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The electrophysiology of the bilingual brain

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Abstract

In this chapter, we will focus on how bilinguals cope with reading individual words and sentences in their different languages, and on how electroencephalographic recordings could be used to explore the time course of the cognitive processes underlying bilingual comprehension of visually delivered linguistic stimuli. Event-related brain potentials comparing native and nonnative written language processing have been repeatedly used to reveal effects that occur very early in the stream of processing and that are essential for a correct understanding of the cognitive processes leading to efficient word and sentence processing by multilingual readers. We will summarize the most relevant studies from this field, and we will offer a list of recommendations for researchers aiming at using EEG as a tool to investigate the complex pattern of feed-forward and feedback interactive activations flowing along the visual recognition system that ultimately lead to efficient bilingual reading.

Introduction

As active members of developed modern societies, we are constantly processing information that is delivered to us through the senses in multiple formats. Thus, an individual standing in any street is bombarded with hundreds of simultaneously-delivered stimuli that need to be either discarded or processed. The human brain has, however, developed a series of complex mechanisms to filter and sort multiple items of information, selectively deciding which are to be processed and which ignored. In fact, the human cognitive system has evolved in such a way that it prioritizes the processing of linguistic information from the social context over other types of stimuli that lack intentional communicative purposes. Thus, human beings in modern societies can be seen as receivers of constant streams of linguistic information, mainly in a visual or auditory format, that is intentionally or unintentionally filtered to the cognitive system, processed and then reacted to in a communicative manner. Given the amount of linguistic information present in the modern social environment, it could be said that it is not so easy to be a citizen of the linguistically demanding world, nowadays.

Given the perceptual requirements of our linguistically taxing modern societies, it is predictable that the number of languages used in each specific social context will exponentially increase the cognitive demands on the human being reacting and interacting in this context. Learning to see and understand words and sentences written in different languages possibly requires from the multilingual individual an extra effort that monolingual individuals do not have to make. Nonetheless, the compensation for this extra effort is considerable, allowing multilingual individuals to react to linguistic information from different sources and informants and in different formats (i.e., in different languages) that are unintelligible to monolinguals, and increasing their communicative skills and access to information. Although it may not be easy to become a multilingual citizen of the linguistically complex multilingual world today, it is certainly worth the effort.

In this chapter, we will focus on how bilinguals read words and sentences in their first (L1) and second (L2) languages by focusing on the electrophysiological signatures of bilingual reading. There are, of course, many different definitions and profiles of bilingualism, each referring to different dimensions and factors of language acquisition and usage, such as the age of acquisition (AoA) of the L2 (e.g., early vs. late bilinguals), the sequence of L1 and L2 acquisition (e.g., simultaneous vs. sequential bilinguals), the levels of proficiency in each language (balanced vs. non-balanced bilinguals) or the context in which the L2 has been learned (*natural immersion* vs. *classroom learning*). Across cultures and societies, it is easy to find individuals who had acquired their two languages very early in life during childhood (e.g., bilinguals societies like the Basque Country, Catalonia or Wales). These individuals are typically considered early bilinguals, due to their early age of second language acquisition (L2 AoA; as opposed to individuals who had acquired their second language later in life, during adolescence or adulthood; i.e., late bilinguals). Bilingual societies are therefore characterized by the existence of early bilinguals (simultaneous bilinguals, in most cases, given that the two languages are often acquired simultaneously during childhood), that in general terms are balanced in their degree of knowledge and use of the two languages. However, it should be considered that most modern societies are not purely bilingual in essence, and that the presence and knowledge of a second language largely varies across cultures. This way, the majority of bilinguals in the world correspond to sequential bilinguals (i.e., individuals who have acquired the second language after having acquired and consolidated the mother tongue), who are in most cases non-balanced in their degree of knowledge and dominance of their languages (i.e., the first language is the most dominant, used and known one). Still, this admittedly simplistic reductionism of the typology of bilinguals does not capture the entire complexity of the linguistic reality, and we anticipate that the idiosyncrasy of each bilingual group or sample needs to be correctly identified and defined in order to understand the scope of the findings here reviewed. In this chapter, we will attempt to be explicit with regards to these important factors, indicating the type of L1and L2 users who have been tested in each study. Nonetheless, the reader should note that here we will use the terms “bilingual” and “multilingual” in a general manner, to refer to different profiles of L2 users with different levels of proficiency, ranging from second language learners with relatively low proficiency in their newly acquired L2, to bilinguals with native or native-like skills in both languages.

In this chapter, we will focus on how bilingual and multilingual individuals cope with reading in their different languages, referring to the cognitive processes underlying bilingual comprehension of visually delivered linguistic stimuli. These will be examined from an electrophysiological perspective, as there are convincing arguments for adopting this approach. Human cognition can, of course, be studied from multiple perspectives and different technical and methodological approaches, and electrophysiology is not the only way to examine how the mind/brain functions. However, to understand the cognitive processes involved in bilingualism, it is important to understand the nature of the neural activity occurring within the cerebral cortex. That this is the case can be seen by a quick Internet search using keywords related to bilingualism and electrophysiology or electroencephalography. This will result in an impressive number of articles reporting highly influential results that are currently guiding scientific activity in the field of bilingual reading comprehension.

That there is such a striking amount of research exploring the electrophysiology of the bilingual brain is hardly surprising. Electroencephalographic (EEG) recordings are a relatively inexpensive yet extremely effective and rich source of information about the stream of processes that constructs cognition in the human brain. Together with magnetoencephalographic recordings (MEG) and eye-tracking techniques, EEG is one of the most appropriate techniques for identifying the fast time course of linguistic processes, given its exquisite temporal resolution. The extensive use of EEG recordings to explore and understand the cognitive processes underlying bilingual language comprehension is, therefore, grounded in decades of intensive EEG research on monolingual language processing.

Electroencephalographic recordings allow researchers to tap into the mechanisms of human cognition by registering the neural activity of thousands of millions of neurons, principally the pyramidal neurons that largely make up the cortex, due to their synchronous activity and similar orientation. By means of electrodes strategically located on the scalp, this electrical activity of populations of neurons is registered and quantified over time. Then, by averaging the EEG associated with the processing of a specific type of stimuli (e.g., items from one experimental condition) recorded over a number of trials, the signal-to-noise ratio is improved, allowing for a fine-grained analysis of the processes that hold constant across trials and eliminating the electrical activity corresponding to unstable or noisy processes that are not relevant from a cognitive point of view (e.g., some markers of biological activity, such as electromyographic responses). In this way, for half a century, EEG researchers have focused on event-related brain potentials (ERPs), conceived as the averaged electrophysiological response to a specific type of stimuli.

Using this technique, large amounts of evidence have been gathered about the nature of bilingual language processing. In particular, due to the high temporal resolution of ERPs, they allow for a detailed analysis of the time course of the cognitive processes underlying bilingual reading processes which are difficult to track using purely behavioral techniques that only consider final reaction times, as illustrated in the seminal study by Thierry and Wu (2007). These authors, exploring automatic translation processes in Chinese-English bilinguals, illustrated the importance and utility of electrophysiological recordings for close examination of the reading-related processes that take place in the multilingual brain. The results of this study, described below, have been extremely influential in the field for a number of reasons. Apart from the theoretical importance of the findings, this study was able to perfectly exemplify how ERPs can uncover critical effects that could otherwise be overlooked if only behavioral results are considered. The scientific value and importance of ERPs indeed lies in their ability to reveal effects that may occur very early in the stream of processing and to differentiate these effects from those occurring later (information that cannot be fully captured by behavioral techniques).

In this chapter, we summarize and synthesize some of the most relevant findings from the bilingual electroencephalographic literature, paying special attention to how bilingual individuals read words and sentences in their native and nonnative languages. Given the extensive use of EEG recordings in this research area, the present chapter is not the first synthesis of decades of research on bilingual reading (e.g, van Hell and Kroll, 2012; see also van Heuven & Dijkstra, 2010). However, we believe that the length, depth, and structure of the current chapter offer additional information specifically about bilingual word and sentence reading. Furthermore, this chapter is primarily aimed at researchers who are tackling their first theoretical and practical experience with this technique.

Reading Individual Words

Although being exposed to individual words without a context is not the most common reading situation for a bilingual reader, research on how readers process words in isolation provides a unique way to examine the mandatory steps of word processing that take place during lexical access. In fact, by examining how bilinguals recognize individual words in their first and second languages, researchers have the opportunity to further explore (i) how the adult brain acquires and integrates new lexical representations (e.g., those representations belonging to the L2), and (ii) how these new representations interact with the existing ones (i.e., L1 vs. L2 interactions) at different levels of word processing.

The use of electrophysiological measures to study the processing of individual words during reading has been extremely useful in isolating the underlying cognitive processes leading to efficient word recognition in monolingual reading, as well as for identifying the time course of these processes (e.g., Grainger, Kiyonaga, & Holcomb, 2006; Petit et al., 2006). By combining ERP recordings with the visual presentation of words, many studies have shown that, at least for readers of alphabetic languages, visual word recognition is first mediated by a series of mental operations devoted to processing the low-level visual features of letters. After this, the visual word recognition system proceeds to the identification of the letters composing the words and to the mapping of the graphemes with their corresponding sounds, leading to an initial activation of the whole word form at the orthographic and phonological levels. Finally, the reader's brain accesses the conceptual level of representation, thus activating the word's semantic representation (see Grainger & Holcomb, 2008).

The use of ERPs in the study of bilingual visual word recognition (L1 and L2 processing), though much more scarce and recent, has so far indicated that bilingual reading is not essentially different from monolingual reading at many levels of processing and that the basic steps sketched above take place in a similar manner and time. However, this increasing number of bilingual ERP studies has provided additional insights into when cross-language interactions take place, when the differences and the similarities between L1 and L2 reading are manifested by bilinguals of different characteristics (e.g., L2 AoA, different L2 proficiency levels, different scripts) and when the specific language (L1 or L2) of a visually presented word is perceived and processed (see Moreno, Rodríguez-Fornells, & Laine, 2008; van Heuven & Dijkstra, 2010, for recent reviews on ERPs and bilingual language processing).

In the following sections we review the ERP evidence so far on these aspects of bilingual individual word reading. This review will be organized based on whether this evidence has been acquired in experimental settings involving the presentation of words belonging to one of the two languages of interest (single-language context) or in experimental settings involving the presentation of words from both languages of a bilingual (dual-language context). This distinction is considered to be critical when establishing the patterns of L1 and L2 visual processing as well as their interactions at the word level.

On the one hand, studies with experimental paradigms in which all the critical items belong to one language provide more reliable information on the comparison of L1 and L2 word processing, given that the only way in which some characteristics, properties or word-forms of the non-target language can modulate target language processing is by implicitly activating representations of the non-target language. Critically, such single-language experimental contexts are also considered to be ideal for revealing the extent of automatic co-activation of the representations of the two languages of a bilingual, since they do not explicitly provide the bilinguals with cues to intentionally or explicitly activating the task-irrelevant (i.e., non-target) language. On the other hand, studies in which bilinguals are presented with words belonging to their two languages are especially well-suited for identifying cross-language interactions at different levels of word processing.

Bilingual word processing in single-language contexts

The majority of studies aimed at establishing how bilinguals visually process words have focused on how bilinguals process words whose lexical representations (orthographic or phonological) are partially or totally shared across their two languages, as compared to the processing of words whose lexical representations do not share any segments across the two languages. By investigating the differences in the processing of these word types, researchers have explored whether or not single word processing is affected by the presence of complete or partial cross-language formal overlap in single- and dual-language contexts (see Guo, Misra, Tam, & Kroll, 2012, and Peeters, Dijkstra, & Grainger, 2013, for reviews). Evidence about whether words of both languages automatically activate each other has been crucial in establishing whether lexical activation is language-specific or not. Furthermore, by using electrophysiological measures, researchers have been able to identify the word processing stages at which these effects emerge.

Words with semantic and formal overlap across languages

Some words in a given language have a translation equivalent in another language with largely or completely shared ortho-phonological, lexical, and semantic representations (i.e., identical cognates as *piano* in English and Spanish, and non-identical cognates as *guitar* in English and *guitarra* in Spanish). In contrast, other word pairs of translation equivalents do not have a similar-looking ortho-phonological representation, while they still refer to the same concept (i.e., non-cognates; e.g., *house* and its Spanish translation *casa;* e.g., Dijkstra, Grainger, & van Heuven, 1999; Lemhöfer & Dijkstra, 2004; Lemhöfer, Dijkstra, & Michel, 2004). In the strictest definition of cognates, the two versions of a cognate pair share both orthographic and phonological segments, as in the English-Spanish examples above. However, there are also cognate pairs across languages that do not share their scripts, in which case the overlap is limited to the phonological level (i.e., phonological cognates such as the English word *cannon* and its Greek translation *κανόνι* e.g., Voga & Grainger, 2007).

With regards to the processing of cognates in comparison to non-cognates, numerous behavioral studies have established that when reading, bilinguals process cognates faster than non-cognates and that this benefit, termed as the *cognate facilitation effect*, is larger for identical than for non-identical cognates and larger as a matter of increased overlap across the two readings of a cognate pair (e.g., Christofanini, Kirsner, & Milech, 1986; Dijkstra, Miwa, Brummelhuis, Sappelli, & Baayen, 2010). Moreover, cognate effects are more likely to emerge when processing L2 words rather than L1 words (de Groot, Delmaar, & Lupker, 2000; van Hell & Dijkstra, 2002). In a recent ERP study, Midgley, Holcomb, and Grainger (2011) examined when in the time course of word processing this benefit appears for cognates (as compared to non-cognates), and whether this pattern is constant for L1 and L2 words. The authors presented English and French partial cognate and non-cognate words organized in blocks by language to a group of English (L1) learners of French (L2). Participants were asked to silently read words for comprehension and to perform a go/no-go semantic categorization task. Midgley et al. found that for both L1 and L2 items, the differences in the processing of cognates and non-cognates were located mainly in the N400 time-window. The N400 component is a classic ERP component conceived as a negative-going deflection peaking at around 350-400 ms after target word onset that has typically been linked to lexical access and semantic processing. In this study, the N400 peaks elicited upon presentation of L1 non-cognate items were more negative-going as compared to those elicited when participants were processing L1 cognates, and this was also the case for the N400 effects elicited by L2 cognates as compared to non-cognates. This pattern suggests that in both L1 and L2, the form-to-meaning mapping is costlier for non-cognates than for cognates. It also provides evidence for language-independent lexical activation, since both L1 and L2 cognate recognition benefited from the ortho-phonological overlap with their non-target language counterparts. While the L2 cognate advantage was a clearly expected outcome based on the existing behavioral evidence in L2 word processing, the appearance of a cognate effect in L1 words was partially unexpected. Interestingly, while the L2 N400 cognate effect was robust, starting after the first 400 ms of word processing and lasting until the later 500-800 ms time-window, the L1 N400 cognate effect had a shorter duration (from 200 to 500 ms). The difference in the timing of the L1 and L2 N400 cognate effects was interpreted by the authors as reflecting a difference in the cross-language activation patterns underlying the cognate effects in the dominant and the non-dominant language. Midgley et al. proposed that upon presentation of an L1 cognate, its L2 translation becomes partially activated, which in turn sends activation back to its L1 counterpart via direct links between the two word forms, thus facilitating its processing. Within the framework of the *Revised Hierarchical Model* (RHM; e.g., Kroll & Stewart, 1994; Kroll et al., 2010), such L2-to-L1 links at the lexical level between translation equivalents are established early during L2 acquisition, as a result of the common association of the new L2 words to their L1 translations. In line with the RHM's proposal that the links of L1 words to their corresponding meaning are stronger than the links of the L2 words, the later-arising and longer lasting L2 N400 cognate effect would be reflecting the fact that the processing of L2 cognates is benefitted by the activation received from their L1 translation via the activation of the shared meaning taking place at a later moment in time.

More recently, Peeters, Dijkstra and Grainger (2013) investigated the processing of orthographically identical French-English cognates (e.g., *message*) both at the behavioral and at the electrophysiological level. This subtype of cognate has been thus far under-studied, since when reading identical cognates it is unclear whether bilinguals identify them as belonging to their dominant or to their non-dominant language. In order to identify the representational status of identical cognates, Peeters et al. took advantage of the fact that the N400 has been found to be sensitive to word frequency manipulations and examined the processing of identical cognates, by performing an orthogonal word frequency manipulation of both readings of cognates. They included identical cognates with high or low lexical frequencies in both French and English as well as identical cognates whose lexical frequencies differed across their French and English readings, and compared them against English non-cognate words. Late French-English bilinguals were asked to perform English lexical decisions while ERPs were recorded. (Please note that throughout this chapter, for any language combination such as French-English, the language listed first is the L1 [French] and the second one is the L2 [English]). The behavioral responses showed cognate facilitation effects for all identical cognates, which were larger for cognates with low English word frequency. Furthermore, the authors found word frequency effects for words with high English frequency as compared to low English frequency. The electrophysiological data were in the same direction, showing cognate facilitation effects (i.e., more negative-going waves for non-cognates) as well as a widely distributed English word frequency effect (i.e., more negative-going waves for identical cognates with low English frequency as compared to those with high English frequency) and a shorter French word frequency effect in the N400 epoch. Furthermore, cognates produced more positive waveforms in the 600-900 ms time-window than control words. Critically, the ERP data allowed the authors to discriminate between word frequency effects in English (L2) and French (L1) in the processing of identical cognates. They found an English (L2) N400 word frequency effect for cognates with low English and high French frequency vs. those with high English and low French frequency, suggesting that, despite the fact that bilinguals had acquired English late in life and were clearly more proficient in French than in English, they were more influenced by the L2 reading of the cognate and its lexical characteristics (e.g., word frequency). The authors interpreted these findings as providing evidence in favor of the existence of common orthographic and semantic representations shared by identical cognates but two distinct phonological and morphemic representations, one for each of the two readings of a cognate.

Words with formal overlap and different meanings across languages

In contrast to cognate words, which have a cross-language counterpart with which they share their meaning as well as part of their lexical representation, there are other words that have extensive cross-language overlap at the lexical level but that correspond to different concepts. Research on the processing of words exclusively overlapping at the ortho-phonological level has been extremely informative with regard to (i) the extent to which pure cross-language orthographic or phonological overlap influences L1 or L2 processing, and (ii) whether words of both languages compete with each other during lexical access, thus providing crucial information on whether the bilingual lexicon is functionally unique or language-specific. Based on whether these words share part or their entire orthographic representation or their phonological representation with words from the other language of a bilingual, we could consider the following types of lexical entries: *interlingual homophones* (i.e., words with largely or completely overlapping phonological representations but different orthographic representations across two languages; e.g., *cow /kau/* in English and *kou /kAu/,* meaning "cold" in Dutch), *interlingual homographs* (i.e., words from two languages sharing their orthographic and phonological representations; e.g., *red* in English and *red* meaning "net" in Spanish), and *interlingual orthographic neighbors* (i.e., words of the same length sharing all but one of their letters with a given word of the other language of a bilingual; e.g., the orthographic neighbors of the word *cat* are the words *bat*, *fat*, *mat*, *cab*, etc.; see Coltheart et al., 1977).

Most of the studies examining interlingual homophones with behavioral measures have thus far used experimental paradigms involving the presentation of both words of the homophonic pair, or have tested pseudo-homophones (namely, nonwords sharing their sound with existing words of the non-target language but differing in their spelling; e.g., Brysbaert, Van Dyck, & Van de Poel, 1999). These studies have primarily used priming paradigms and they have consistently shown facilitative effects on the processing of target words of either the L1 or the L2 when preceded by homophonic words or nonwords of the non-target language (masked or unmasked) as compared to when primed by control words of the non-target language (e.g., Dimitropoulou, Duñabeitia, & Carreiras, 2011a). Masked priming paradigms are characterized by the initial presentation of a pattern mask for around 500 ms followed by the brief presentation of a prime item (for around 50 ms) which can be either related or unrelated to an explicitly presented target item. Under these presentation conditions, participants are typically unaware of the existence of the primes and consequently, any effect observed on the processing of the targets is considered to be automatic and unconscious in nature. In contrast, unmasked or explicit priming paradigms lack this brief and masked prime presentation procedure, making the relationship between primes and targets explicit to the participants. The consistent pattern found in priming studies with homophones has supported the view that the activation of the phonological code is extremely fast and that the phonological representations of the words interact with each other irrespective of whether they belong to the same language or not. Furthermore, the fact that these cross-language phonological facilitation effects have not been found to depend on the relative frequency of the test items has led researchers to propose that the effects are more likely located at the sub-lexical phonological level (e.g., Dimitropoulou et al., 2011a; Duyck, 2005; Duyck, Diependaele et al., 2004; Van Wijnendaele & Brysbaert, 2002). In the few studies examining the processing of interlingual homophones in the presence of only one of the words composing the homophonic pair (single-word contexts), the results are less straightforward. In two of the first single-presentation studies on cross-language homophones, results showed a disadvantage in processing for interlingual homophones as compared to control words or to words having either orthographic or orthographic and semantic overlap with words of the non-target language (Dijkstra, Grainger, & van Heuven, 1999; Doctor & Klein, 1992). However, in later studies this pattern has not been replicated, leading to somewhat conflicting results (see Dijkstra et al., 2004; Haigh & Jared, 2007).

Recently, Carrasco-Ortiz, Midgley and Frenck-Mestre (2012) used ERPs to establish the pattern of effects caused by interlingual homophones under single word presentation conditions (either inhibition or facilitation) and to further examine whether cross-language phonological overlap influences the lexical selection process. These authors recorded ERPs while French-English bilinguals performed a go/no-go semantic categorization task on English (L2) words which either had a homophonic pair in French or not. The authors focused on the N400 component since under single-word presentation conditions this component is sensitive to ease of lexical access (Federmeier & Kutas, 1999; Kutas & Federmeier, 2000), while its amplitude has been found to be proportional to the effort made in integrating the word’s phonological information (Holcomb, 1993). A monolingual English group was also tested for control purposes. As expected, only the bilingual group showed a reduced N400 amplitude for interlingual homophones as compared to control English words, thus providing support for the hypothesis that cross-language phonological overlap facilitates L2 processing even in a pure monolingual (L2) context. As such, these findings were interpreted in the same line as the previous behavioral reports of facilitative cross-language phonological effects (e.g., Haigh & Jared, 2007). Given the reduction of the N400 for interlingual homophones, the authors proposed that there were no signs of any inhibition at the lexical level as a result of the cross-language overlap across homophones.

The pattern of behavioral effects found when the critical words are interlingual homographs completely sharing their orthographic and at least part of their phonological representation across languages also represents a source of conflict. So far, inhibitory, facilitative and null effects have been reported for interlingual homographs as compared to control words (e.g., Dijkstra, Van Jaarsveld, & Ten Brinke 1998; Lemhöfer & Dijkstra, 2004; von Studnitz & Green, 2002). Dijkstra and colleagues (1998) found that bilingual lexical decisions to Dutch-English interlingual homographs were costlier as compared to English control words when these words were included in an English-only experimental context, suggesting that even in apparently monolingual contexts, the words from both languages compete for selection. Furthermore, this inhibitory effect was larger when homographs had a high lexical frequency in Dutch (the non-target language) and a low English frequency, as compared to when the Dutch frequency was relatively low, providing evidence of the co-activation of the two versions of the homographic pair. Kerkhofs, Dijkstra, Chwilla and de Bruijn (2006) carried out a similar manipulation of the lexical frequency of interlingual homographs in an English (L2) semantic priming lexical decision task, while recording both behavioral and electrophysiological responses with a group of late and highly proficient Dutch-English bilinguals. The authors found inhibitory effects for interlingual homographs in the reaction times as well as increased N400 amplitudes as compared to control words. They also explored whether the magnitudes of the N400 semantic priming effects were modulated as a function of language (L1 vs. L2) and cross-language similarity. They found that L2 words primed by semantically related L2 primes showed smaller N400s than when primed by unrelated primes. Notably, this semantic priming N400 effect interacted with the frequency of the interlingual homographs, providing strong evidence in favor of a language non-selective activation account, as suggested by the *Bilingual Interactive Activation Model*s (BIA, BIA+, e.g., Dijkstra & van Heuven, 2002). It also indicated that these cross-language interactions have a lexico-semantic component and that words of the non-target language are processed as potential candidates for lexical selection.

The view that non-target language activation proceeds up to the semantic level has been directly supported by a recent ERP study also testing interlingual homographs. In this study, Hoshino and Thierry (2012) presented English prime-target pairs that were either semantically related or unrelated and asked English-Spanish bilinguals to perform a go/no-go semantic relatedness judgment task upon target presentation only when these targets were displayed in red color. The authors analyzed the ERP responses only to the targets that were free from motor artifacts (i.e., the targets displayed in black). Critically, targets in these trials were English-Spanish interlingual homographs (e.g., *pie*, meaning "foot" in Spanish) and primes were English non-cognates that were either semantically related or unrelated to the English target language meaning of the interlingual homograph (e.g., *apple-pie* vs. *rug-pie*) or semantically related or unrelated to the task-irrelevant Spanish meaning of the interlingual homograph (e.g., *toe-pie* vs. *stove-pie;* see also Martín, Macizo, & Bajo, 2010). The authors found smaller N400 amplitudes on targets preceded by semantically related as compared to unrelated primes, and this semantic relatedness N400 effect was present for both the English (target language) as well as for the Spanish (non-target language) meaning of the interlingual homograph. Nevertheless, in a later 500-650 ms time-window corresponding to the *Late Positive Component* (LPC), there was a more positive-going waveform when targets were preceded by primes related to the English meaning of the interlingual homograph as compared to when they were preceded by unrelated primes, but this semantic relatedness LCP was absent when the semantic relationship involved the Spanish meaning of the homograph. The LCP has been associated with more explicit processing and with the re-evaluation of the stimuli (e.g., Martin, Thierry, & Démonet, 2010; see also Müller, Duñabeitia, & Carreiras, 2010). The overall pattern of effects suggested that, even if both meanings of the interlingual homograph are activated, the meaning corresponding to the non-target language is inhibited after 400 ms, while the one corresponding to the task-relevant language is consciously and intentionally processed up to a later stage.

Finally, effects revealing lexical competition across languages have also been repeatedly found in studies testing cross-language neighbors. In this area of research, behavioral studies have shown that the number of orthographic neighbors a given word has, both within and across languages, modulates its processing. Van Heuven, Dijkstra and Grainger (1998) found that response times to English words were faster when these words had many English orthographic neighbors. However, responses to English targets with many Dutch orthographic neighbors were slowed down as compared to English words with a low number of orthographic neighbors in Dutch (see also Grainger & Dijkstra, 1992). This critical set of findings showed that upon presentation of a given word to a bilingual, activation proceeds to orthographically similar words of the target language as well as of the non-target language, and words from both languages compete for lexical access and selection. Using electrophysiological recordings, Midgley, Holcomb, Van Heuven, and Grainger (2008) examined the pattern of ERP effects generated by a manipulation of the cross-language orthographic neighborhood of French (L1) and English (L2) words. Relatively proficient French-English bilinguals were presented with French or English words (blocked by language) and were asked to perform a go/no-go semantic categorization task. The critical words had either many or few orthographic neighbors in the non-target language, while the density (i.e., the number of orthographically similar words) of the within-language orthographic neighborhood was controlled for. Their results showed increased N400 amplitudes for both English (L2) and French (L1) words with dense neighborhoods in the non-target language as compared to words with a small number of cross-language neighbors, confirming the behavioral findings of competition of cross-language neighbors and further locating these at the time of lexico-semantic word processing. Nevertheless, this orthographic density N400 effect was more pronounced for the target words in the L2.

Words with distinct lexical representations across languages

The ERP studies described above were all intended to provide an exclusively monolingual experimental context, in order to avoid any intentional activation of the non-target language of bilinguals and to provide conclusive evidence of automatic and implicit cross-language activation. Nevertheless, given the extensive amount of orthographic and/or phonological features of the specific types of words used as critical materials across the two languages of interest (i.e., cognates, interlingual homophones, homographs and cross-language orthographic neighbors), it could be argued that their mere presentation could have evoked the activation of the task-irrelevant language. In other words, the use of words with formal overlap across languages could be functioning as an artificial dual-language context. Thierry and Wu (2007; see also Wu & Thierry, 2010) were able to circumvent this limitation and to examine whether the task-irrelevant native language of bilinguals is active during reading in the L2 by using a cross-script language combination (Chinese-English) with an implicit manipulation in an exclusive L2 (English) context with non-cognate items. Specifically, late and proficient Chinese-English bilinguals were presented with English word pairs upon which they had to perform a semantic relatedness task, while both behavioral and electrophysiological measures were being collected. Critically, the Chinese translations of half of the prime-target pairs, both semantically related and unrelated, shared a character. The authors found an N400 effect of semantic relatedness, with smaller N400 amplitudes for semantically related pairs as compared to semantically unrelated word pairs. While the presence of the “hidden” overlapping Chinese character did not modulate participants’ behavioral performance, it modulated the ERPs recorded. Pairs with the critical hidden Chinese character repetition yielded smaller N400 effects than those without it. This finding demonstrated that the Chinese non-cognate translation was active while reading exclusively English (L2) words. It furthermore provided strong evidence supporting the view that bilinguals keep both languages active during reading, irrespective of the presence of cues of cross-language activation.

Even if cognates are quite common across most alphabetic languages, the vast majority of words composing each language are non-cognates. Along these lines, Midgley, Holcomb, and Grainger (2009) examined the ERP correlates of the L1 word processing advantage over L2 word reading in three groups of English learners of French who differed in their levels of L2 proficiency. Participants were presented with English and French non-cognate items, blocked by target language, and performed a go/no-go semantic categorization task by pressing a button upon presentation of an animal name. The authors analyzed the EEG responses on the critical non-animal trials. When late and relatively low proficient English-French bilinguals were tested, differences between L1 and L2 words appeared at the N400 time-window, when the settling of a form-meaning mapping is proposed to take place (e.g., Van Petten & Kutas, 1990). At posterior sites, the N400 effect was larger for L1 words, while at anterior sites the effect arose 150 ms later for L2 words. When late and non-proficient French-English bilinguals completed the experiment with a different set of non-cognates, a similar pattern of L1 and L2 N400 differences emerged, with L2 words producing a prolonged N400 peak. However, when a more proficient group of French-English bilinguals was tested, the latency shift in the N400 for L2 words as compared to L1 words was reduced as compared to the less proficient groups. This pattern suggests that the N400 effects are sensitive to the relative language dominance of the bilinguals as well as to their level of L2 competence during single word reading.

Bilingual Word Processing in Dual-Language Experimental Settings

Studies on bilingual visual word recognition in which words from both languages of a bilingual are present allow manipulation of cross-language relationships of interest. In this way, researchers ensure that bilinguals will activate both languages at the intended level, thus obtaining information on the structure of the cross-language sub-lexical, morphological lexical, and semantic links (e.g., Duñabeitia, Dimitropoulou, Morris, & Diependaele, 2013). It has been mainly in the last decade that these dual-language experimental settings have been combined with the use of ERPs to examine the time course of the processes underlying bilingual visual word recognition and the cross-language interactions taking place at the word level. Apart from studies investigating cross-language interactions at distinct levels of processing, there are a growing number of bilingual ERP studies addressing a different aspect of bilingual word processing: the computation of L1 and L2 language membership during reading and the relative degree of L1 and L2 activation. Critically, this type of evidence can be exclusively obtained in experiments in which participants are exposed to a dual-language setting.

Cross-language lexico-semantic interactions during word reading

ERP evidence from studies testing the cognitive processes underlying cross-language lexico-semantic interactions is crucial in establishing the structure of the bilingual lexico-semantic representational system. Interestingly, to isolate cross-language interactions exclusively motivated by the semantic relationship between words of both languages, most researchers have opted for examining the processing of words that apart from their semantic relationship do not have any formal cross-language overlap, such as cross-language non-cognate semantic associates (e.g., *window* in English and *casa*, the Spanish word for “house”) or non-cognate translations (e.g., *casa-house*; see Perea, Duñabeitia, & Carreiras, 2008, for review). Only a small number of studies have addressed the issue of whether cross-language lexico-semantic interactions are modulated by cross-language ortho-phonological overlap.

Rodríguez-Fornells, Rotte, Noesselt, Heinze and Münte (2002) as well as Martin, Dering, Thomas and Thierry (2009) used ERPs to examine whether or not the non-attended language is semantically active when bilinguals process words of the target language, and reported a highly contrasting pattern of effects. In the first of these studies, Rodríguez-Fornells et al. presented early and relatively balanced Spanish-Catalan bilinguals with a stream of Catalan and Spanish words and nonwords. The authors performed a lexical frequency manipulation on both Catalan and Spanish items. Participants were asked to provide a motor response each time an existing Spanish word appeared on the screen and to disregard Catalan words and nonwords. The ERPs showed a lexical frequency N400 effect only for the Spanish target words, with reduced N400 amplitude emerging for high frequency Spanish words as compared to low frequency Spanish words. Interestingly, no such frequency effect was observed for the non-attended Catalan words, leading the authors to propose that the words of the non-target language were rejected before accessing their meaning. In other words, the findings by Rodríguez-Fornells et al. supported the view that there is no non-target language lexico-semantic activation when bilinguals consciously process words of a given language. Martin et al. (2009) addressed the same issue in two experiments and obtained a very different pattern of effects. The authors presented early and fluent English-Welsh bilinguals with English and Welsh words. In the first experiment, bilinguals were asked to indicate whether English words had more or less than five letters and to disregard the Welsh words. In the second experiment participants performed the same task but this time, they were asked to make the same judgment on the length of the Welsh items and to disregard the English words. Martin et al. manipulated the language membership and the semantic relationship of the words, thus creating within and across-language word pairs that were either semantically related or unrelated. The behavioral results confirmed that the letter-length judgment task had effectively oriented participants' attention away from the semantic relationship across words, since there were no behavioral effects of semantic relatedness in either of the two experiments. Still, in both experiments, significant N400 effects of semantic relatedness were found, with smaller N400 amplitudes to English and Welsh targets preceded by semantically related words as compared to when they were preceded by unrelated words. Notably, these N400 semantic priming effects were present for both the target and the non-attended languages. The set of findings reported by Martin and colleagues shows firstly, that, at least, early and highly proficient bilinguals process L2 words up to the semantic level. Secondly, these findings suggest that both languages of a bilingual are active and effectively processed up to the conceptual level, even when no attentional resources are placed upon them, contrasting with the claims of Rodríguez-Fornells et al.

In a different line of studies aimed at testing explicit bilingual lexical access, Yudes, Macizo and Bajo (2010), Palmer, Van Hooff and Havelka (2010) and Guo, Misra, Tam and Kroll (2012) combined the translation recognition task with ERPs to examine different aspects of the time course of semantic activation and its interaction with the formal properties of the words. Yudes and colleagues (2010) recorded the behavioral and electrophysiological responses of late and fluent Spanish-English bilinguals, who were asked to decide whether English (L2) cognate and non-cognate target words were the correct translation of Spanish (L1) primes. Results showed that the cognate status of the words affected responses, with cognates yielding faster and more accurate responses as well as reduced N400 amplitudes, as compared to non-cognates. These findings suggest that the formal overlap across cognate translations facilitated their co-activation at the lexico-semantic level.

Palmer, Van Hooff, and Havelka (2010) used the same task in combination with ERP recordings to examine the timecourse of the co-activation of non-cognate translations across the two translation directions (i.e., from L1 to L2 and vice versa), with late but proficient English-Spanish and Spanish-English bilinguals. As expected, the results showed that incorrect translations led to larger N400s than correct translations, while they also found a modulation of the N400 effect as a result of the translation direction. The N400 difference between correct and incorrect translations was larger in the L1-to-L2 translation direction than in the opposite translation direction, replicating the asymmetric pattern of translation effects repeatedly reported at the behavioral level. The authors interpreted their findings as providing evidence in favor of the RHM's claim that the L1 translation is automatically activated when processing L2 words (e.g., Kroll & Stewart, 1994).

Although they also used the translation recognition task, Guo et al. (2012) exclusively focused on the trials involving incorrect translations to investigate the time course of cross-language lexico-semantic activation with two groups of proficient Chinese-English bilinguals. The authors manipulated the formal (phonological) or semantic relationship of the incorrect Chinese translation with the correct translation of the target English words, to examine whether the activation of the L1 translation equivalent is influenced by formal or semantic factors during L2 processing. In their first experiment, the authors used a long 750 ms stimulus onset asynchrony (SOA) and in their second experiment they used a shorter SOA (300 ms). In both experiments, the authors found comparable interference effects for Chinese words either semantically or phonologically related to the correct Chinese translation of the target English (L2) words, as compared to their corresponding control Chinese words. Critically, for the long SOA (750ms) conditions, ERPs revealed a different time course for semantic and phonological interference effects. Chinese distractors that were semantically related to the translation of the English targets elicited smaller N400 as compared to the unrelated controls, and significant differences were also observed for the LPC that varied as a function of the polarity of this component (anterior vs. posterior LPC). Form-related distractors elicited a larger P200 and LPC than control words. At the shorter SOA (300 ms), the pattern of ERP effects was slightly different. While semantic interference effects were obtained in the N400 and the LPC time-windows, the form interference effect was only obtained in the later LPC time-window. The overall pattern of effects indicated that even highly proficient bilinguals automatically activate the L1 translation of L2 words. Importantly, the fact that a P200 effect was found for L1 distractors formally related to the L1 translation of the L2 targets demonstrated that this activation of the L1 translation takes place before L2 words are semantically processed. The P200 is a positive going electrical potential peaking at about 200 ms that is modulated by the degree of overlap between visually presented items at multiple levels (e.g., ortho-phonological, semantic).

Unlike these studies where participants were required to overtly process the relationship between translation equivalents, Alvarez, Holcomb, and Grainger (2003) and Geyer, Holcomb, Midgley, and Grainger (2011) opted to examine the ERP pattern of mental translation while bilinguals were asked to perform a task that did not direct their attention to the processing of translation pairs. In these studies, bilinguals were presented with a stream of words in both languages and researchers manipulated the relationship and the language of words presented in subsequent trials, in such a way that participants could be presented with the same word twice (i.e., within-language repetition), with non-cognate translation equivalents, or with unrelated words from the same or from different languages. This design allowed the authors to directly contrast the effects caused by within-language repetition to those caused by cross-language repetition (i.e., translation) as well as the ERP effects associated to a language change across two successive trials (see below for further discussion on language-switching effects). Alvarez et al. tested relatively low proficient English-Spanish bilinguals and asked them to perform semantic categorizations on the words presented. Geyer et al., on the other hand, tested very proficient Russian-English bilinguals who were asked to perform a generalized lexical decision task. In both studies, within-language repetition effects emerged in the 150-300 ms time window, with more negative going peaks for within-language unrelated words than for within-language repetitions. Alvarez et al. also found such an effect for words preceded by their non-cognate translation as compared to their cross-language controls. Within the N400 time window, within-language repetition effects as well as translation effects were obtained for both L1 and L2 items in both studies. Still, while in the study by Geyer and colleagues target language did not interact with relatedness either in the within or in the cross-language conditions (i.e., a symmetric pattern of within-language repetition and translation N400 effects), in the study by Geyer and colleagues the magnitudes of the N400 effects were modulated by the target language. Specifically, the Spanish (L2) N400 within-language repetition effect was larger than the English (L1) one. With regard to the N400 translation effect, larger N400 differences were obtained for L1 words preceded by their L2 translation than vice versa. The asymmetric pattern of translation effects found by Alvarez et al. was interpreted as resulting from the clearly different levels of proficiency in the L1 and L2 of the participants, while the symmetric pattern of effects reported by Geyer et al. was thought to be related to the more balanced levels of proficiency of the Russian-English bilinguals tested.

Although these ERP studies have been very informative with regard to the patterns of cross-language lexico-semantic interaction underlying the processing of translation equivalents, a number of recent ERP studies have opted for subliminally presenting one of the two translation equivalents, in order to ensure that the effects obtained are not contaminated by cognitive processes related to the conscious perception of the lexico-semantic relationship between the translations (see Altarriba & Basnight-Brown, 2007). These studies followed the masked priming procedure, which, in its standard version, involves the presentation of a pattern mask (e.g., #####) followed by a brief presentation of a prime word (around 50 ms), which is immediately replaced by a target word (see Forster & Davis, 1984). Under these conditions, participants are not able to consciously perceive the prime, thus making it impossible to intentionally process its relationship with the target. In an adaptation of the masked priming task to study translation equivalents (i.e., the masked translation priming paradigm), the prime is either the translation of the target or an unrelated control word of the non-target language. In the last two decades, numerous behavioral studies have examined masked translation priming effects with non-cognate translations and have established a clear asymmetric pattern, at least with late and non-balanced bilinguals performing lexical decisions on the targets: faster responses are found to the L2 targets when preceded by their L1 translation as compared to those preceded by an unrelated L1 word, while this facilitation is smaller and more elusive in the opposite translation direction (e.g., Gollan, Forster, & Frost, 1997; Jiang, 1999; Jiang & Forster, 2001; see Dimitropoulou, Duñabeitia, & Carreiras, 2011a, for review).

Following the increasing amount of interest in masked translation priming effects, recent ERP studies have used the masked priming paradigm to test the timecourse of the activation of non-cognate translation equivalents under strategy-free conditions (Duñabeitia, Dimitropoulou, Uribe-Etxebarria, Laka, & Carreiras, 2010; Hoshino, Midgley, Holcomb, & Grainger, 2010; Midgley et al., 2009; Schoonbaert, Holcomb, Grainger, & Hartsuiker, 2011). Non-cognate masked translation priming ERP effects have thus far been reflected in two components: the N250 and the N400. Within the monolingual masked priming ERP literature, more negative-going waves within both the N250 and the N400 time windows have been associated with more effortful target processing. With regard to the N250 effect, this processing has been proposed to tap into the mapping of pre-lexical to whole-word form representations, whereas the N400 effect has been proposed to tap into the form-to-meaning mapping process (see Grainger & Holcomb, 2009, for review).

Midgley and colleagues (2009) were the first to study ERP non-cognate masked translation priming effects by recording electrophysiological responses in L1 (English) and L2 (French) words preceded by their non-cognate translations or by unrelated masked primes. The authors also included a within-language repetition priming condition, along with its within-language control, to directly compare the ERP modulation caused by within and across-language repetitions. Participants were relatively proficient unbalanced French-English bilinguals who were asked to perform a semantic categorization task with L1 and L2 targets. In the cross-language conditions, they obtained a clearly asymmetric pattern of effects, with significant N250 and N400 modulations emerging only for L1 primes and L2 targets (i.e., more negative-going waveforms in the unrelated as compared to the translation condition). Within the masked translation priming framework, the N250 component was proposed to reflect the first instance of the automatic co-activation of the lexical representations of translations, while the N400 effect was interpreted as the electrophysiological marker of the match between the semantic representations of the prime and target. Furthermore, Midgley et al. found that, unlike the masked translation priming effects, the masked identity priming effects were symmetrical across languages (L1-L1 and L2-L2). Hoshino et al. (2010) fully replicated Midgley et al.'s findings using the same design and task but with a cross-script language combination (Japanese and English). Hoshino et al. also reported a significant modulation of the N/P150 ERP component (a component that is assumed to reflect early processes involved in mapping visual features onto higher level form representations), with L2 targets producing more negative-going waves when preceded by unrelated L1 primes as compared to when preceded by their L1 translation pairs. The authors related this effect to an additional advantage in the processing of the L1 masked primes due to the visual cue provided by the change in script (i.e., primes were written with Kanji characters and targets with Roman letters). The non-cognate ERP masked translation priming asymmetry has also been reported with the lexical decision task used in the majority of the behavioral non-cognate masked translation priming studies. However, in this study by Schoonbaert et al., (2011) testing English-French bilinguals, the usual asymmetric pattern was observed in the presence of significant N250 and N400 effects in the backward translation direction (from the L2 to the L1), as well as larger forward (from the L1 to the L2) translation priming N400 effects. Surprisingly, the asymmetry reported in the N250 time window showed an inverse pattern, with a larger effect appearing in the backward translation direction. Nonetheless, it should be noted that this study did not use classic masked priming procedures as the prime presentation times used were relatively long (120 ms).

In contrast to these asymmetric patterns mentioned above, Duñabeitia et al.'s (2010b) results are the only ones to report symmetric ERP non-cognate masked translation priming effects. In their study, they tested a group of Spanish-Basque simultaneous and balanced bilinguals of similar characteristics to the ones tested in a parallel behavioral version of this study (see Duñabeitia, Perea, & Carreiras, 2010). Participants performed a semantic categorization task on both Spanish and Basque targets. Fully replicating the behavioral findings obtained with the Spanish-Basque bilinguals, the results of this ERP study showed significant bi-directional N400 masked translation priming effects which were of similar magnitude across the two translation directions. However, unlike other ERP masked translation priming studies, Duñabeitia et al. did not find any N250 modulation in the cross-language translation conditions. Nonetheless, it should be noted that this study is the only ERP study so far to test balanced simultaneous bilinguals in a masked translation priming paradigm and that this could be the reason underlying the differences between this study and other studies testing unbalanced sequential bilinguals.

Processing language membership during word reading

Identifying language membership is not a straightforward process and recent research has shown that both the linguistic profiles of the readers and the specific characteristics of the target words play a crucial role during this process (see Casaponsa, Carreiras, & Duñabeitia, 2014, for review). De Bruijn, Dijkstra, Chwilla and Schriefers (2001) investigated the processing of the language membership of Dutch-English interlingual homographs by using a multiple priming paradigm in combination with ERP recordings. In this paradigm, two word primes preceded each target. Dutch-English bilinguals were presented with the interlingual homograph as the second word of the triplet, preceded either by a Dutch or by an English word. The manipulation of the language membership of the first word of the triplet aimed at providing either an L1 or an L2 context that could bias the processing of the language membership of the subsequently presented interlingual homograph (e.g., Dutch (L1) context: *ZAAK–ANGEL–HEAVEN),* or English (L2) context: *HOUSE-ANGEL-HEAVEN*, where *ANGEL* corresponds to an interlingual homograph). The authors also manipulated the semantic relationship between the interlingual homograph and the subsequently presented target, in such a way that the target could either be semantically related to the English meaning of the interlingual homograph (e.g., *HOUSE-ANGEL-HEAVEN*) or unrelated to either the English or the Dutch meaning of the homograph (e.g., *HOUSE-ANGEL-LAUNCH*). Participants were asked to perform a generalized lexical decision task upon target presentation (i.e., are all the items of the triplet Dutch/and or English words?), while behavioral and electrophysiological responses were being recorded. The behavioral and ERP responses showed significant semantic priming effects, with shorter reaction times and smaller N400 amplitudes found for targets preceded by semantically related English words as compared to unrelated words. However, this effect was not modulated by the language context provided by the initial word of the triplet, either at the behavioral or at the electrophysiological level. This pattern indicates that the prior presentation of an L1 word is not enough to suppress the activation of the L2 meaning of the interlingual homograph.

In contrast to the study by de Bruijn et al. (2001), which addressed semantic processing of words without a clear language membership (interlingual homographs), ERP studies examining the way in which bilinguals identify the two languages during bilingual visual word recognition have focused on the processing of the language membership of items that are not shared across-languages (i.e., non-homographic non-cognate words). In fact, most of the existing information in this regard has been obtained from studies investigating the cost observed when bilinguals switch between languages, referred to as the *code-switching cost* (e.g., Alvarez et al., 2003; Chauncey, Grainger, & Holcomb, 2011). The seminal studies exploring this cost were reported in the word production domain (e.g., Costa & Santesteban, 2004), in which the code-switching cost has been classically interpreted as the result of the inhibition needed to suppress the non-target language following a code-switch (see Kroll, Bobb, Misra, & Guo, 2008, for review). However, code-switching costs have also been reported when bilinguals switch between languages during reading (e.g., Grainger & Beauvillain, 1987; Thomas & Allport, 2000). In the comprehension modality, where word processing proceeds in a bottom-up way, there is an on-going debate regarding the locus of the code-switching cost and the computation of the language membership of words. On the one hand, the BIA model proposes that the language membership of a given word is readily computed as part of the lexical processing of the word (e.g., Grainger & Dijkstra, 1992), while, on the other hand, the BIA+ model proposes that the language tag is provided after the activation of the lexical representation, at a later task-dependent processing stage (e.g., Dijkstra & van Heuven, 2002).

Alvarez et al. (2003) were the first to report such visual code-switching costs with ERPs in the word comprehension domain. As previously described, these authors presented late, relatively non-proficient English-Spanish bilinguals with mixed lists of English and Spanish words while participants performed a semantic categorization task. When examining the processing of the language switches by comparing the ERP responses to words preceded by words of the same language with the responses to words preceded by words of the other language, the authors found greater negativities in the 500-700 ms time window for words involved in a language switch. However, in the earlier N400 time window this code switching cost was only obtained in one of the directions at test (namely, when the switch was from the L1 to the L2). This pattern of asymmetric ERP code-switching costs across the two language switching directions suggested that with relatively non-proficient unbalanced bilinguals, the language switch in the L2 to L1 direction takes longer to emerge. Furthermore, given the fact that the L1-to-L2 code-switching cost appeared in the N400 time window, when form-to-meaning integration is proposed to take place, the authors concluded that their findings supported the view that the inhibition associated with the code-switching cost is applied at the lexical level, as the BIA model proposes (e.g., van Heuven, Dijkstra, &

Grainger, 1998).

Geyer et al. (2011) followed the same experimental procedure, this time with a generalized lexical decision go/no-go task, to test whether the same pattern of asymmetric ERP effects as reported by Alvarez et al. (2003) would be obtained with highly proficient late Russian-English bilinguals who were living in an L2 context. Although the authors' primary focus was on translation effects, their design also allowed for the investigation of code-switching costs with bilinguals with a higher level of L2 competence than those tested by Alvarez et al. Geyer and colleagues predicted that, given the high level of competence in the second language of their bilinguals, L1-L2 processing differences would be diminished and thus a more symmetric pattern of code-switching costs would be obtained across the two switching directions, both in terms of the timing and the magnitude of the effects. The results confirmed their prediction. Small but significant code-switching costs appeared in the N400 component and in the 500-850 ms time window, which did not interact with the direction of the language switch. The symmetric pattern of code-switching costs found with highly proficient bilinguals suggested that these effects depend on the relative level of L1 and L2 competence, as the BIA model proposes (Grainger & Dijkstra, 1992). Moreover, the fact that these ERP code-switching costs were found in trials that did not require an overt response was thought to further support the BIA model's account of code-switching costs, since unlike the Inhibitory Control (IC) assuming that bilingual language processing is in a way analogous to non-linguistic physical actions that consist of different mental task schemas that compete with each other to reach a goal, and unlike BIA+ models, the BIA model proposes that these processing costs should not be affected by task demands.

Even though the language switches were not predictable in these studies, since they randomly appeared within the experimental list, participants were able to intentionally process the language membership of the test items, since they were explicitly and overtly presented. In other words, the obtained pattern of code-switching costs could have been considerably contaminated by strategic and attention-related processes. As in the case of the studies investigating the processing of translation equivalents, researchers exploring switch cost effects in language comprehension have also taken advantage of the implicit presentation provided by the masked priming paradigm to study the electrophysiological correlates of the code-switching cost in bilingual visual word recognition. In this line, Chauncey, Holcomb and Grainger (2008; see also Chauncey, Holcomb, & Grainger, 2011) tested French-English bilinguals with an intermediate level of English proficiency. Participants performed a go/no-go semantic categorization task on French or English targets preceded by unrelated masked primes either in English or in French. Chauncey et al. found evidence for automatic code-switching costs across primes and targets in both the N250 and the N400 time windows as compared to non-switching conditions. These effects depended on the directions of the language switches, with L1 primes and L2 targets eliciting larger negativities in the N250 time window as compared to non-switch trials, and L2 primes preceding L1 targets eliciting more negative-going peaks within the N400 range (see also Midgley et al., 2009). Given the appearance of code-switching costs in the early N250 component (typically linked to the interface between sub-lexical and whole-word representations; Grainger & Holcomb, 2008; 2009), the authors proposed that in trials involving a prime-target language switch, the activation of the language node corresponding to the prime inhibits the lexical representations of the target's language, giving rise to this early switch-cost effect, in line with the interpretation of code-switching costs offered by the original BIA model (e.g., van Heuven et al., 1998). Following this early stage, the inhibitory activation is then propagated to the later N400 component, when the form-meaning integration takes place. The asymmetric pattern of code-switching costs across the two switching directions was also taken as evidence in favor of the BIA model, since it was thought to reflect the fact that bilinguals with a higher L1 than

L2 proficiency level take longer to process L2 primes and consequently to activate the L2 language node, hence causing a delayed language switching cost in the L2-to-L1 switching direction. The findings reported by Duñabeitia et al. (2010b) testing simultaneous and balanced Basque-Spanish bilinguals partly supported this view. Their results replicated the overall pattern of masked priming ERP code-switching effects first reported by Chauncey et al. (2008). Significant N250 and N400 masked code-switching costs were obtained, but these effects were highly similar for both Basque and Spanish targets. The fact that the asymmetric pattern of code-switching costs found with unbalanced bilinguals disappeared when native-like balanced bilinguals were tested (as in the case of Duñabeitia et al.), indicates that the relative level of proficiency of the bilinguals and the AoA of each language critically modulate these effects.

Reading Sentences

L2 sentence reading

The main research question in sentence reading in a second language is whether L1 and L2 processing mechanisms are completely different and separate, or, in contrast, whether L1 and L2 processes are completely or partially overlapping. Several studies have shown that even highly proficient L2 readers have persisting difficulties in syntactic processing (Johnson & Newport, 1989; Weber-Fox & Neville, 1996), while others report cases of L2 readers who have reached a native-like processing level (Birdsong, 1992). It is important to keep in mind that similarities in behavioral measures between L1 and L2 processing do not necessarily mean that the underlying cognitive and neural processing is equivalent in a first and a second language. As argued above, neurophysiological measures can contribute essential evidence to this debate, and recording electrophysiological activity can provide detailed information on the timing and degree of activation of neural networks. Comparing ERP activity in L1 and L2 reading thus provides important information on the similarities and differences between L1 and L2 processing, even where the final behavioral outcome is identical in the two situations. Consequently, it is not surprising that the ERP technique has been a popular approach to investigating the question of convergence or divergence of L1 and L2 sentence processing mechanisms.

In their seminal study, Ardal and colleagues (1990) explored ERPs elicited by semantic violations in sentences. They showed that the classic N400 effect was delayed in bilinguals. Interestingly, this was the case in bilinguals reading in L2, but also (to a lesser extent) in bilinguals reading in their first language. In this study, the N400 component was not modulated by age of acquisition of the second language (earlier or later than age 11). In contrast, one of the most widely-cited ERP experiments on bilingual sentence reading published by Weber-Fox and Neville in 1996 showed a different pattern of results. They tested the influence of L2 (English) age of acquisition on sentence reading. The sentences read were either correct or included semantic or syntactic violations. They showed that semantic processing was slower in bilinguals who acquired their L2 after the age of 11, as compared to monolinguals and bilinguals who had acquired L2 earlier in life (N400 effects for semantic violation delayed in time). The N400 effect in this context is classically defined as the magnitude of the difference in amplitude between the N400 elicited by a semantic violation and that elicited by a semantically correct word in the same position (Kutas & Hillyard, 1980). Syntactic processing was affected by delays in L2 learning as short as 1-3 years, and was revealed by a difference in the morphology of the ERP components reflecting syntactic processing (N125, left-lateralized negativity and P600). The authors argued that delays in L2 exposure might be associated with a reduced left hemisphere specialization in language processing (see Proverbio et al., 2004, for similar arguments of lesser degree of hemispheric lateralization during L2 processing).

These two early studies show the variability in results obtained in L2 sentence processing. However, interestingly, in spite of the considerable variability in the results—depending on the languages tested, the paradigms used in the studies and other multiple factors—the considerable literature on bilingual sentence reading has led to several consistent observations. In the following sections, we review these findings.

The majority of ERP studies on bilingual sentence reading have explored semantic and morphosyntactic processing. There are also many parallel ERP studies in the auditory modality (testing auditory sentence comprehension instead of sentence reading; see Friederici et al., 2002; Hahne, 2001; Hahne & Friederici, 2001; Isel, 2007; Mueller et al., 2005; Mueller, 2006; Ojima et al., 2011; Rossi et al., 2006; Sanders & Neville, 2003), but in the current chapter we will only focus on sentence reading. In most of these studies, L2 and L1 readers were presented with correct sentences, sentences containing semantic violations (e.g., "Peter likes to eat eggs and *socks* for breakfast", violation in italic) and/or sentences containing syntactic or morphosyntactic violations (e.g., "Peter *like* to eat eggs for breakfast", "Peter wants a *egg* for breakfast"). The ERP waves elicited by the critical words of the sentences (specific words making the sentence semantically and/or syntactically correct or incorrect) were compared across groups. As discussed in the following section, most studies have underscored the importance of two major factors in bilingualism: age of acquisition and proficiency. These factors are probably interrelated and we will see that both are important in determining the timing of semantic and morphosyntactic processing during sentence reading (see Moreno & Kutas, 2005).

Semantic processing during L2 sentence reading

It has been repeatedly observed that the classic N400 effect associated with semantic processing is slightly reduced in amplitude and/or delayed in time when reading in the L2 as compared to the L1 (e.g., Ardal et al., 1990; Kutas & Kluender, 1991; Moreno & Kutas, 2005; Newman et al., 2012; Ojima et al., 2005; Proverbio et al., 2004; Weber-fox & Neville, 1996, 2001; see Kutas et al., 2009; Moreno et al., 2008; Mueller, 2005, for reviews). Some studies have revealed that the N400 semantic congruity effect is reduced and/or delayed even in the first language of a bilingual, as compared to a monolingual (Ardal et al., 1990; Meuter et al., 1987; but see Proverbio et al., 2002 for no monolingual versus L1 bilingual differences). This result suggests that acquiring more than one language has consequences for semantic processing, even when reading in the native language. Proverbio et al. (2002) suggested that even if L2 semantic processing can reach a native-like level, differences between semantic processing in reading in L1 versus L2 persist. The authors compared monolinguals and early, highly proficient bilinguals reading sentences where the last word was correct, semantically incorrect, or syntactically incorrect (e.g., "Something tickled me", "I would like to read this dog", "He ended up by forgetting his to go out"). They observed an N400 effect in the two groups when reading semantic violations. Nevertheless, the ERP response to semantic violations was left-lateralized in bilinguals and right-lateralized in monolinguals. So far, the results from semantic processing during second language reading are relatively congruent, showing a reduced and delayed N400 effect. This delay in the N400 semantic effect is interpreted as the result of an extended lexical search and/or a lower degree of automaticity for L2 processing (Ardal et al., 1990; Weber-Fox & Neville, 1996).

In a recent study, Braunstein et al. (2012) did not only investigate L2 semantic processing during sentence reading by using semantic violations, but also using word cloze probability. Word cloze probability in a sentence is the probability that a speaker would complete the sentence by using a particular word (e.g., "road" would have a 90% cloze probability if 90% of the readers would complete the sentence "Peter was walking down the..." by using the word "road"). Braunstein et al. presented L2 readers with sentences ending with a semantically incongruent word, a highly expected word (i.e., high cloze probability), or an unexpected, but still semantically correct, word (i.e., low cloze probability). Semantically incongruent and unexpected final words elicited N400 effects that were delayed in L2 relative to L1 readers. Thus, this experiment revealed the notion that semantic processing during L2 sentence reading varies as compared to L1 sentence reading, even in a “natural” context with no semantic violations.

As argued earlier, research on bilingual sentence reading has also benefited from experiments studying aspects of semantic processing other than brain reactions to semantic violations. Interesting paradigms already used in investigations of L1 sentence processing have been successfully applied to L2 reading. For instance, a productive line of research has been established on the active role of the reader when processing sentences in L2, by exploring anticipation and semantic integration. Anticipation processes refer to the active role of individuals when predicting upcoming linguistic information in a sentence. That is, comprehenders do not read or listen passively, but rather try to anticipate probabilistically the next words (or discourse topics) that are likely to appear in the sentence (e.g., DeLong et al., 2005). This ability is fundamental in language processing, inasmuch as it reduces processing load and helps interlocutors to free resources to plan their utterances during a conversation, thus smoothing communication (Pickering & Garrod, 2007). By integration processes we refer to those processes that allow comprehenders to combine semantic information contained in the sentence with world knowledge (e.g., Hagoort et al., 2004). That is, comprehenders not only pay attention to the meaning of the words but they also analyze how such information matches their knowledge about the world. These integration processes are fundamental to a proper understanding of the communicative act, and therefore to going beyond mere linguistic analysis. It is largely admitted that difficulties in L2 sentence reading stem, at least partly, from incomplete or faulty syntactic parsing (see below) or slow/more difficult semantic access (see above). This may lead to deficiencies in anticipation and integration processes as compared to L1 processing. However, as we will see below, the number of studies exploring these issues is markedly low, and more research is needed in order to assess whether (and how) these processes function in L2 sentence comprehension.

Active word anticipation during L2 sentence reading has been recently explored, but has to be further investigated since results so far are not conclusive. Martin et al. (2013) explored word anticipation in L2 sentence reading by comparing English natives (L1 readers) and Spanish-English bilinguals (L2 readers). Each sentence ended in an expected or unexpected noun (high versus low word cloze probability; see above). Importantly, in this study, no semantic violation was used (see also Braunstein et al., 2012). Contrary to L1 readers, L2 readers failed to show the N400 modulation elicited by word anticipation. The authors concluded that L2 readers do not anticipate upcoming words during sentence comprehension to the same extent as L1 readers do. Strong conclusions cannot be drawn so far because the same research group has recently obtained discrepant results testing different samples of bilinguals. In another study, Foucart and colleagues (2014) compared L1 and L2 readers in a similar sentence reading task in which sentences ended in expected versus unexpected words (e.g., "She has a nice voice and always wanted to be a singer/an artist”). Spanish monolinguals (L1 readers), Spanish-Catalan early bilinguals (L1 readers) and French-Spanish late bilinguals (L2 readers) were compared. The classic N400 pattern revealing word anticipation was observed in the three groups of participants. The data revealed that (at least when the L1 and L2 are closely related) L2 readers are able to anticipate upcoming words in a similar way to L1 readers and that identical processes are involved. It is important to note that Martin et al. used phonological article-noun agreement in English as the critical manipulation, and that this phonological rule does not exist in Spanish (the participants' L1). Foucart et al. (2014) used gender agreement in Spanish as the critical manipulation, this rule being similar in French (the first language of L2 readers in their study). Thus, word anticipation during L2 sentence reading seems to be highly influenced by L1/L2 similarities. Further investigation is needed before drawing any strong conclusions since only two studies have explored word anticipation in L2 reading, thus far. Nevertheless, these recent results show the interest of using critical paradigms from research on L1 sentence reading in order to investigate further semantic processing during L2 sentence reading without resorting to semantic violations.

To summarize, most studies on semantic processing during sentence reading reveal similarities between L1 and L2 processing (Kotz & Elston-Güttler, 2004; Ojima et al., 2005). The main and most frequent observation of a delayed and reduced N400 effect in L2 relative to L1 processing suggests that differences between L1 and L2 semantic processing are mostly quantitative and not qualitative in nature. This quantitative difference might be due mainly to a slowdown or decrease in efficiency of semantic processing mechanisms in a second language (see Kutas et al., 2009; Moreno et al., 2008; Mueller, 2005 for reviews). Note that whether L2 semantic processing is native-like or not seems mainly to depend on proficiency.

Syntactic and morphological processing during L2 sentence reading

In studies of L1 syntactic processing using violation paradigms, the most common ERP result observed is a biphasic pattern of early negativity (normally left-lateralized), followed by P600 effects. The P600 is a positive deflection in the waveform which peaks around 600 milliseconds after stimulus onset, and the P600 effect is classically defined as the magnitude of the difference in amplitude between the P600 elicited by a syntactic violation and that elicited by a syntactically correct word in the same position (Hahne & Friederici, 1999). It is considered to reflect processes of reanalysis and syntactic repair (Friederici, 2002; Osterhout et al., 1994) and more globally, the difficulty of syntactic integration (Kaan et al., 2000). The earlier left-lateralized negativity is commonly considered an index of early-stage syntactic processing mechanisms (Friederici, 2002). Although this is a common pattern for L1 morphosyntactic processing, for bilingual syntactic processing, the results have not been consistent. Ojima et al. (2005) observed that syntactic violations embedded in sentences elicited a left-lateralized negativity in English natives and Japanese-English highly proficient late bilinguals (tested in English, their L2). This left-lateralized negativity was not observed in Japanese-English low proficient late bilinguals also tested in L2. However, Chen et al. (2007) reported a very different pattern of results revealing that subject-verb agreement violations elicited a late *anterior* negativity and no P600 effects in native Chinese-L2 English readers of intermediate proficiency. Steinhauer et al. (2006) also investigated ERPs during syntactic violation reading in L1 and L2 and found a different pattern of results again. The classic pattern of left-lateralized negativity followed by a P600 component was observed in native readers. However, low proficiency L2 readers elicited only a P600 effect, suggesting that L2 readers cannot automatically process syntactic violations in a native-like manner within the first 500 ms following the violation (Steinhauer et al., 2006; see Hahne, 2001; Weber-Fox & Neville, 1996 for similar arguments). Weber and Lavric (2008) tested English natives and German-English bilinguals reading English sentences containing morphosyntactic violations in the final word (e.g., "The door had been locked" versus "The door had been locks"). Morphosyntactic violations elicited the classic P600 effect in English natives, while German-English bilinguals reading in L2 showed the expected P600 effect, but also an N400 effect. This observation of an N400 modulation by morphosyntactic violations might suggest that processing morphosyntactic violations in an L2 relies on the lexico-semantic system (see also Tanner et al., 2013b). However, note that some studies on L1 sentence processing have also reported N400 modulations in response to morphosyntactic violations (e.g., Bentin & Deutsch, 2001; Severens et al., 2008).

As highlighted by the above studies, and as will be discussed below, the results observed in studies of L2 morphosyntactic sentence processing are not as consistent as those of semantic processing. We propose that this larger discrepancy in studies of L2 morphosyntactic processing relative to L2 semantic processing might be explained, at least partly, by the wider range of different processes and paradigms used in research on morphosyntactic processing. This area has explored a wide variety of paradigms (not only using syntactic violations) and has tested very different types of structure (subject-verb agreement, gender or number agreement, referential ambiguities, closed- versus open-class word processing, etc.), leading to a considerable variability in the phenomena observed. Interestingly, Osterhout et al. (2006) investigated syntactic violation processing in L2 English learners of French after one, four, or eight months of instruction and compared it to processing in French natives. Before 4 months of instruction, subject-verb agreement violations in L2 readers elicited an N400 effect. In contrast, after 4 months of instruction, subject-verb agreement violations were processed similarly in L1 and L2 readers (similar P600 effects were observed in the different groups; see White et al., 2007 for similar findings). However, determiner-number agreement violations elicited a P600 effect in L1 readers but not in L2 readers, even after 8 months of instruction (Osterhout et al., 2006). These results are congruent with our main assumption that processing of different morphosyntactic structures in L1 and L2 will vary.

In the above studies of morphosyntactic processing during L2 sentence reading, L1 and L2 readers were presented with correct sentences and sentences containing morphosyntactic violations. Interestingly, and unlike the field of semantic L2 processing, a large number of studies have also explored morphosyntactic processing using paradigms in which no violation is inserted in the sentences. In the following section, we will review these studies on syntactic integration and ambiguities.

Regarding function word processing, several studies have suggested that a similar network is involved in L1 and L2 in the processing of function words, with delays reported in L2 readers (Weber-Fox & Neville, 2001). Briefly, function words in English are closed-class words that are primarily related to grammatical aspects of sentence processing (e.g., articles, determiners, conjunctions, prepositions). In contrast, open-class (content) words primarily convey referential meaning (e.g., nouns, verbs, adjectives). Neville et al. (1992) reported that high-frequency closed-class and open-class words all elicited left anterior negativities that were larger and earlier for closed-class words than for open-class words. Those waves were respectively termed N280 and N350 by the authors (see also Brown et al., 1999). Later, in the 400-600 ms time window, closed-class words elicited a broad negative shift that was not observed when open-class words were displayed (Brown et al., 1999; Neville et al., 1992). Weber-Fox and Neville (2001) tested function word reading in bilinguals of various ages of acquisition and monolinguals. They observed the N280 component in all participant groups, the peak being delayed in bilinguals who learned English after the age of seven. The processing of open-class words was similar in all groups (similar N350 latencies and distributions; Weber-fox & Neville, 2001). As for the processing of regular and irregular participles, Hahne et al. (2003, 2006) observed that L2 readers use two different processing routes to process regular and irregular words, as is the case in L1 readers: rule-based decomposition might be used to process regular words, and lexical storage might be used to process irregular words. The authors concluded that relatively automatic morphosyntactic processes can be implemented in the L2 reader's brain (see Clahsen & Fesler, 2006a). Note that this implementation certainly depends on the complexity of the morphosyntactic rule under consideration and the similarity of the rules in L1 and L2 (Mueller, 2005). The idea that some morphosyntactic processes can be implemented similarly in the L1 and L2 was also argued by Kotz et al. (2008), who suggested that L2 readers can process syntax in a similar way to L1 readers (see also Diependaele, Duñabeitia, Morris, & Keuleers, 2011, for a similar argument applied to the processing derivational morphology by bilinguals). The authors tested temporary syntactic ambiguity that was a language-specific phenomenon of English. They observed that the classic P600 effect elicited by temporary syntactic ambiguity was similar in English natives and Spanish-English highly proficient bilinguals.

Despite the high variability in results, some influential interpretations of L1/L2 differences in syntactic processing assume that the syntactic representations that L2 readers compute during sentence comprehension are shallower and less detailed than those of native readers (Clahsen & Fesler, 2006b). It could also be that L2 readers underuse syntactic information in L2 processing (Marinis et al., 2005; Weber-Fox & Neville, 1996) and/or that difficulties in mapping discourse onto syntax constrain L2 performance (Hopp, 2009).

In summary, it can be argued that it is difficult to achieve L2 morphosyntactic processing in a native-like manner, and it is almost never the same as that of the L1 (Ojima et al., 2005; see Kotz, 2009, for a review). Note, however, that this idea of fundamental differences in language processing in the L1 versus L2 is challenged by several studies showing similar electrophysiological signatures in syntactic processing during sentence reading in L1 and L2 (e.g., Bowden et al., 2007; Steinhauer et al., 2009; see also Rossi et al., 2006 in the auditory modality). Similar P600 effects for L1 and L2 readers are reported in several studies suggesting that controlled syntactic reanalysis and repair can be acquired by L2 readers and achieved in a native-like way in some domains of grammar (Clahsen & Fesler, 2006a; Kotz et al., 2008; but see Chen et al., 2007, and Ojima et al., 2005, for no P600 modulation by syntactic violations in L2 readers). Early, more "automatic" morphosyntactic processing mechanisms (reflected by left-lateralized negativities), however, seem to be much more difficult to acquire, especially where L2 proficiency is low. This absence of early anterior negativities seems to be a typical result in studies of syntactic processing in late and low proficiency L2 readers (Bowden et al., 2007; Hahne et, al., 2003; 2006; Mueller et al., 2005; Steinhauer et al., 2006; Weber-Fox & Neville, 1996; see Kutas et al., 2009; Moreno et al., 2008; Mueller, 2005; Steinhauer et al., 2009 for reviews). However, it seems that L2 readers do not have systematic problems with all aspects of grammar, but more with real-time computation of complex hierarchical representations (Clahsen & Fesler, 2006a). We can conclude, therefore, that L2 adult readers use lexico-semantic cues during sentence reading as native readers do, but are less able to cope with structurally-based parsing strategies (see Clahsen & Fesler, 2006b; Papadopoulou & Clahsen 2003).

Influence of proficiency and age of acquisition in L2 sentence reading

As stated above, Braunstein et al. (2012) explored the influence of L2 proficiency on semantic processing during sentence reading. They observed that the N400 latency for semantically correct but unexpected words was modulated by L2 proficiency. This was an indication that L2 proficiency influences the speed of semantic processing during sentence reading. The fact that L2 proficiency contributes to the speed of semantic processing has been also observed in previous studies (Ardal et al., 1990; Moreno & Kutas, 2005). However, other studies have suggested that the age of L2 acquisition, and not proficiency, is the factor determining L1/L2 processing differences (e.g., Proverbio et al., 2004). Hence, it still remains to be clarified whether proficiency and/or age of acquisition are able to capture and explain the differences between L1 and L2 sentence reading. In fact, these two variables are usually highly correlated, making it difficult to disentangle the contribution of one *vis-à-vis* the other (see Moreno & Kutas, 2005). Interestingly, Newman et al. (2012) also observed that the N400 amplitude to semantically appropriate words was larger for participants with lower English proficiency. Thus, it seems that language proficiency affects semantic processing in general, even during correct sentence reading. The proficiency of the language used in reading does not only affect semantic violation processing. It rather seems that proficiency modulates the main semantic processing system (see Newman et al., 2012). Note that previous studies have already revealed that proficiency in L2, but also in L1, modulates semantic processing (e.g., Moreno & Kutas). For instance, Pakulak and Neville (2010) observed that P600 amplitude was correlated with the individual's proficiency in L1.

The importance of proficiency in native-like acquisition of processing mechanisms has also been highlighted by studies on syntactic processing in L2. The early anterior negativity and P600 effects have been shown to be strongly affected by proficiency in the L2 (e.g., Bowden et al., 2007; Steinhauer et al., 2006; see also Hahne, 2001; Hahne & Friederici, 2001; and Rossi et al., 2006, for studies testing the auditory modality). In order to investigate effects of language proficiency, Weber-Fox et al. (2003) tested syntactic and semantic processing during sentence reading in normal and highly skilled readers. They observed that the N280 elicited by closed-class words was delayed in normal readers relative to highly proficient readers. In contrast, the N350 component elicited by open-class words did not vary between normal and highly proficient readers. Interestingly, this pattern was consistent with previous observations with various groups of bilinguals (Weber-Fox & Neville, 2001). It seems that open-class word processing is independent of language proficiency (in native or non-native language). In contrast, the speed of closed-class word processing is a sensitive index of language proficiency (Weber-Fox et al., 2003). The following broad negative shift typically observed for closed-class but not open-class words (Brown et al., 1999; Neville et al., 1992) was also affected by language proficiency, but the interpretation of this finding is still unclear given the little evidence in the literature for such effects. Finally, the classic N400 component elicited by semantic violations was significantly smaller in amplitude in highly proficient L1 readers relative to normal L1 readers. This result, in accordance with previous literature, suggests that semantic processing is highly affected by language proficiency: the larger the proficiency (in L1 or L2) the smaller the reliance on sentence context for word recognition (Holcomb et al., 1992; Weber-Fox et al., 2003).

Age of L2 acquisition is also an important variable to take into account when investigating L2 sentence processing, with some studies providing support for the idea of a critical or sensitive period for L2 semantics and syntactic processing, ending more or less at the age of puberty (Clahsen & Fesler, 2006a; Weber-Fox & Neville, 1996). It has been observed that L2 readers who acquire their second language before late childhood can often reach native-like L2 processing levels, while L2 acquisition later than that shows evidence of difficulties in semantic and/or syntactic processing or L2 processing that is not similar to L1 readers (Johnson & Newport, 1989; Ojima et al., 2005; Weber-Fox & Neville, 1996, 2001). Thus, it has been argued that the earlier the L2 is acquired, the more native-like the linguistic processing achieved (but see Birdsong, 1992; Bongaerts, 1999; Friederici et al., 2002; Rossi et al., 2006, for evidence against the critical period hypothesis). Some of the strongest evidence for a critical or sensitive period in L2 acquisition comes from studies of syntactic processing in L2 sentence reading. The fact that evidence of early automatic morphosyntactic processing mechanisms (reflected by left-lateralized negativities) is scarcely ever reported in late L2 readers, would seem to indicate that the development of some complex underlying syntactic processes requires prerequisites available only during childhood, in most cases at least.

Note that some authors consider that age of acquisition and proficiency should not be considered as independent factors since they are usually highly correlated. Thus, the influences of age of acquisition and proficiency can be considered together, as proposed by Moreno and Kutas (2005). Accordingly, the latency of the N400 component varies with proficiency and age of acquisition. They report that the latency of the N400 effect in L2 readers is positively correlated with age of acquisition and negatively correlated with fluency. Finally, one current view on proficiency and age of acquisition effects in L2 sentence reading is that age of acquisition would mainly affect syntactic, morphological, and phonological processing, while proficiency would better explain lexical and semantic processing (Hernandez & Li, 2007; Johnson & Newport, 1989; Weber-Fox & Neville, 1996).
It is important to note that age of acquisition and proficiency are generally considered to be the two main factors influencing L2 sentence processing. Nevertheless, several other factors are important to take into account when investigating sentence processing in a second language. For instance, L1 to L2 similarity highly modulates sensitivity to grammatical processing in L2. In Tokowicz and MacWhinney's (2005) study, English-Spanish bilinguals were presented with grammatically correct or incorrect sentences varying in the type of syntactic processing under study. They compared a function that is similar in English and Spanish (noun-verb agreement; e.g., "El niño están jugando" [The boy(singular) are(plural) playing]) and a function that is different in English and Spanish (determiner-noun agreement; e.g., "Ellos fueron a un fiesta" [They went to a(masculine) party(feminine)]). The classic P600 effect was significant in L2 readers for subject-verb agreement violations (constructions that are formed similarly in L1 and L2) but not for determiner-noun agreement violations (constructions that differ between L1 and L2). The authors concluded that L2 readers process L2 syntax in a way that depends on the similarities between L1 and L2 (Tokowicz & MacWhinney, 2005). Gillon-Dowens et al. (2010) also explored the influence of L1 to L2 similarities on electrophysiological correlates of L2 morphosyntactic processing.

Spanish natives, serving as a control group, were presented with grammatically correct sentences and with sentences containing number or gender agreement violations in Spanish. The results showed the typical expected ERP pattern of an early anterior negativity followed by a P600 effect in response to both agreement violations. A group of late L1 English-L2 Spanish readers also showed a qualitatively similar early negativity-P600 pattern. More importantly, however, in this group, unlike the native Spanish group, quantitative differences (i.e., amplitude and onset latency differences) between the two types of agreement violations were observed, with greater amplitudes for number than for gender processing. Since number agreement is a syntactic feature of both Spanish and English and gender agreement is not a feature of English, the authors concluded that transfer processes from L1 to L2 significantly influenced syntactic processing (see Gillon-Dowens et al., 2011, for similar argument on L1 transfer observed in ERP data). Sabourin et al. (2008) also investigated electrophysiological correlates of L1 grammar transfer during L2 sentence processing. They presented Dutch natives with verbal domain dependency violations, or grammatical gender violations. Those L1 readers showed a significant P600 effect for both types of violations. German-Dutch bilinguals also showed a P600 effect for both violations. L2 readers who had a Romance language as their L1 showed a P600 effect only for verbal domain violations. The authors concluded that neural correlates for L1 and L2 are similar when morphosyntactic processing rules are shared between the two languages (e.g., verbal domain dependency in Dutch, German and Romance languages). However, rules that differ in L1 and L2 do not result in similar neural processes in the two languages (e.g., grammatical gender rules that differ in Dutch and Romance languages; Sabourin et al., 2008). Foucart and Frenck-Mestre (2011) confirmed that L2 morphosyntactic processing is modulated by the similarity of the rules at play in L1 and L2. They studied various gender agreement violations in French natives and German-French advanced bilinguals. Foucart and Frenck-Mestre reported similar P600 effects in the two groups when agreement rules were similar in French and German, whereas no P600 effect was observed in L2 readers when agreement rules differed across languages. These studies demonstrate how the fine-grained temporal resolution of the ERP technique is currently being widely explored by cognitive neuroscientists to investigate cross-linguistic influence effects (see also Gabriele et al., 2013).

To conclude, we would like to point out a potential shortcoming of ERP research on bilingual sentence reading that could explain part of the inconsistent results observed up until now. Almost all ERP studies in the field have reported data averaged over trials and participants. But variability across participants is very high when considering bilinguals. L2 processing skills are subject to strong individual variability that can lead to problems of interpretation of classic ERP components that are computed by averaging across individuals. This potential problem was extensively studied by Tanner et al. (2013a). They revealed significant individual differences in L2 readers' ERP responses to morphosyntactic violations. Strikingly, the violations elicited N400 effects in some participants and P600 effects in others. Better accuracy in sentence acceptability judgments was associated with larger brain responses in both the N400 and P600 time windows. In a similar study, Tanner et al. (2013b) replicated the observation that morphosyntactic violations elicit N400 effects in some L2 readers and P600 effects in others (despite homogeneous high L2 proficiency and long-term L2 exposure). In this study, they also showed that higher L2 proficiency is associated with larger brain responses. These results, in accordance with Osterhout et al.'s (2006) study, suggest that L2 learners go through distinct stages of learning, with inter-individual variability in the rate of progression through these stages (see White et al., 2007; Steinhauer et al., 2009, for similar proposal). More importantly, these studies also reveal that investigation of between-subject variability can sometimes be highly informative. Therefore, investigation of individual ERP responses should be combined with standard analysis of grand average waveforms in future research on L2 sentence reading. In the next sections we attempt to provide current and future users of EEG technology with a guide for good practices that can provide the field of multilingual reading with a snapshot of how the multilingual brain functions when processing words and sentences in the native and in the nonnative language(s).

Summary and Conclusions

This chapter aimed at offering a complete description of the most relevant EEG studies on the field of bilingual written word and sentence comprehension. The time window in which a given letter string passes from being a mere sequence of graphemes to acquiring the word status takes around 300 milliseconds (see Duñabeitia & Molinaro, 2013, for review), and recent evidence from monolingual and multilingual ERP studies has been extremely valuable in demonstrating how lexical representations from the first and second language are acquired, consolidated and accessed by readers with different proficiency profiles in their second language. The initial part of this chapter covered this issue in depth. Following this initial section, we discussed evidence showing strong L1-L2 interactions at the ortho-phonological, lexical and semantic levels of processing, both in single-language and in dual-language contexts. As seen in the first section of this chapter, the complexity of the possible cross-linguistic interactions at different levels of processing (e.g., cognates, interlingual homophones and homographs, cross-linguistic ortho-phonological neighbors) highly complicates the proposal of a unified account of bilingual lexical access that could be ultimately used to explain bilingual visual word recognition.

Rather, EEG data on the processing of ortho-phonologically similar or dissimilar lexical representations suggest that any integrated theoretical account of bilingual visual word recognition would necessarily require the previous full description of the different time courses associated with the processing of each type of cross-linguistically interacting lexical representations, which would require the conscientious design of well-motivated individual experiments tapping onto the multiple stages yielding lexical access (i.e., orthography, phonology, morphology, semantics). In the second section of this chapter, we summarized the evidence from L1 and L2 sentence reading EEG experiments, trying to elucidate whether native and nonnative syntactic and semantic processing mechanisms partially overlap, or alternatively, whether they are different in essence. As in the case of studies on bilingual single word processing, studies exploring semantic and morphosyntactic processes in a sentence context have revealed that both age of L2 acquisition and proficiency in the nonnative language are crucial in determining the timing of semantic and morphosyntactic processing during sentence reading. EEG data at this regard have consistently shown that the time course associated with syntactic and semantic processing of phrases is highly sensitive to the readers' profiles and that ERP components can vary qualitatively and quantitatively as a function of L2 AoA and proficiency. Finally, in the following section, we present a brief description of a series of good practices that could be used by researchers in this field to effectively use EEG recordings to assess how ortho-phonological, lexical, morphosyntactic and semantic processing varies between the native and the nonnative language in bilinguals. In this section, we will refer to specific aspects related to the design of an experiment, the data acquisition process and the critical stage of data analysis, which will ultimately guide novice researchers in the process of becoming experts in the field.

Best Practices For Running ERP Experiments

ERPs calculated based on raw electroencephalographic data are electric voltage differences between an active electrode and a reference one, usually on the order of few microvolts. This measure provides researchers with a multidimensional dependent measure of brain activity, since ERPs can vary in:

a. *Time*: ERPs have high temporal resolution that is reliable on the order of tens of milliseconds.
b. *Amplitude*: ERP components can be larger or smaller (in terms of voltage differences) when comparing two conditions.
c. *Polarity*: ERPs are positive/negative deflections, as compared to a zero-level baseline.
d. *Scalp topography*: ERPs can differ in their topographical distribution, possibly reflecting the recruitment of different brain substrates.

Experimental designs

The researcher can observe variation of some ERP components on a lot of dimensions (based on the levels of the independent variable). These variations determine the so-called ERP effect that is assumed to reflect different patterns of brain activation in different experimental conditions/groups. Usually, the definition of an ERP effect is not that simple and requires a good knowledge of preceding ERP literature referring to a specific component. Even in this case, however, the experimental design employed in an ERP experiment is critical to interpreting a specific ERP effect. For this reason, it is important to define a simple and robust design, without too many conditions. This is even more important in the case of bilingual experiments, where usually the by-group comparison is mandatory, or at least, highly recommended (e.g., L1 vs. L2 readers). Experimental designs with a large number of manipulations embedded in complex factorial designs typically make the interpretation of the possible emerging interactions highly complicated, and in ERP studies, this becomes even more critical considering the aforementioned multidimensionality of the ERP dependent measure. This is the so-called *explosion of dimensions* that is responsible for the misinterpretation of the results in many ERP studies. Hence, the first rule of thumb in designing an ERP experiment is to design well-motivated, self-explanatory, and robust experimental designs. Keep things simple. The specific ERP effect that the experiment is targeting should always be kept in mind. The experimenter should be able to advance predictions about a specific ERP component based on the available scientific literature. This is a critical issue, since a good set of predictions can considerably ease the interpretation of some specific ERP effects. An *exploratory expedition* without specific and well-motivated predictions is the worst possible approach for a young researcher.

After the definition of a sufficiently powerful and clear experimental design, the researcher has to select a good-enough number of observations to enter in each cell of this experimental design (namely, a sufficient number of items/participants per condition; for an in-depth discussion see also Picton et al., 2000). EEG measures are inherently noisy, since sensors (typically Ag/AgCl electrodes) do not only capture brain activity but also electromagnetic noise originating from both the lab environment and the participant under study. As stated in the introductory part of this chapter, ERPs derive from averaging (time intervals of EEG raw recordings after time-specific events) across multiple repetitions of the same class of stimuli. Through this averaging procedure, what is unrelated to the stimulus (i.e., noise) disappears, while the resulting ERPs would reflect brain reactions that are constant across those repetitions. Thus, before entering the lab for the experimental session, it is important to construct a material set with a high number of observations for each experimental condition, given that the larger the number of repetitions, the larger the amount of noise deleted from the ERP estimation. This is defined by the signal-to-noise ratio (SNR) estimate that reflects the level of desired signal with reference to the level of background noise. It has been demonstrated that the SNR for ERPs becomes higher while increasing the number of observations for a specific event. However, after a certain number of repetitions, the SNR curve reaches a ceiling level and does not increase significantly even if we increase the number of repetitions. The exact number of items per condition depends on the ERP component(s) of interest. As another general rule, we may consider that the earlier a component is, the larger the number of observations we should have. In typical psycholinguistic designs, a good number of items per cell can vary between 50 and 100 (also depending on the available material in the linguistic scenario of interest). It should be kept in mind that a large number of items per experimental condition will be very useful for an optimal evaluation of single-subject’s ERPs. As already mentioned above, individual variability is an important factor in second-language learning studies (e.g., Tanner et al., 2013), and in order to be able to capture this variability, experimental designs must be powerful enough to allow single-subject analysis.

A similar discussion can be applied to the selection of a reasonable number of participants per group. In a typical ERP experiment, for the grand-averaged data (ERPs averaged across multiple participants) the number of participants should not be less than 18-20. Of course, a higher number of participants will lead to a better (statistical) estimation of group-level effects. Nonetheless, experimental goals can differ, since some researchers can be more interested in group-level differences, while others may focus on individual variability. In both cases, we suggest collecting data at least from 30 participants per group, since the group-level estimation will be more (statistically) solid, and there will be more individual variability available to estimate which single-subject parameters (e.g., IQ, working memory span, etc.) reliably modulate an ERP effect of interest.

After the selection of proportionally balanced groups of participants and the identification of a solid set of materials, the experimenter will face the process of selecting both the on-line and the off-line technical parameters related to EEG acquisition. In the two following sections we will discuss the *data acquisition* parameters for collecting EEG data and the *data analyses* parameters for extracting reliable ERP results.

Data acquisition

Data acquisition mainly refers to the technical parameters we use for running an ERP experiment. The overall rule in this section is to acquire as much data as possible. However, how much data does it make sense to acquire? Currently, many EEG systems come with caps in which a pre-defined number of electrodes (typically 19, 32, 64, 96 or 128) are fixed to constitute a standardized pattern often referred to as the 10-20 or 10-10 systems (Picton et al., 2000). The selection of the number of electrodes to use has to be done considering that the larger the number of electrodes, the longer it will take us to mount the EEG cap for each participant before starting the experiment. In some experiments, it is worth using a higher number of electrodes since we aim to determine with great detail the scalp distribution of a specific ERP component. With a high-density array of electrodes (greater than 64) it will be possible to perform source analyses for a specific ERP deflection (keep in mind though that reliable source reconstruction also requires a detailed 3D model of the anatomy of the participants' head). Otherwise, in typical cognitive neuroscience studies, a smaller number of electrodes (less than 64) is sufficient to obtain good ERP data. This is due to the fact that electric dipoles (the ones determining the familiar ERP deflections) do not have high spatial resolution when recorded over the scalp, and can be measured over multiple electrodes. In summary, it should be kept in mind that by increasing the number of electrodes, we will not increase our sensitivity in the estimation of an ERP component.

One of the most important choices is the selection of the right position for the reference. In many studies, the best solution is to select the left mastoid as the on-line reference (to which all the scalp electrodes will refer; see Molinaro et al., 2011, for a discussion of how ERP effects can depend on the reference choice). This solution is considered as the "standard", even if there is no counterargument in selecting alternative positions such as the right mastoid, the vertex electrode (Cz), or the tip of the nose. It is convenient in all cases to also record activity over the two mastoids to operate an off-line re-reference of the data. This is the standard solution used in many studies on language processing, and it is important to use it for cross-study comparisons. On the other hand, using both mastoids as a reference (linked-mastoid solution) is not optimal (see Picton et al., 2000).

Finally, we will discuss the importance of a correct selection of the amplifier settings. These last technical parameters are crucial since this is one of the crucial steps in which there is no way back once we have made a choice. Two critical parameters are of special interest: the sampling rate and the on-line filters. As for the sampling rate (i.e., the number of points per second characterizing the voltage signal) the value should be larger than 250 Hz (250 points per second). This value also determines the temporal resolution at which you can estimate an ERP effect (in the 250 Hz case the resolution is of 1 data point every 4 ms). Our suggestion is to record the EEG signal at 500Hz-1kHz, since modern computers have enough memory resources to process such data. Having a high sampling rate is not too critical for

ERP analyses (where the “real” temporal resolution for estimating a cognitive process is various tens of milliseconds). However, more sophisticated analyses can require a lot of data points (time-frequency decomposition for example, see below) to provide reliable information in short time periods. Using a low sampling rate will preclude us from reanalyzing ERP data with more sophisticated techniques.

EEG are made up of multiple signals overlapping at multiple frequencies (Hz, number of cycles per second for an oscillatory signal). In principle, ERP data mainly reflect brain activity in the EEG frequency range up to 30-40 Hz. Usually, this frequency limit is applied to “clean” the signal when it is too noisy and to provide smooth waveforms. It should be noted, however, that neural activity can oscillate at very high frequencies (intracranial recordings can measure activity at 200 Hz, the so-called “ripples”). Currently, sophisticated methods of EEG analyses have identified significant cognitive activity around ~100 Hz (upper values for gamma activity). For this reason, amplifiers are usually set to record activity from very low frequencies (0.01 Hz, oscillatory activity that correlates with the functional magnetic resonance imaging (fMRI) BOLD signal, Hipp et al., 2012) to very high ones (400-500 Hz). Again, this wide frequency range captures much more than what a researcher would need for a regular ERP study, but it should be kept in mind that such recordings may be extremely useful in the near future if one aims toward approaching a set of data from multiple perspectives.

Finally, it is worth mentioning that data acquisition should be performed trying to keep all the electrode impedance values below 5-10 kOhm (indicating good electric contact between the electrodes and the scalp), and the experimental participant should be invited to stay quiet and relaxed during the recording session. A good acquisition session always implies less work during the following stages of data analysis. For this reason, the experimenter should be responsible for reducing the amount of non-electrophysiological activity in the EEG recordings.

Data analyses

After data acquisition, the skeleton of a typical ERP analysis usually follows a few fixed steps with a not-too-flexible order: re-referencing, filtering, epoching, baseline correction, artifact evaluation, and average. This order can be changed, but some steps are a prerequisite for others, and this notion should always be kept in mind.

The process of re-referencing is critical to establish the reference electrode/s for all the active electrodes. Usually, in language experiments, there is the tendency to select a “balanced” reference (e.g., the algebraic average of the activity recorded from the two mastoids). In some cases, when the number of electrodes is high enough (greater than 64) an average reference can be computed reflecting an imaginary electrode that corresponds to the average activity of all electrodes. This location-independent solution represents a good alternative to other methods, but it can be biased by a few electrodes with high amplitudes when the number of sensors is too low.

As discussed above, ERP activity is usually measured in the frequency bands between 0.1 and 30Hz. These frequencies are the ones with the most power and, for this reason, survive the averaging procedure. The selection of the lower threshold is critical and should not be too high, especially when analyzing long-lasting ERP components (with an overall estimated oscillation cycle of 1 sec). In those cases, a high-pass filter slightly higher than 0.5 Hz is capable of washing out such components. This is due to the fact that filters do not usually cut exactly at the indicated frequency, but they can reduce the power in a larger frequency window. For instance, a 0.5Hz high-pass filter can reduce at 50% the power of frequencies up to 2Hz.

The selection of the time interval of interest should consist of (i) a brief interval preceding the target event in which no difference between two experimental conditions is expected, and (ii) an interval after the target event that should be long enough for a good (visual and statistical) estimation of the modulation of the specific ERP component(s). In principle, the interval preceding the event (i.e., the baseline) should reflect no brain activity whatsoever. However, in many experiments, it is possible that some activity is going on before the presentation of a target stimulus (for example, in sentence processing experiments). In those cases, it should be explicitly stated why the activity in the pre-stimulus interval should not differ between conditions.

The baseline correction procedure tries to bring to the zero-voltage level the activity before the event that we just discussed. Usually, the baseline activity is subtracted (or divided) from the post-stimulus whole epoch. As previously indicated, there are many assumptions behind this procedure. For example, it is assumed that before stimulation there is no activity in the brain, but this is highly unlikely. Our brain is always working, and even if this pre-stimulus activity can be of no interest for the researcher, he/she should be aware of possible (expectation) effects originating before the presentation of a stimulus that can affect post-stimulus activity.

"Cleaning" the EEG signal from artifacts (eye-movements and muscular activity in particular) is also a crucial step. In fact, ERPs are averages of activity across multiple segments of an EEG recording, and it is well known that algebraic means can be largely biased by outliers, so that it is possible to observe effects in the ERP waveforms that can reflect some residual artifactual activity (especially when some artifacts, like blinks, can be orders of magnitude larger than the brain activity of interest). The most common way to deal with an artifact is to remove the epochs containing it by visually inspecting all the epochs for each participant. This can be a lengthy procedure, but certainly it is the most reliable one. (Note that there is no computer algorithm as good at recognizing artifacts as the human eye/brain). Some automatic and semi-automatic procedures are available to reject "bad" epochs. These procedures provide good approximations for the ERP extraction but they are not perfect.

A different approach aims at "correcting" artifacts instead of at deleting them (consequently saving a higher number of epochs for the analysis). The most efficient approach employs Independent Component Analysis (ICA) to detect components reflecting eye-movements, and to regress them from the EEG signal (Delorme & Makeig, 2004). However, this procedure is not risk-free, since the critical activity of interest can be involuntarily removed from the data. Our suggestion is to employ correction procedures only in cases in which it is really necessary, and for the whole dataset (i.e., for all participants). In fact, these procedures alter the reality of the signal and should be used only as a last resort, and always supervised by some expert's eyes.

The last step of the analysis involves the averaging stage. After averaging across multiple epochs and grand-averaging across participants, the ERP waveforms will be available for visual inspection and statistical evaluation. By-item analyses are not very common in the ERP literature, although they can be really interesting in some cases (DeLong et al., 2005; Molinaro et al., 2012). We highly recommend that researchers consider this option, given its high informative value.

As already mentioned, single-subject averages are the main basis for statistical analyses. In general, two types of information can be employed to quantify some components. For some long-lasting ERP components the averaged amplitude from a specific time interval of interest can be extracted across all electrodes. This can be done for ERP components with a duration of more than 200 ms (such as, for example, the N400; Kutas & Hillyard, 1980). A different approach is typically used for the estimation of earlier, more "peaky" and short-lasting components. In these cases the maximum value in a time interval (i.e., the amplitude of the peak expressed in microVolts) and the latency of that data point (in milliseconds) is extracted for each individual participant. This approach is critical in experiments exploring early components, since it can handle cross-individual variability in the latency of the peaks relatively well.

Recently, alternative types of analyses that aim at decomposing the EEG signal across time in different frequency components are being explored and used (e.g., Davidson & Indefrey, 2007; Molinaro et al., 2013; Pérez et al., 2012; for review, see Bastiaansen & Hagoort, 2006). As indicated above, EEG represents the summation of different signal at different frequencies, and there is a family of methods (i.e., Hanning window, Multitapers, Wavelets) that can be employed to estimate the power of each specific frequency component across time. Usually, the accuracy of the time-frequency estimation depends on a large number of data points, specifically for high frequencies (such as gamma activity). Such decomposition of the EEG signal can be very useful in obtaining a detailed view of how different brain processes operate in parallel at different frequencies. At the same time, however, this type of analysis provides the researcher with another dimension or dependent factor that can increase the complexity of the data being analyzed. Hence, the researcher should carefully consider the general picture obtained from the different types of analysis, since the risk of interpreting some false positives is considerably high. In addition, the literature in this regard is not voluminous, since there are consistent scientific reports using time-frequency analyses only from the mid-90s, while ERPs have been used for almost half a century. Furthermore, the methods of analysis of the time-frequency domain are still under development. For these reasons, the researcher should strongly rely on his/her experimental hypothesis to interpret the data while keeping constantly in touch with the rich and active EEG world-wide community. Besides, the researcher should be aware of the existence of a large body of literature on methodological and practical aspects of EEG, and he/she should consider that a correct stepwise approach to the electrophysiology of the bilingual brain should start with a comprehensive reading and understanding of basic aspects of this technique that have been already compiled by experts in the field (e.g., Handy, 2009; Luck, 2005; Luck & Kappenman, 2012).

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List of Keywords

Age of acquisition (AoA), Balanced bilinguals, Bilingual Interactive Activation Model (BIA), Bilingual word recognition, Code-switching cost, Cognate facilitation effect, Conceptual level, Critical period hypothesis, Cross-language neighbors, Cross-language repetition, Electroencephalography (EEG), Event related potentials (ERPs), Forward translation, Function word processing, Generalized lexical decision task, Inhibitory Control Model (IC), Inhibitory effect, Integration processes, Interference effects,

Interlingual homograph, Interlingual homophones, Interlingual orthographic neighbors, Irregular words, Language non-selective activation, Language-independent lexical activation, Late bilinguals, Late Positive Component (LPC), Letter-length judgment task, Lexical access, Lexical competition, Lexical search, Lexical selection, Masked translation priming paradigm, Morphology, Morphosyntactic processing, Multiple priming paradigm, N400, Non-balanced bilinguals, Orthographic neighbors, P600, Phonological cognates, Phonological level, Pre-lexical, Revised Hierarchical Model (RHM), Semantic Categorization task, Semantic Categorization task, Semantic integration, Semantic priming effects, Semantic processing, Semantic representations, Simultaneous bilinguals, Syntactic integration, Syntactic processing, Translation recognition task, Visual word recognition, Whole-word form representation, Word frequency, Word processing, World knowledge

Thought Questions

- How do single ortho-phonological and lexico-semantic brain networks process different scripts?
- What's the time course of lexical processing in bilinguals with varying degrees of AoA and proficiency in the second language?
- Which is/are the electrophysiological marker/markers of bilingual lexical access?
- What are the temporal dynamics of syntactic processing of typologically different vs. similar languages?
- What's the oscillatory pattern associated with nonnative language processing?

Suggested Student Research Projects

- Use EEG time-frequency information from word or sentence processing to predict whether individuals are native or nonnative speakers of a given language.
- Create an EEG database of bilingual single word reading using representative words from the language and a high number of participant's electroencephalographic responses.
- Study the time course of language switching using different explicit and implicit paradigms and EEG recordings.
- Explore the time course of bilingual syntactic processing by co-registering EEG activity and eye-movements.

Related Internet Sites

- http://www.bangor.ac.uk/bilingualism/
- http://www.bcbl.eu/
- http://www.bilingualism-matters.org.uk/
- http://blri.weebly.com/
- http://kutaslab.ucsd.edu/
- http://www.neurocoglaboratory.org/

Suggested Further Readings

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