, and models. In A. De Groot, & J. F. Kroll (Eds.), *Tutorials in bilingualism: Psycholinguistic perspectives* (pp. 225–254). Mahwah, NJ.: Lawrence Erlbaum Associates.
- Grosjean, F., Li, P., Münte, T. F., & Rodriguez-Fornells, A. (2003). Imaging bilinguals: When the neurosciences meet the language sciences. *Bilingualism: Language and Cognition*, 6(2), 159–165.
- Hahne, A. (2001). What's different in second-language processing? Evidence from event-related brain potentials. *Journal of Psycholinguistic Research*, 30(3), 251–266.
- Hahne, A., & Friederici, A. D. (2001). Processing a second language: Late learners' comprehension mechanisms as revealed by event-related brain potentials. *Bilingualism: Language and Cognition*, 4(2), 123–141.
- Hahne, A., Mueller, J. L., & Clahsen, H. (2006). Morphological processing in a second language: Behavioral and event-related brain potential evidence for storage and decomposition. *Journal of Cognitive Neuroscience*, 18(1), 121–134.
- Hernandez, A. E., Dapretto, M., Mazziotta, J., & Bookheimer, S. (2001). Language switching and language representation in Spanish-English bilinguals: An fMRI study. *Neuroimage*, 14(2), 510–520.
- Hernandez, A. E., & Reyes, I. (2002). Within- and between-language priming differ: Evidence from repetition of pictures in Spanish-English bilinguals. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 28(4), 726–734.
- Holtzheimer, P., Fawaz, W., Wilson, C., & Avery, D. (2005). Repetitive transcranial magnetic stimulation may induce language switching in bilingual patients. *Brain and Language*, 94(3), 274–277.
- Jackson, G. M., Swainson, R., Cunnington, R., & Jackson, S. R. (2001). ERP correlates of executive control during repeated language switching. *Bilingualism*, 4(2), 169–178.
- Jackson, G. M., Swainson, R., Mullin, A., Cunnington, R., & Jackson, S. R. (2004). ERP correlates of a receptive language-switching task. *The Quarterly Journal of Experimental Psychology A*, 57(2), 223–240.
- Jansma, B. M., Rodriguez-Fornells, A., Möller, J., & Münte, T. F. (2004). Electrophysiological studies of speech production. In T. Pechmann, & C. Habel (Eds.), *Multidisciplinary approaches to language production (Trends in Linguistics)* (pp. 361–396). Berlin: Mouton de Gruyter.

- Karayanidis, F., Coltheart, M., Michie, P. T., & Murphy, K. (2003). Electrophysiological correlates of anticipatory and poststimulus components of task switching. *Psychophysiology*, *40*(3), 329–348.
- Kluender, R., & Kutas, M. (1993). Bridging the gap—Evidence from ERPs on the processing of unbounded dependencies. *Journal of Cognitive Neuroscience*, *5*(2), 196–214.
- Kolers, P. A. (1966). Reading and talking bilingually. *American Journal of Psychology*, *79*(3), 357–376.
- Kroll, J. F., & Stewart, E. (1994). Category interference in translation and picture naming—Evidence for asymmetric connections between bilingual memory representations. *Journal of Memory and Language*, *33*(2), 149–174.
- Kutas, M., & Federmeier, K. D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Sciences*, *4*(12), 463–470.
- Kutas, M., Federmeier, K. D., Coulson, S., King, J. W., & Münte, T. F. (2000). Language. In J. T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), *Handbook of psychophysiology* (2nd ed., pp. 576–601). Cambridge: Cambridge University Press.
- Kutas, M., & Hillyard, S. A. (1980a). Event-related brain potentials to semantically inappropriate and surprisingly large words. *Biological Psychology*, *11*(2), 99–116.
- Kutas, M., & Hillyard, S. A. (1980b). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science*, *207*(4427), 203–205.
- Kutas, M., & Hillyard, S. A. (1984). Brain potentials during reading reflect word expectancy and semantic association. *Nature*, *307*(5947), 161–163.
- Kutas, M., & Kluender, R. (1994). What is who violating? A reconsideration of linguistic violations in light of event-related brain potentials. In H. J. Heinze, T. F. Münte, & G. R. Mangun (Eds.), *Cognitive electrophysiology: Basic and clinical applications* (pp. 183–210). Boston: Birkhäuser.
- Lehtonen, M., & Laine, M. (2003). How word frequency affects morphological processing in mono- and bilinguals. *Bilingualism: Language and Cognition*, *6*, 213–225.
- Li, P. (1998). Mental control, language tags, and language nodes in bilingual lexical processing. *Bilingualism: Language and Cognition*, *1*, 93.
- Macnamara, J., & Kushnir, S. L. (1971). Linguistic independence of bilinguals—Input switch. *Journal of Verbal Learning and Verbal Behavior*, *10*(5), 480–487.
- McLaughlin, J., Osterhout, L., & Kim, A. (2004). Neural correlates of second-language word learning: Minimal instruction produces rapid change. *Nature Neuroscience*, *7*(7), 703–704.
- Meiran, N., Chorev, Z., & Sapir, A. (2000). Component processes in task switching. *Cognitive Psychology*, *41*(3), 211–253.
- Mestres-Misse, A., Rodriguez-Fornells, A., & Münte, T. F. (2007). Watching the brain during meaning acquisition. *Cerebral Cortex*, *17*(8), 1858–1866.
- Mesulam, M. M. (2002). The human frontal lobes: Transcending the default mode through contingent encoding. In R. T. Knight, & D. T. Stuss (Eds.), *Principles of frontal lobe function* (pp. 8–30). New York: Oxford University Press.
- Meuter, R. F. I., & Allport, A. (1999). Bilingual language switching in naming: Asymmetrical costs of language selection. *Journal of Memory and Language*, *40*(1), 25–40.
- Miniussi, C., Marzi, C. A., & Nobre, A. C. (2005). Modulation of brain activity by selective task sets observed using event-related potentials. *Neuropsychologia*, *43*(10), 1514–1528.
- Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences*, *7*(3), 134–140.
- Moreno, E. M., Federmeier, K. D., & Kutas, M. (2002). Switching languages, switching palabras (words): An electrophysiological study of code switching. *Brain and Language*, *80*(2), 188–207.
- Moreno, E. M., & Kutas, M. (2005). Processing semantic anomalies in two languages: An electrophysiological exploration in both languages of Spanish–English bilinguals. *Brain Research Cognitive Brain Research*, *22*(2), 205–220.
- Mueller, J. L. (2005). Electrophysiological correlates of second language processing. *Second Language Research*, *21*(2), 152–174.
- Mueller, J. L. (2006). L2 in a nutshell: The investigation of second language processing in the miniature language model. *Language Learning*, *56*, 235–270.
- Mueller, J. L., Hahne, A., Fujii, Y., & Friederici, A. D. (2005). Native and nonnative speakers' processing of a miniature version of Japanese as revealed by ERPs. *Journal of Cognitive Neuroscience*, *17*(8), 1229–1244.
- Münte, T. F., Heinze, H. J., Matzke, M., Wieringa, B. M., & Johannes, S. (1998). Brain potentials and syntactic violations revisited: No evidence for specificity of the syntactic positive shift. *Neuropsychologia*, *36*(3), 217–226.

- Näätänen, R., Gaillard, A. W., & Mantysalo, S. (1978). Early selective-attention effect on evoked potential reinterpreted. *Acta Psychologica (Amsterdam)*, 42(4), 313–329.
- Näätänen, R., Lehtokoski, A., Lennes, M., Cheour, M., Huutilainen, M., Iivonen, A., et al. (1997). Language-specific phoneme representations revealed by electric and magnetic brain responses. *Nature*, 385(6615), 432–434.
- Nenonen, S., Shestakova, A., Huutilainen, M., & Naatanen, R. (2003). Linguistic relevance of duration within the native language determines the accuracy of speech-sound duration processing. *Brain Research Cognitive Brain Research*, 16(3), 492–495.
- Nicholson, R., Karayanidis, F., Bumak, E., Poboka, D., & Michie, P. T. (2006). ERPs dissociate the effects of switching task sets and task cues. *Brain Research*, 1095, 107–123.
- Nicholson, R., Karayanidis, F., Poboka, D., Heathcote, A., & Michie, P. T. (2005). Electrophysiological correlates of anticipatory task-switching processes. *Psychophysiology*, 42(5), 540–554.
- Nieuwenhuis, S., Yeung, N., van den Wildenberg, W., & Ridderinkhof, K. R. (2003). Electrophysiological correlates of anterior cingulate function in a go/no-go task: Effects of response conflict and trial type frequency. *Cognitive, Affective and Behavioral Neuroscience*, 3(1), 17–26.
- Norman, D. A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behavior. In R. J. Davidson, G. E. Schwartz, & D. Shapiro (Eds.), *Consciousness and self-regulation* (pp. 1–18). New York: Plenum.
- Opitz, B., & Friederici, A. D. (2004). Brain correlates of language learning: The neuronal dissociation of rule-based versus similarity-based learning. *Journal of Neuroscience*, 24(39), 8436–8440.
- Osterhout, L., McLaughlin, J., Pitkanen, I., Frenck-Mestre, C., & Molinaro, N. (2006). Novice learners, longitudinal designs, and event-related potentials: A means for exploring the neurocognition of second language processing. *Language Learning*, 56, 199–230.
- Paradis, M. (1989). Bilingual and polyglot aphasia. In F. Boller, & J. Grafman (Eds.), *Handbook of neuropsychology* (pp. 117–140). Amsterdam: Elsevier.
- Peltola, M. S., Kujala, T., Tuomainen, J., Ek, M., Aaltonen, O., & Naatanen, R. (2003). Native and foreign vowel discrimination as indexed by the mismatch negativity (MMN) response. *Neuroscience Letters*, 352(1), 25–28.
- Penfield, W., & Roberts, L. (1959). *Speech and brain mechanisms*. Princeton, NJ: Princeton University Press.
- Picton, T. W., Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, R., Jr., et al. (2000). Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria. *Psychophysiology*, 37(2), 127–152.
- Portin, M., & Laine, M. (2001). Processing cost associated with inflectional morphology in bilingual speakers. *Bilingualism: Language and Cognition*, 4, 55–62.
- Poulisse, N., & Bongaerts, T. (1994). First language use in second language production. *Applied Linguistics*, 15, 36–57.
- Price, C. J., Green, D. W., & von Studnitz, R. (1999). A functional imaging study of translation and language switching. *Brain*, 122(Part 12), 2221–2235.
- Proverbio, A. M., Cok, B., & Zani, A. (2002). Electrophysiological measures of language processing in bilinguals. *Journal of Cognitive Neuroscience*, 14(7), 994–1017.
- Proverbio, A. M., Leoni, G., & Zani, A. (2004). Language switching mechanisms in simultaneous interpreters: An ERP study. *Neuropsychologia*, 42(12), 1636–1656.
- Rivera-Gaxiola, M., Silva-Pereyra, J., & Kuhl, P. K. (2005). Brain potentials to native and non-native speech contrasts in 7- and 11-month-old American infants. *Developmental Science*, 8(2), 162–172.
- Rodriguez-Fornells, A., De Diego Balaguer, R., & Münte, T. F. (2006). Executive control in bilingual language processing. *Language Learning*, 359, 133–190.
- Rodriguez-Fornells, A., Rotte, M., Heinze, H. J., Nosselt, T., & Münte, T. F. (2002). Brain potential and functional MRI evidence for how to handle two languages with one brain. *Nature*, 415(6875), 1026–1029.
- Rodriguez-Fornells, A., van der Lugt, A., Rotte, M., Britti, B., Heinze, H. J., & Münte, T. F. (2005). Second language interferes with word production in fluent bilinguals: Brain potential and functional imaging evidence. *Journal of Cognitive Neuroscience*, 17(3), 422–433.
- Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology-General*, 124(2), 207–231.
- Rushworth, M. F. S., Passingham, R. E., & Nobre, A. C. (2002). Components of switching intentional set. *Journal of Cognitive Neuroscience*, 14(8), 1139–1150.
- Ruthruff, E., Remington, R. W., & Johnston, J. C. (2001). Switching between simple cognitive tasks: The interaction of top-down and bottom-up factors. *Journal of Experimental Psychology-Human Perception and Performance*, 27(6), 1404–1419.

- Sanders, L. D., Newport, E. L., & Neville, H. J. (2002). Segmenting nonsense: An event-related potential index of perceived onsets in continuous speech. *Nature Neuroscience*, *5*(7), 700–703.
- Sebastian-Galles, N., Rodriguez-Fornells, A., de Diego-Balaguer, R., & Diaz, B. (2006). First- and second-language phonological representations in the mental lexicon. *Journal of Cognitive Neuroscience*, *18*(8), 1277–1291.
- Shestakova, A., Huottilainen, M., Ceponiene, R., & Cheour, M. (2003). Event-related potentials associated with second language learning in children. *Clinical Neurophysiology*, *114*(8), 1507–1512.
- Sohn, M. H., & Anderson, J. R. (2001). Task preparation and task repetition: Two-component model of task switching. *Journal of Experimental Psychology-General*, *130*(4), 764–778.
- Tremblay, K., Kraus, N., & McGee, T. (1998). The time course of auditory perceptual learning: Neurophysiological changes during speech-sound training. *Neuroreport*, *9*(16), 3557–3560.
- Ullsperger, M., & von Cramon, D. Y. (2001). Subprocesses of performance monitoring: A dissociation of error processing and response competition revealed by event-related fMRI and ERPs. *Neuroimage*, *14*(6), 1387–1401.
- Wang, Y., Xue, G., Chen, C., Xue, F., & Dong, Q. (2007). Neural bases of asymmetric language switching in second-language learners: An ER-fMRI study. *Neuroimage*, *35*(2), 862–870.
- Weber-Fox, C. M., & Neville, H. J. (1996). Maturation constraints on functional specializations for language processing: ERP and behavioral evidence in bilingual speakers. *Journal of Cognitive Neuroscience*, *8*(3), 231–256.
- Weber, C., Hahne, A., Friedrich, M., & Friederici, A. D. (2004). Discrimination of word stress in early infant perception: Electrophysiological evidence. *Brain Research Cognitive Brain Research*, *18*(2), 149–161.
- Werker, J. F., & Tees, R. C. (1984). Cross-language speech-perception—Evidence for perceptual reorganization during the 1st year of life. *Infant Behavior and Development*, *7*(1), 49–63.
- Winkler, I., Kujala, T., Tiitinen, H., Sivonen, P., Alku, P., Lehtokoski, A., et al. (1999). Brain responses reveal the learning of foreign language phonemes. *Psychophysiology*, *36*(5), 638–642.
- Wylie, G. R., Javitt, D. C., & Foxe, J. J. (2003). Cognitive control processes during an anticipated switch of task. *European Journal of Neuroscience*, *17*(3), 667–672.
- Yeung, N., Botvinick, M. M., & Cohen, J. D. (2004). The neural basis of error detection: Conflict monitoring and the error-related negativity. *Psychological Review*, *111*(4), 931–959.