The neurocognition of switching between languages: A review of electrophysiological studies

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Abstract

The seemingly effortless switching between languages and the merging of two languages into a coherent utterance is a hallmark of bilingual language processing, and reveals the flexibility of human speech and skilled cognitive control. That skill appears to be available not only to speakers when they produce language-switched utterances, but also to listeners and readers when presented with mixed language information. In this chapter, we review electrophysiological studies in which Event-Related Potentials (ERPs) are derived from recordings of brain activity to examine the neurocognitive aspects of comprehending and producing mixed language. Topics we discuss include the time course of brain activity associated with language switching between single stimuli and language switching of words embedded in a meaningful sentence context. The majority of ERP studies report that switching between languages incurs neurocognitive costs, but –more interestingly- ERP patterns differ as a function of L2 proficiency and the amount of daily experience with language switching, the direction of switching (switching into L2 is typically associated with higher switching costs than switching into L1), the type of language switching task, and the predictability of the language switch. Finally, we outline some future directions for this relatively new approach to the study of language switching.

The neurocognition of switching between languages: A review of electrophysiological studies

When bilinguals talk amongst one another they frequently use two languages within the same utterance. Listeners who overhear a conversation in which bilinguals switch between languages are often impressed by this seemingly effortless switching of languages. The merging of two languages into a coherent utterance not only reveals the flexibility of human speech, but also demonstrates highly skilled cognitive control. Importantly, such skills appear to be available not only to speakers when they produce language-switched utterances but also to listeners and readers when presented with mixed language information.

Recent behavioral experimental studies on the cognitive mechanisms of language switching provide more insight into the co-activation and interaction across the bilinguals' two languages, the processing costs associated with switching between languages, and how bilinguals resolve competition between different cognitive systems (for reviews, see e.g., Meuter 2005; Meuter this volume). In the past decade, researchers have also begun to study language switching from a neurocognitive perspective. Multiple approaches are used but in this chapter, our main focus is on studies that examined language switching using one particular neurocognitive method, namely the recording of Event-Related Potentials (ERPs; for recent reviews of studies of language switching using neuroimaging methods, e.g., functional magnetic resonance imaging (fMRI) or positron emission tomography (PET), see Abutalebi & Green 2007; 2008; for a critical review on neuroimaging techniques in research on bilingualism, see de Bot 2008). As we will discuss, an important advantage of the ERP technique is its high temporal resolution that enables a study of task-related neural activity at millisecond precision.

Like the behavioral experimental studies, these ERP studies examine language switching in bilinguals who perform language switching tasks in an experimental situation. The focus in this chapter therefore is on controlled, task-induced language switches in production or comprehension tasks in a bilingual experimental setting, and not on spontaneous language switches as they occur in natural discourse situations (See, e.g., Jake & Myers-Scotton, this volume, for analyses of code-switches in natural discourse, and Kootstra, van Hell, & Dijkstra, this volume, for a novel approach to study language switches during discourse in a controlled laboratory setting.) We do think it is important that experimental (behavioral and ERP) studies try to model language switching as it occurs in natural situations, a point we return to at the end of our chapter.

Throughout this chapter, we use the term *language switching* to denote any switching between languages, in comprehension and in production. For the purposes of our discussion, language switching thus encompasses the switching of languages between single, unconnected items (e.g., words, numbers) as well as the switching of languages between words or phrases embedded in a meaningful sentence or discourse context. The latter type of switching is often referred to as code-switching (see Introductory chapter, this volume).

We review ERP studies that examined the production and perception of the switching of languages within a series of single items (pictures, numbers, or words) and of words embedded in a meaningful sentence. We specifically focus on studies that examined language switching in bilinguals. See van Hell and Tokowicz (in press) for a review of studies that examined bilinguals' sentence processing in L1 or in L2. Questions we seek to address include the following: What do ERP studies tell us about the time course of brain activity associated with switching between languages? Does switching between languages incur neurocognitive costs comparable to behavioral switching costs? What are the neural correlates of cognitive control and inhibition involved in language switching? Before reviewing the empirical studies on language switching, we discuss the basics of the ERP technique in language research and its application to furthering our understanding of language switching.

Basic principles and applications of ERPs in language research

Electrodes placed in key positions on the scalp can measure variations in electrical activity produced by large populations of brain cells. The recording of voltage variations over time is called the Electroencephalogram (EEG). ERPs are derived from the large amplitude EEG through a filtering process, and reflect regularities in electrical brain activity that are time-locked to an external event (see, e.g., Fabiani, Gratton, & Coles 2000; Handy 2005; Kutas, Federmeier, Couson, King, & Muente 2000; Luck 2005, for excellent introductions to ERP recordings and analyses). For example, when a stimulus word is presented to a reader on a computer screen, there are small voltage changes in the EEG that are time-locked to the onset of the presentation of that word. These voltage changes make up the ERP signal and reflect brain activity that is related to the presentation and processing of that particular word. ERPs thus provide an on-line, millisecond-by-millisecond record of the brain's electrical activity during mental processing. ERPs therefore can be used to index ongoing language-related perceptual and cognitive processes as they unfold over time.

An ERP signal consists of a series of positive and negative peaks (known as *components*) related to stimulus processing. Exogenous components occur early in the ERP signal (within 100 ms of stimulus onset) and are evoked by the physical properties of the stimulus (e.g., its color or brightness). In contrast, endogenous components reflect cognitive aspects of processing and are therefore most relevant for studies on neural activation associated with language processing. Endogenous components occur later in the ERP signal (at least 100 ms post stimulus onset).

ERP components are characterized by polarity, latency, amplitude, topographic scalp distribution, and a functional description of the cognitive processes they are assumed to index. An ERP component has either a positive polarity (positive-going wave, labeled by P), or a negative polarity (negative-going wave, labeled by N). Latency reflects the time course of the ERP signal and comprises onset latency (the time at which a component begins), rise time (the time it takes to go from a low value to a high value), peak latency (the time at which a component reaches its peak amplitude), and duration (the length of the component). Components are often labeled according to their polarity and peak amplitude latency (e.g., N400 is a negative-going wave with a peak amplitude occurring around 400 ms post-stimulus onset). A component's relative peak amplitude is assumed to reflect the degree of engagement of the associated cognitive processes. For example, the amplitude of the N400 decreases as the semantic relation between a word and the sentence in which it is embedded increases (e.g., Kutas & Federmeier 2000). ERP components further have a characteristic topographical scalp distribution. Although scalp distribution alone does not indicate the location of the neural generator in the brain, comparing distributional information across experimental conditions and across studies can provide important insights. Moreover, two components that are similar in polarity and latency but that differ in terms of scalp distribution (e.g., the N400 and Left Anterior Negativity, LAN) are assumed to reflect different cognitive processes. Accordingly, ERP components are described also in terms of the cognitive processes they are assumed to reflect and the experimental manipulation to which they are assumed to be sensitive.

The main ERP components that are reported in the ERP studies on language switching are the N2 and the N400 components, and the Late Positivity Complex (LPC; also known as P600). As its name suggests, the N2 is a negative-going potential. It develops around 200 ms after stimulus onset, and is distributed mainly over fronto-central electrode sites. The fronto-central N2 is elicited on tasks in which a response needs to be withheld and tasks that require response and strategic monitoring (for a recent review, see Folstein & Van Petten 2008), and is therefore believe to index cognitive control. The N2 also is usually enhanced in trials containing conflicting information and requiring an unexpected response. Gajewski, Stoerig, and Falkenstein (2008) suggest that the N2 is related to response selection, i.e., the cognitive process of assigning a specific response to a specific response category. The selection process is intensified and prolonged in conflict-trials that demand revision of the prepared response plan. Based on neuroimaging studies that indicate that the anterior cingulate cortex (ACC) is involved in response conflict monitoring (see for a review, Botvinick, Cohen, & Carter 2004) and in response selection (e.g., Roelofs, van Turennout, & Coles 2006; Turken & Swick 1999), it is probable that the fronto-central N2 probably originates from the ACC.

The aforementioned N400 is a large-amplitude negative-going wave in the 300-500 ms latency range. It reaches its peak amplitude around 400 ms after stimulus onset, and is usually largest over central and parietal electrode sites. The N400 indexes the integration of meaning and world knowledge (e.g., Hagoort, Hald, Bastiaansen, & Petersson 2004; Kutas & Federmeier 2000; Kutas & Hillyard 1980). It is enhanced, for example, when there is a semantic incongruency (e.g., Kutas & Hillyard 1980) or when words are difficult to integrate into a given linguistic context (e.g., van Petten, Coulson, Rubin, Plante, & Parks 1999).

The LPC (or P600) is a positive-going wave that appears slightly after the N400 time window and extends for several hundred milliseconds. It typically has a broad posterior scalp distribution and, like the N400, is largest over centro-parietal scalp regions. The LPC is believed to reflect sentence-level integration (e.g., Kaan, Harris, Gibson, & Holcomb 2000) or re-analysis (e.g., Friederici 1995), sentence-level restructuring related to executive control (Kolk & Chwilla 2007), and memory retrieval processes (e.g., Paller & Kutas 1992). Late positivities are also associated with the processing of an unexpected or improbable task-relevant event (e.g., Coulson, King, & Kutas 1998; McCallum, Farmer, & Pocock 1984), or with a reconfiguration of stimulus-response mapping (e.g., Moreno, Rodriquez-Fornells, & Laine 2008). The LPC thus appears to reflect more explicit sentence-level wrap-up or meaning revision processes that, in the case of language switching, could be interpreted as the integration or active preparation of a language switch.

This brief overview of the ERP components believed to reflect cognitive processes central to language processing begs the question of what the ERP technique can contribute to the study of language switching. Corpus studies of code-switched utterances provide valuable information on the structural aspects of switching between languages and factors in the sociolinguistic context that potentially affect code-switching (see, e.g., Backus, this volume). Cognitive, behavioral studies on language switching provide important information on the cognitive processes associated with language switching (see, e.g., Marian, this volume; Meuter, this volume). However, by the very nature of the measures that are used, behavioral studies typically measure the end-state of the process, e.g., the moment a language-switched word can be named. Because ERPs provide an on-line, millisecond-by-millisecond record of the brain's activity during cognitive processing, they provide valuable information on the timing and degree of neural activation as language processing unfolds in real time. ERPs therefore are particularly helpful in providing insight into the temporal dynamics of sub-processes associated with language switching, processes that drive and determine the behavioral response but occur before it is realized. Additionally, ERPs can provide further insight into the nature of the cognitive costs typically experienced when switching between languages.

Review of ERP studies of language switching

This review of studies using ERPs to examine bilinguals' switching between languages is divided into two parts. In the first part, we discuss studies that focus on the switching of languages when reading or naming a series of unconnected single items (e.g., pictures, numbers, or words). Of the studies that examined language switching from a cognitive experimental point of view, bilinguals' switching between single items has received most empirical attention in the literature. We therefore first discuss some classical reaction time (RT) studies and the major theoretical interpretations, and then proceed with a more extensive review of ERP studies using this same experimental paradigm. In the second part, we review the (few) studies that examined language switching of words embedded in interconnected discourse, a linguistic context that more closely resembles the context of study of linguistic approaches to language switching (or code-switching). Table 1 presents an overview of the studies we discuss, listing the language switching tasks, the type of bilinguals that were examined, and the main findings.

Insert Table 1 about here

Language switching with single stimuli: Behavioral evidence

Although language switching is often perceived by bilinguals as requiring little or no cognitive effort, experimental studies indicate that there is a measurable cost associated with switching between languages, in both production and perception (e.g., Costa & Santesteban 2004; Kolers 1966; Li 1996; MacNamara & Kushnir 1971; Meuter & Allport 1999; Soares & Grosjean 1984; Thomas & Allport 2000). Particularly in the past decade, numerous studies have examined how bilinguals switch between series of single numbers, pictures, or words, in order to gain more insight into the mechanisms of lexical selection and cognitive control of languages (for reviews, see, e.g., Meuter 2005; this volume).

In a typical language-switching experiment, bilingual speakers read aloud a series of words alternately presented in their first language (L1) or in their second language (L2), or are asked to name pictures or numbers in their L1 or L2 depending on a particular cue (e.g., the color of the item). In RT studies, the language switching cost is defined as the latency difference between switch trials (in which the language of response changed from that used on the previous trial) and non-switch trials.

In a classical behavioral study, Meuter and Allport (1999) examined language switching in bilinguals with English as their L1 or L2, and either French, German, Italian, Portuguese, or Spanish as the other language. Participants judged themselves to be reasonably proficient in L2. The bilinguals had to name single digits presented against a colored background, with the color cueing the response language (either L1 or L2). Language switches could thus occur from L1 into L2, or vice versa, and were unpredictable (p[switch] = 0.3). The results showed that response latencies on the switch trials were slower than on the non-switch trials. Importantly, the language-switching cost was larger when switching from the weaker L2 into the dominant L1 than vice versa. This effect is referred to as the asymmetrical language-switching cost, and has inspired a wealth of further research. Meuter and Allport (1999) explain their results in terms of the Task Set Inertia interpretation of task-switching. For language production in L2, active suppression of the competing L1 is needed. This active inhibition of L1 may persist involuntarily into the processing of the stimulus for the next trial. When in the next trial a response must be made in L1, this inertia results in a large switch cost. In contrast, for language production in L1, little suppression of the competitor language L2 is needed, and switching into L2 on a subsequent trial does not incur a strong cost. When bilingual speakers are about equally proficient in L1 and L2, language switching costs should be virtually identical, which has indeed been reported (Costa & Santesteban 2004; Meuter and Allport 1999).

Consistent with the notion that on producing a response in one language alternative responses in the nontarget language are deactivated is Green’s (1998) Inhibitory Control (IC) Model. The IC model proposes that language task schemas, part of a general language control system that is external to the bilingual lexico-semantic system, control language actions (e.g., to name a picture in L1 or in L2). The language task schemas either inhibit or activate lemmas in the lexico-semantic system, tagged for language-specific information. In order to speak in one language, all active lemmas whose language tags do not correspond to the intended language must be inhibited. For example, if the bilingual wants to speak in the weaker L2, the L2 task schema has to suppress the L1 task schema and must inhibit the L1 lemmas in the lexico-semantic system.

How does the IC model explain language switching, and the asymmetrical language-switching cost? When the speaker switches into the other language, the task schema that is currently active has to be suppressed and the previously inhibited task schema has to be reactivated, which results in a language-switching cost. Asymmetrical switching costs stem from differences in the relative strength of the bilinguals' two languages. Because the L1 is typically stronger and more active than L2, naming in the weaker language L2 requires an active suppression or inhibition of the stronger competitor L1. As L1 is more strongly inhibited and thus requires more time to be reactivated, switching from L2 to L1 is more effortful than vice versa. See for alternative accounts, Finkbeiner, Almeida, Janssen, and Caramazza (2006) and Verhoef (2008).

Meuter and Allport's (1999) study inspired many researchers to further investigate language switching and asymmetrical switching cost, focusing on topics like the role of the relative strength of the switched languages (by varying language fluency in up to four different languages; e.g., Costa and Santesteban 2004; Costa, Santesteban, & Ivanova 2006; Meuter this volume; Philipp, Gade, & Koch 2007), script differences between the switched languages (e.g., Orfanidou & Sumner 2005), or the bilinguals' language learning history and level of proficiency (e.g., Costa and Santesteban 2004). See Meuter (this volume) and Kroll, Bobb, Misra, and Guo (2008) for an overview.

The (few) ERP studies that examined language switching within this paradigm focused on the following questions: What are the neural correlates associated with language switching from L1 (typically the dominant language) into L2 (typically the weaker language), and vice versa? Specifically, how is the asymmetry, observed when switching between languages mastered at varying levels of proficiency, indexed by the distributions and relative amplitudes of ERP components and, if differences are observed, what do they reveal about the cognitive processes believed to underlie language switching? Also, what is the time course of switching between languages?

Language switching with single stimuli: Review of ERP evidence

In ERP studies, switching cost denotes a modulation of an ERP component in response to switch trials compared to non-switch trials. Two ERP studies examined language switching with single stimuli using a production task: digit naming (Jackson, Swainson, Cunnington, & Jackson 2001) and picture naming (Christoffels, Firk, & Schiller 2007; see Table 1). Jackson, Swainson, Cunnington, and Jackson (2001) studied language-switching costs in bilinguals whose native language was English but who spoke either French, German, Spanish, Mandarin, or Urdu as the second language (see Table 1 for more details). Most bilinguals had learned L2 between 13-18 years, some during infancy and some as adults. Self-ratings of L2 proficiency indicated that they were moderately proficient in their L2. In a speeded digit naming task, the bilinguals were presented with single colored digits and had to name each digit in the language cued by the color. The authors used a delayed naming procedure, in which they asked participants to delay their naming response until the digit disappeared from the screen. The series of switch and non-switch trials followed a fully predictable sequence, with two consecutive trials in each language and a language switch on every second trial (a variation of the alternating runs paradigm; Rogers & Monsell 1995).

The response latencies showed a switching cost: Bilinguals were slower in naming digits on switch trials than on non-switch trials. The switching cost was larger for L1 than for L2, but Jackson et al. (2001) did not observe the cross-over interaction as had been obtained by Meuter and Allport (1999). The bilinguals' ERP patterns showed a language switching related modulation of three components assumed to reflect distinct cognitive processes in the course of executing the digit naming language switching task. The ERP responses showed an enhanced early left fronto-central negativity (N50) for switch trials compared to non-switch trials. This early N50 effect likely reflects the detection of a physical change in the visual stimulus: On switch trials, but not non-switch trials, the color of the digit changed from that on the previous trial. The N50 effect is thus not directly related to cognitive processes related to language switching. The ERP responses further showed an enhanced left fronto-central negativity starting at 320 ms after stimulus onset (N320) for switch trials compared to non-switch trials, but this effect was found only when switching from L1 into L2 and not when they switched from L2 into L1. Jackson et al. (2001) interpret this negativity as a frontal N2, a component that in the visual Go/No-Go paradigm is associated with the decision to suppress a response on the No-Go trial (e.g., Konishi et al. 1999; in a Go/No-Go task participants are required to respond to one type of stimulus while withholding the response to another type of stimulus). Recently, however, the N2 has also been associated with response conflict monitoring (e.g., Folstein & Van Petten 2008; Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof 2003). Jackson et al. (2001) propose that switching into L2 requires the active suppression of L1, and that language switching involves frontal brain regions. Since the bilinguals were more proficient in their L1 than in their L2, inhibitory processes may be stronger when switching into L1 than vice versa, in line with the inhibition assumption of Green's (1998) Inhibitory Control Model. Finally, for switch trials (compared to non-switch trials) a sustained increase in the magnitude of the Late Positivity Complex (LPC) was observed between 385 ms and 700 ms after stimulus onset at the parietal sites. This LPC effect was not modulated by switch direction. Jackson et al. propose that this enhanced late positivity (LPC) associated with switch trials signifies executive control of response selection, as this same component has also been observed in a Stroop interference task (Liotti, Woldorf, Perez, & Mayberg 2000).

Christoffels, Firk, and Schiller (2007) also examined language control in a language switching production task (see Table 1). They tested native speakers of German who had studied in the Netherlands for at least 2.7 years, and were moderately fluent speakers of Dutch, as indicated by their mean score on a Dutch lexical decision test and self-ratings of proficiency. Participants were asked to name 48 pictures in German or Dutch (which is a larger set than the single digits used by Jackson et al. 2001). The color of the picture signaled the response language. Here, unlike Jackson et al. (2001) but similar to Meuter and Allport's (1999) original design, the switch trials occurred unpredictably. To examine whether variation in form overlap between translation equivalents modulated ERP patterns of language switching, the pictures to be named were either cognates between German and Dutch (words that are similar in form and meaning, e.g., 'Apfel-appel' [apple]) or non-cognates (e.g., 'Teller'-'bord' [plate]).

The ERP data showed an enhanced fronto-central negativity between 275-375 ms (N2) and between 375-475 ms for non-switch trials compared to switch trials, but this effect was found only for switching from L2 into L1, and not vice versa. Thus

Christoffels et al.'s speakers' ERPs showed a switching benefit and not the switching cost observed by Jackson et al. (2001). The behavioral data yielded the typical switching cost pattern in that naming latencies for switch trials were longer than for non-switch trials. However, the switching costs in both directions were similar. In addition, the language switching effects were not markedly different for cognate and non-cognate pictures.

How can these contrasting findings be accounted for? Jackson et al. interpret their data in terms of response inhibition of L1 when switching to L2, but this same mechanism cannot account for the switching benefits Christoffels et al. (2007) observed for switches into L1. Christoffels et al. instead propose that bilinguals do not rely on response inhibition on every single trial but, in mixed language situations such as those induced by the language-switching task, may reduce the level of activation of L1 to facilitate language production in L2 (see also Meuter 2005). As a consequence, a mixed language context has a profound impact on L1 production but hardly on L2 production.

It should be noted, however, that the divergent results of Jackson et al. (2001) and Christoffels et al. (2007) simply may be related to major differences in the design and procedures of the two studies. For example, in Jackson et al. (2001), participants could fully predict the occurrence of the language switches and it is known that the predictability of responses potentially modulates the N2 component (see, e.g., Folstein & Van Petten 2008). Moreover, participants in the Jackson et al. study named a restricted set of single digits, whereas Christoffels et al. used a much larger set of pictures. In neither study were the bilinguals highly proficient in their L2 but those tested by Jackson et al. were highly heterogeneous in terms of the type of L2 and the age of first exposure to the L2. Furthermore, Jackson et al., but not Christoffels et al., used a delayed naming procedure. While such a delayed response procedure prevents EEG recordings from being contaminated by motor artifacts (see, e.g., Krause, Lang, Laine, Kuusisto, & Pörn 1996), withholding a naming response may invite response inhibition processes that potentially modulate the ERPs and that may interact with processes of language control and language switching. Moreover, the fronto-central N2 component has multiple functional correlates (see Folstein & Van Petten, 2008), including response conflict and response selection.

In a recent study, Verhoef (2008) noted that in the studies of Jackson et al. (2001) and Christoffels et al. (2007) the color of the digit and picture indicated in which language the bilingual had to respond, and argues that this results in a confound of endogenous and exogenous control. Building on the task-switch literature (e.g., Rogers & Monsell 1995), Verhoef distinguishes two types of attentional control related to language switching: endogenous and exogenous control. Endogenous control is a top-down, intentional, voluntary process that is driven by a person's internal goals, intentions, or expectancies. Exogenous control is a bottom-up, automatic, involuntary process triggered by an external stimulus. Using the cue-stimulus paradigm in a language switching study, Verhoef recorded cue-locked ERPs to separate endogenous control processes from exogenous control processes (See Table 1). Dutch-English bilinguals were first presented with a language precue, which after 750 ms was followed by a target picture that had to be named. The response language on consecutive trials could be the same (non-switch trials) or different (switch trials). The reaction time analyses showed longer naming latencies on switch trials than on non-switch trials, in the two switching directions. So, the symmetrical switching costs observed in balanced bilinguals (Costa & Santesteban 2004) can also be obtained in unbalanced bilinguals when given sufficient time to prepare for a language switch (and to allow optimal endogenous control). The cue-locked ERPs showed an enhanced early posterior negativity (200-350 ms window) for switch trials compared to non-switch trials on the L2 trials, but not on the L1 trials. This was followed by an enhanced late anterior negativity (350-500 ms window) for switch trials compared to non-switch trials for both languages. Verhoef (2008) concludes that this study identified two distinct ERP effects related to endogenous language control: an early switch-related negativity between 200-350 ms (for L2 but not for L1), followed by a later negativity between 350-500 ms (in both directions). She takes these effects to imply that the early switch-nonswitch effect for L2 reflects the bilingual's disengaging from the nontarget L1, while the late frontal switch-nonswitch effect reflects engaging in the target L2. Bilinguals can thus orient their selective attention towards the target language prior to a language switch, and bias their naming performance.

Given the conflicting patterns and accounts, additional research is needed to gain more insight into the neural correlates of switching between single items in a naming task, and possible factors that modulate the ERP patterns. The current ERP studies using naming tasks (Christoffels et al. 2007; Jackson et al. 2001; Verhoef 2008) do warrant the conclusion that language switching engages processes of cognitive control at a very early stage in both digit and picture naming tasks within the language switching paradigm, and in bilingual speakers of different languages and with different language learning backgrounds. Moreover, Jackson et al. (2001) also obtained evidence for a late positivity (LPC).

Jackson et al. (2001) and Christoffels et al. (2007) examined language switching between single words in a naming task. Jackson, Swainson, Mullin, Cunnington, and Jackson (2004), Alvarez, Holcomb, and Grainger (2003), and Chauncey, Grainger, and Holcomb (2008) studied language switching of single words during reading. Jackson et al. (2004) tested native English speakers with French, German, or Spanish as their L2. Age of L2 acquisition ranged from birth to adulthood, and self-ratings of L2 proficiency indicated a moderate level of L2 proficiency. Participants were presented with a series of single number words in L1 and L2 and had to decide whether the number word was odd or even by pressing one of two buttons. In the language-switching condition, language-switches occurred on every second trial and were fully predictable.

The ERP data yielded no language-switch related modulations of the N2 component, nor of the LPC. The behavioral data did show a switching cost in L1, but not in L2. Exploratory analyses in the 150-350 time window yielded an enhanced right temporo-parietal negativity (in both languages) and a decreased left central positivity (in L2 only) for switch trials compared to non-switch trials. Exploratory analyses in the 400-500 ms window yielded an enhanced right anterior frontal negativity for non-switch compared to switch trials that reached significance only for the L1 trials. At this point, without further ERP evidence, these switch-related modulation effects observed in receptive language switching are difficult to relate straightforwardly to models of language switching (see Jackson et al., 2004, for some explanations of their data and suggestions for ERP designs to test these explanations). However, the absence of a clear modulation of the N2 and of the LPC is in contrast to the ERP patterns observed in language switching during speech production, i.e., digit naming (Jackson et al. 2001) and picture naming (Christoffels et al. 2007; Verhoef 2008). Jackson et al. (2004) interpret the absence of the modulation of the N2 and the presence of the similar early switch-related negativity for L1 and L2 as an indication that there is no language-specific lexical selection mechanism for receptive language switching. However, this interpretation is difficult to reconcile with the language-specific early left central positivity that was related to language switching. They further suggest that language switching costs, which they did observe in the behavioral data for L1, arise from outside the lexico-semantic system (e.g., the task schema's in Green's (1998) model).

Jackson et al.'s (2004) absence of language-specific ERP components in response to receptive language switching is not paralleled by the receptive language switching studies of Alvarez, Holcomb, and Grainger (2003) and Chauncey, Grainger, and Holcomb (2008). Alvarez et al. studied switching costs using a semantic categorization task in native speakers of English who were beginning learners of Spanish. Participants rated their proficiency in their L2 substantially lower than their L1, which was confirmed by translation performance tasks. ERP responses were recorded to single words in L1 or L2 (presented in a mixed list) that were preceded on the previous trial by a same-language word (e.g., dog – dog or brazo – brazo) or by its translation (e.g., dog – perro or brazo – arm). Participants had to decide if the word referred to a body part, irrespective of language of presentation, and only if it did they had to press a button (go/no-go semantic categorization task). The results showed that the amplitude of the N400 was modulated by language switching, but only when switching from L1 to L2. This asymmetry disappeared in the later ERP component, the LPC. Specifically, after 500 ms post stimulus onset a negative deflection was observed in both language switching directions.

Like Alvarez et al. (2003), Chauncey, Grainger and Holcomb (2008) also examined language switching on words preceded by another word, but in the Chauncey et al. study the target words were preceded by masked prime words (Experiment 1) or briefly presented prime words (100 ms, Experiment 2). These prime words were unrelated to the target word, and could be in the same or in the different language. Conditions were blocked by language of the target. A go/no-go semantic categorization task was used (as in Alvarez et al. 2003). The participants were native speakers of French who were moderately proficient in English. In both experiments, language-switch related modulations of the N250 and the N400 were obtained. In the 175-300 ms window

(N250), the ERPs on switch trials were more negative-going than the ERPs in the non-switch trials, particularly when switching from L1 to L2. In the 375-550 ms epoch (N400), language-switching effects were also present, in both switch directions, although there were subtle topographic differences for the two switch directions (see Chauncey et al., 2008, for more details).

The language switch effect found in the N250 after only a very brief exposure to a prime in the other language is a remarkable finding. In a given block of trials, and particularly in Experiment 1 in which the primes were masked, participants were only aware of the targets that were presented in the same language. Chauncey et al.'s findings can be seen as evidence for the brain's automatic and unconscious response to language switches in comprehension. The authors propose that the effects arise from the automatic top down modulation of activation of lexical representations, in line with the original Bilingual Interactive Activation (BIA) model (Grainger & Dijkstra 1992). Specifically, prime words in a particular language rapidly activate the corresponding language node, and this language node then inhibits the representation of all words in the irrelevant language. Where prime and target are in different languages, the language node corresponding to the prime thus also inhibits that target word's representation, leading to a language switching cost.

In sum, the data obtained by Chauncey et al. (2008) and Alvarez et al. (2003) suggest that language switching cost in comprehension does not only arise from outside the lexico-semantic system, as suggested by Jackson et al. (2004) to explain the absence of switching-related modulations of early ERP components and the simultaneous presence of such effects in their behavioral data. Rather, it would appear that at least part of the language switching effect in comprehension stems from fast-acting and automatic modulation of lexico-semantic representations.

The five studies reviewed here, all of which examined ERP patterns in response to language switching (of single numbers, pictures, and words), have yielded a rich set of findings. The study of language switching using the ERP technique is still in its early stages, and the findings obtained so far are far from conclusive, as is also the case in the corresponding behavioral studies (see Meuter this volume) and neuroimaging studies (see Abutalebi & Green 2008). These divergent findings may be at least in part related to the substantial methodological differences across the five studies, including variations in the language proficiency and learning history of the bilinguals, whether or not language switch trials were predictable, the experimental set-up, and variations in comprehension and production tasks. The results are promising, however, and the ERP technique successfully reveals the temporal unfolding of neural events associated with the different subprocesses of language switching. One characteristic shared by all the ERP studies reviewed here is that the bilinguals tested were at best only moderately proficient in their L2. The fact that their ERP responses were different for language switch trials compared to non-switch trials suggests that, at an early stage in L2 learning, L2 learners already have developed control processes related to language switching, at least when responding to individual items. In the next section, we review ERP studies that examined language switching of words embedded in meaningful sentences. As we will see, these studies examined bilinguals that were fairly proficient to highly proficient in their L2.

Switching words embedded in context: Review of ERP evidence

Although the switching of words embedded in a sentence context is the more natural and ecologically valid variant of language switching tasks, to date only a few ERP studies have used whole sentences as stimulus materials (Moreno, Federmeier, & Kutas 2002; Proverbio, Leoni, & Zani 2002; see Table 1). Moreno et al. (2002) asked English-Spanish bilinguals to read sentences for comprehension. The bilinguals were native English speakers with rather high proficiency in Spanish as evidenced by their self-ratings and their performance on a vocabulary test. They were presented with English sentences (e.g. 'Each night the campers built a ..') that ended either in the most expected English word (here: 'fire'; non-switch), its Spanish translation ('fuego'; language switch), or a lexically related (and semantically less expected) English word ('blaze'; lexical switch). Half the sentence were normal, moderately constraining sentences, and the other half were idiomatic expressions (e.g., 'Too many cooks spoil the ..' [broth/caldo]). Language switching was always from L1 (English) into L2 (Spanish). The type of sentence-final word was unpredictable, as was therefore the occurrence of a language-switch.

Moreno et al. (2002) argued that, if language switching incurs a cost at the level of lexical access and semantic integration, then the language-switched items should elicit an increased N400 response. On the other hand, if bilingual readers treat a switch of language as a change in form rather than a change in meaning, the language-switched items should elicit an enhanced late positivity (LPC). Moreno et al.'s rationale for the latter prediction is that late positivities are associated with the processing of an unexpected or improbably task-relevant event (e.g., Coulson, King, & Kutas 1998; McCallum, Farmer, & Pocock 1984). The ERP patterns associated with the language switched and non-switched sentences showed that the response to language switches in the 250-450 ms window (N400) was more negative than to non-switches, but this effect was only observed in the regular sentence contexts and not in the idiomatic expressions. These language-switch effects in the regular sentences had a left, frontally skewed distribution, which is not typically observed for N400 effects. The response to language switches was more positive than that to non-switches in the 450-650 ms window (early LPC) and in the 650-850 ms window (late LPC), for both the regular and idiomatic sentences. Subsequent regression analyses to examine individual differences among the bilinguals showed that a higher L2 proficiency level was associated with earlier peak latency and smaller amplitude of the posterior late positivity (450-850 ms) elicited by language switches.

Moreno et al.'s bilinguals' ERP responses to language switched and non-switched words embedded in sentences elicited an increased late positivity, but not an unequivocal modulation of the N400. Moreno et al. propose that a language switch occurring in a sentence may not be more difficult to process at the semantic level than a non-switch (as evidenced by the absence of an enhanced N400). Rather, bilinguals may treat a language switch more as an unexpected event at a non-linguistic level, which supports the hypothesis that costs associated with language switching arise from outside the bilingual lexico-semantic system, and may originate in the competition between task schemas that coordinate the output of the lexico-semantic system with the response task. Furthermore, Moreno et al.'s finding that the peak latency and amplitude of the LPC varied as a function of L2 proficiency suggests that the more proficient L2 speakers noticed the language switch earlier, and found the language switch less unexpected and easier to integrate into the sentence structure.

Highly fluent bilinguals, who frequently use two languages interchangeably were studied by Proverbio et al. (2004): eight professional Italian-English simultaneous interpreters (all polyglots). Of all studies reviewed in this chapter, these bilinguals are the most fluent L2 speakers. They probably had the most experience with switching between languages given that they are professionally trained and specialized to translate from one language into the other (Christoffels & de Groot, 2005). Proverbio et al. presented incomplete sentence frames in Italian or English ('e.g., 'Global market is facing serious'), about 3200 ms later followed by the presentation of the final word that completed the sentence. This final word was presented either in the other language (language switch; here 'problemi') or in the same language (non-switch; 'problems'), and could be semantically congruent or incongruent with the sentence frame. A large number of target words were cognates, but the authors did not manipulate cognate status nor controlled for this factor. Participants were instructed to read the sentences and target words, and to decide whether the final word was a sensible sentence completion. The different sentences and targets conditions were presented in a blocked design, so at the beginning of a block participants knew the language of the sentences and of the target, hence, language switch trials were predictable.

In the ERP analyses, Proverbio et al. focused on the N1 (between 130-200 ms), the N400 (between 300-500 ms), and the LPC, and found switch-related modulations of the N1 and the N400. No switch-related effects on the LPC were observed. At the left hemisphere sites, but not the right hemisphere sites, the N1 was larger to non-switched sentences than to language switched sentences. Also, only in the semantically incongruent condition a language-switch related modulation of the N1 was observed. The ERP analyses also yielded an increased N400 for language switched sentences compared to non-switched sentences. This N400 effect was considerably larger when switching from L1 into L2 than from switching from L2 into L1. Interestingly, this same direction of switching cost was obtained in the analysis of RTs. This pattern is in the opposite direction of the asymmetrical switching cost reported by Meuter and Allport (1999). However, it parallels the findings of Alvarez et al. (2003) and Chauncey et al. (2008). We will get back to this issue later.

Thus even when bilinguals could perfectly predict the occurrence of a language switch, their ERP responses showed an enhanced N400 to language switched trials as compared to non-switch trials, and their behavioral responses showed longer latencies to switch trials. Unlike Moreno et al. (2002), Proverbio et al. (2004) did not find an LPC effect. It is difficult to compare the results of these two studies directly, however, because of considerable differences in the type of bilinguals studied, the predictability of the language switches, and the instructions given to the participants (i.e., reading for comprehension in Moreno et al. versus sensibility judgments in Proverbio et al.). More research is needed to clarify under which conditions language switching modulates ERP components, but the two studies do indicate that the N400 and the LPC are critical components associated with the comprehension of language switched words in meaningful sentence contexts. Note that a modulation of the N400, but not of the LPC, has also been observed in the studies that examined language switching of single words during reading (see Table 1 for an overview).

The materials of Proverbio et al. were rather abstract sentences extracted from European Union meetings, whereas Moreno et al. used simpler concrete sentences and idiomatic expressions. Several behavioral studies showed that bilingual word reading in sentence context is affected by linguistic characteristics of the sentence context, like the semantic constraint of the sentence, i.e., the extent to which the target word can be predicted on the basis of the preceding sentence context (e.g., Schwartz & Kroll 2006; van Hell & de Groot 2008). Moreno et al. and Proverbio et al. do not provide reports on the semantic constraints of the sentence contexts they used, although it is likely that the semantic constraint of Moreno et al.'s idiomatic expressions is much higher than that of the regular sentences. Another factor known to affect bilingual comprehension is the cognate status of words (see e.g., van Hell & Dijkstra 2002). The stimuli listed by Moreno et al. and Proverbio et al. indicate that their stimuli included cognates and non-cognates as critical target words, but this factor was not explicitly manipulated.

Both these factors, i.e., the semantic constraint of the sentences and the cognate status of target words, were controlled in an ERP study by Brenders and colleagues (2004; Brenders, Dijkstra, & van Hell 2005). Although the main focus of this study was on ERP patterns of lexical access in sentence context, a re-analysis of the data proved to be informative on how ERP patterns of language switched words presented in a sentence context varies as a function of the semantic constraint of the sentence and the cognate status of the switched word. Brenders (2004) examined fairly fluent adult Dutch-English bilinguals, all classroom learners of L2 English who started learning English in the fifth grade of primary school (± age 10). They were visually presented with L1 Dutch sentences followed by an L2 English target word and all-Dutch control sentences (Experiment 1: L1 to L2 switches), or with L2 English sentences followed by an L1 Dutch target word and all-English control sentences (Experiment 2: L2 to L1 switches). Half the Dutch and English sentences had a high semantic constraint (e.g., 'The father took the sick child to the ..') and the other half had a low semantic constraint (e.g., 'The mother made an appointment with the ..'). Semantic constraint was assessed in prior norming studies. Half the target words were cognates (e.g., 'doctor/dokter'), and half were non-cognates (e.g., 'skirt/rok'). The bilinguals were instructed to read the sentences and target words attentively. Every so often a trial was followed immediately by a comprehension question, answered by pushing one of two buttons (yes or no). Language switch and non-switch trials were presented unpredictably in mixed lists. When comparing across the two experiments, ERP responses showed a larger switching-related modulation of the N400 when switching from L1 into L2, particularly on the non-cognates, than when switching from L2 into L1. A switch-related LPC effect was observed in both switching directions, in both high and low constraint sentence context conditions and in both cognate and non-cognate conditions.

Brenders' (2004) data showed a larger N400 switching effect when bilinguals switched from L1 to L2 than vice versa. This asymmetry was also observed by Alvarez et al. (2003), Proverbio et al. (2004), and Chauncey et al. (2008) on the N400, and by Jackson et al. (2001) on the N320/N2. Brenders' bilinguals also showed a language switch-related LPC effect. An LPC effect was also observed by Moreno et al. (2002), but not by Proverbio et al. (2004). The absence and presence of an LPC in the ERP pattern may be related to the predictability of the language switch. One interpretation of the LPC is that it is related to the processing of unexpected or improbable events (McCallum et al., 1984). Language switches were unpredictable in the two studies that obtained an LPC effect (Brenders 2004; Moreno et al. 2002), but were predictable in the study that did not obtain an LPC effect (Proverbio et al. 2004). Alternatively, it could be argued that this late positivity is an expression of a linguistic process, and indexes sentence-level integration and re-analysis (Friederici 1995; Kaan et al., 2000) or restructuring related to executive control (Kolk & Chwilla 2007). The LPC is assumed to share functional properties with the P600 (see van Hell and Tokowicz, in press, for a review of bilingual studies on syntactic processing). Language switched words presented at the end of a sentence may engage sentence reanalysis, reintegration and restructuring processes, processes that may be less effortful as the bilinguals' L2 proficiency increases. The L2 proficiency of the professional simultaneous translators who did not show an LPC effect (Proverbio et al.) was considerably higher than the L2 proficiency levels of the bilinguals tested by Moreno et al. (2002) and Brenders (2004), all of who showed an LPC effect. Moreover, the simultaneous interpreters are professionally trained to switch between languages and frequently do so in their professional life. Hence, for these interpreters switching between languages may be more natural (see also Meuter, this volume), and integrating language-switched materials may be less effortful. By contrast, the other bilinguals tested may have had to expend more effort in reintegration and reanalysis of the language-switched sentences, yielding an LPC. Consistent with this idea, the relatively proficient speakers in Moreno et al.'s sample showed an earlier peak latency and a reduced peak amplitude of the LPC. Future research should disentangle the effects of L2 proficiency, amount (and perhaps type) of daily switching experience, and the predictability of the language switch for example by comparing moderately and highly proficient bilinguals (discriminated on the basis of frequency of switching experience) who read sentences containing predictable or unpredictable language switches.

Brain regions involved in language switching: Neuroimaging evidence

The main focus of this chapter is on the time course of brain activity associated with switching between languages. Due to its relatively poor spatial resolution, however, EEG is not the optimal method to localize the specific brain areas that subserve language switching. (However, such information can be obtained with high density EEG recordings.) Neuroimaging techniques, such as fMRI or PET, have a high spatial resolution (but a poor temporal resolution) and can thus delineate the cortical structures engaged in language switching. In this section, we provide a selected overview of neuroimaging studies focusing on brain regions involved in language switching. For an extensive and excellent review, we refer the interested reader to a recent paper by Abutalebi and Green (2008), as well as the neural model recently proposed by these authors.

In one of the earliest neuroimaging studies, Price, Green, and von Studnitz (1999) carried out a PET study with English-German bilinguals who performed a translation task and a switching task from English (L1) into German (L2). Switching between languages was related to a specific activation of the left inferior frontal region (BA 44, Broca's area) and bilateral supramarginal gyri (BA 40), and this activation was not present in the non-switch condition.

Hernandez et al. (2000, 2001) studied language switching in Spanish-English bilinguals using fMRI and found that activity of the dorsolateral prefrontal cortex was greater in the switching condition than in the non-switching condition. The prefrontal cortex is assumed to be related to general executive functions such as response switching and response suppression. Hernandez et al. therefore suggested that the prefrontal cortex serves to attenuate language interference that results from actively enhancing and suppressing languages in alternation.

A recent study by Wang, Xue, Chen, Xue, and Donga (2007) is one of the few fMRI studies that compared the neural substrates of language switching from L2 into L1 and vice versa. Using the event-related (ER)-fMRI technique, Wang et al. examined adult Chinese learners of L2 English who performed a language switching task by naming pictures in L1 or in L2. Switching from L1 into L2, but not switching into L1, was associated with increased activation in several brain areas assumed to be related to executive functions and language control (e.g., bilateral frontal cortices, left anterior cingulated cortex, ACC). An analysis of RTs associated with switching revealed that switching into L1 took longer than switching into L2, in line with the asymmetrical switching cost obtained in behavioral research (e.g., Meuter & Allport 1999).

On the basis of their extensive review of neuroimaging studies using fMRI or PET techniques, Abutalebi and Green (2008) argue that language switching engages brain areas involved in cognitive control. Each of these brain areas may contribute distinct and complementary functions to achieve cognitive control related to language switching. The prefrontal cortex, involved in executive functions, decision making, response selection and inhibition, and working memory, is linked to the anterior cingulated cortex (ACC), a brain area involved in the detection of response conflict. Abutalebi and Green (2008) propose that the prefrontal cortex works together with the ACC and the basal ganglia for response inhibition (i.e., to inhibit non-target language interference). Potential response conflicts are signaled by the ACC to the prefrontal cortex, and the prefrontal cortex biases against incorrect language selection. The more anterior part of the ACC may be engaged in withholding a response to the current language and the more posterior part may be engaged in initiating a response in the now relevant language. Abutalebi and Green further propose that the left and right posterior parietal cortices are involved in language switching. In particular, in case of unpredictable language switches, the left posterior parietal cortex biases selection away from the previous language whereas the right posterior parietal cortex may bias selection towards the current language. In case of expected language switches, parietal activity appears to be absent. Finally, it is proposed that the basal ganglia may subserve language planning through a circuitry of the left basal ganglia and left prefrontal cortex, or the basal ganglia may act along with the supplementary motor area (SMA) to inhibit a prepotent response.

ERP studies on language switching: Concluding remarks

The seemingly effortless switching between languages of bilinguals is driven by intricate cognitive mechanisms that we are now only beginning to understand. Research into the cognitive and neural mechanisms underlying language switching is relatively recent. The few studies that examined the electrophysiological correlates of language switching provide valuable information on the timing and degree of neural activation as language switching unfolds over time but, to date, the available empirical evidence is rather scarce and inconsistent. A wide range of language switching tasks in production and perception have been used, varying from switching languages when processing and responding to unrelated single words, pictures or numbers, to the processing of a language switch in a meaningful sentence context. Furthermore, the bilinguals tested across (and sometimes within) the different studies varied in L2 proficiency, in language learning history, and in the amount of daily experience with language switching. Moreover, L2 proficiency was sometimes assessed using self-ratings only, which is not the most reliable measure of L2 proficiency. Another important point of difference across studies was the predictability of the occurrence of a language switch. Finally, the studies reviewed in this chapter did not consider the possible effect of the expectation of having to sue two languages may moderate the responses (see Meuter 2005 for a more extensive discussion on the necessity of task-specific baselines).

The overview of these studies in Table 1 indicates that the result patterns vary, and that the evidence as of yet is inconclusive (as, by the way, is also true for behavioral and linguistic studies on language switching; see, e.g., Meuter, this volume). More empirical work is needed before we can draw firm conclusions, but the currently available ERP evidence does point at some patterns.

Three major ERP components associated with language switching emerged from the studies reviewed in this chapter are: the N2, N400, and LPC. The N2 is believed to index cognitive control but, as we explained, there is still some debate as to its exact functional significance (response selection, response conflict monitoring, or response inhibition). The language switch-related modulation of the N2 suggests that language switching engages processes of cognitive control at a very early stage in the perception or production of a language switch (starting around 275 ms after stimulus onset). How the precise underlying mechanisms of these early language control processes work is still an open question: Jackson et al. (2001) observed a switching cost when switching into L2, whereas Christoffels et al. (2007) observed a switching benefit when switching into L1.

Several studies observed a modulation of the N400 in language switching compared to situations where the language remained unchanged (Alvarez et al. 2003; Brenders 2004; Chauncey et al. 2008; Proverbio et al. 2004). This N400 modulation indicates that a second component process of language switching entails a fast-acting lexico-semantic integration process. Interestingly, all ERP studies that compared switching into L2 versus switching into L1 observed higher switching cost when switching from L1 into L2 than vice versa, suggesting that lexico-semantic integration is more difficult when processing an item in the weaker language (L2) compared to the stronger language (L1). This asymmetry in switching cost observed in the N400 contrasts with the asymmetry observed in behavioral studies. We will come back to this issue shortly.

The lexico-semantic integration process in language switching can be indexed by a third component associated with language switching, namely the LPC. The LPC is correlated with the processing of unexpected or improbable task-related events, and is believed to index sentence-level integration or reanalysis, as well as restructuring processes related to executive control. Remarkably, LPC effects were obtained in studies with both expected (Jackson et al. 2001) and unexpected (Brenders 2004; Moreno et al. 2002) language switches. How language switching patterns are modulated by expected versus unexpected language switches is one of the issues that need more empirical attention, as we noted earlier. Another factor that deserves more attention in the context of the LPC is the role of relative language proficiency. Specifically, Moreno et al. observed that the peak latency and peak amplitude of the LPC varied as a function of L2 proficiency, suggesting that more proficient L2 speakers noticed the language switch earlier and experienced the switch to be less unexpected that the less proficient L2 speakers. The idea that less proficient bilinguals experience more effort in integrating language switches into the sentence context is corroborated by the fact that Moreno et al.'s (2002) and Brenders (2004)'s moderately proficient bilinguals (who were also less experienced at language switching) showed an LPC, whereas Proverbio et al.'s (2004) highly fluent, professional simultaneous interpreters did not. L2 proficiency-related qualitative and quantitative differences in ERP patterns have also been observed in another domain of bilingual processing, morphosyntactic processing in L2 (for a review, see van Hell & Tokowicz, in press). One direction for future ERP research on language switching, and other domains in bilingual processing, is to further examine the role of L2 proficiency.

Another intriguing finding in the ERP studies is the switch-related modulation of the N400, where switching into L2 was associated with a higher switching cost than switching into L1. The direction of this asymmetry contrasts with the pattern observed in many behavioral studies in which switching into L1 is associated with higher switching costs (for a review, see Meuter this volume). How can we reconcile the apparent different directions of language switching costs observed in (many) ERP studies and (many) behavioral studies? As we noted at the beginning of this chapter, one advantage of the ERP technique is that it provides insight into temporal dynamics of language switching as it unfolds in real time. Behavioral studies (using, e.g., reaction times and percentage errors), on the other hand, measure the end-state of the process, i.e., the moment a language switched item is produced or recognized. The asymmetrical switching cost related to the N400 occurs early in the language switching process, and may reflect the more effortful but fast-acting lexico-semantic integration of an L2 word. The fact that this asymmetry crosses over in the behaviorial studies (with nonbalanced bilinguals) suggests that the asymmetrical switching cost observed there reflect, not earlier subprocesses of language conflict, lexico-semantic integration and sentence-level integration as language switching unfolds in real time, but rather a later stage in processing related to decision making or response preparation (e.g., Thomas & Allport 2000).

ERP studies on language switching: future studies

The theoretical framework of the ERP language switching studies reviewed in this paper only encompasses cognitive models of production and perception that have been developed to explain or fine-tune the language switching of single unrelated pictures, numbers, or words. This is true not only for studies in which bilinguals switched between single, unrelated pictures, numbers or words, but also for studies in which language-switched words were embedded in a meaningful sentence context. In addition to focusing on further refinement of cognitive models of language production and perception, future ERP studies (and cognitive, behavioral studies, for that matter) also should attempt to test the wealth of theoretical models developed within linguistic approaches to language switching, for example, the triggering theory (Broersma & de Bot 2006; Clyne 1980, de Bot, Broersma, & Isurin, this volume), theories that emphasize syntactic equivalence or congruence as a constraining factor in the occurrence of language switches (e.g., Deuchar 2005; Muysken 2000; Poplack 1980; Poplack & Meechan 1995), or the Matrix Language Frame model and the 4-M model (Jake & Myers-Scotton this volume; Myers-Scotton 2005, 2006).

One of the theories originating from linguistic corpus research that can easily be extended to issues related to neural and cognitive processing is the triggering hypothesis (Broersma & de Bot 2006; Clyne 1980; de Bot, Broersma, & Isurin this volume). In short, the lexical triggering hypothesis claims that cognate words can facilitate or trigger a switch to the other language. In a recent study, we examined the neural correlates of lexical triggering, and extended the basic idea to socio-contextual triggering (Witteman & van Hell 2008). We aimed to study whether these two types of triggers can modulate the switching costs traditionally associated with switching between languages. In the lexical triggering study, we asked Dutch-English bilinguals to read sentences containing a language-switched word preceded by a lexical trigger (e.g., the Dutch-English cognate 'supermarket' in the sentence 'This famous supermarket also sells speelgoed to its customers'; [toys]) or preceded by a non-trigger word (here, the noncognate 'store' in 'This famous store also sells speelgoed to its customers'). We conducted three experiments (with different groups of Dutch-English bilinguals). In Experiment 1, bilinguals read Dutch (L1) sentences that contained an English (L2) language-switched word using a self-paced reading task. In Experiment 2, the same materials were presented in an EEG study. Experiment 3 used the same self-paced reading task as Experiment 1, but now the sentences were in the bilinguals' L2, and the language-switched words in L1. Experiment 1 showed no reduced switching cost of language-switched words as a function of lexical triggering. The ERP study yielded the same results: ERP responses to language-switched words were not modulated by the trigger manipulation. However, when the language-switched words were in L1 and the sentences in L2 (Experiment 3), reading latencies of the language-switched words were shorter when these words were preceded by a cognate trigger compared to a noncognate trigger. This indicates that bilinguals' sensitivity to lexical triggering effects in language switching is affected by their proficiency in the two languages.

In the socio-contextual triggering study, we asked three new groups of bilinguals from the same population to read a discourse context that describes a more English-like or Dutch-like situation ('For your daily groceries you can go to Wal-Mart/Albert Heijn'), followed by a sentence that contains a language switch ('This famous store also sells speelgoed to its customers'). Again, we conducted three experiments. In a behavioral experiment (Experiment 1) and an ERP experiment (Experiment 2), the socio-contextual triggering sentence was in Dutch (L1) followed by a Dutch sentence that contained an English (L2) language-switched word. In the third (behavioral) experiment, the sentences were in English (L2) and the second sentence contained a Dutch (L1) language-switched word. Experiment 3 yielded no significant effects of socio-contextual triggering, but the other two experiments did. In Experiment 1, bilinguals were significantly faster to read the language-switched (L2) word when it was preceded by an English-like (L2) situation (e.g., Wal-Mart) than when it was preceded by a Dutch-like (L1) situation (e.g., Albert Heijn). The ERP experiment showed a comparable pattern. The N400 was less negative-going when the L2 language-switched words were preceded by an L2 socio-contextual trigger compared to an L1 socio-contextual trigger. Together, the lexical triggering and the socio-contextual studies show that switching costs can be modulated. More generally, these studies show that linguistic theories that have been developed on the basis of corpus research can be successfully tested in a laboratory situation, using different tasks.

Other important future research topics include the extent to which ERP patterns associated with language switching differ for expected versus unexpected language switches, whether the patterns of language switching vary with the bilinguals' likelihood of switching between languages in their everyday life, and how electrophysiological correlates of language switching are affected by the degree of similarity between languages (e.g., switching between same script versus different script languages, variations in the number of cognates in the two languages, and the phonological and orthographic overlap of language-switched items). It is also important to gain more insight into the role of the bilinguals' relative language proficiency in the two (or more) languages used (or switched between), and the impact of variations of L2 proficiency on language switching. Studies that focus on syntactic processing in bilinguals indicate that variations in L2 proficiency are associated with both qualitative and quantitative variations in EEG brain responses (for review, see van Hell & Tokowicz, in press). The present review of ERP studies on language switching indicates that ERP patterns associated with language switching also vary with L2 proficiency, similar to what has been reported in behavioral studies on language switching (see Meuter, this volume, for a review). Future cross-sectional or longitudinal ERP studies tracking language switching performance over time would allow us to better understand changes in neural activity and cognitive processes associated with developing proficiency in L2. Moreover, future ERP studies may seek to examine more naturally occurring and ecologically valid language switches, for which the linguistic corpora of code-switches are potentially very helpful (see Gardner-Chloros, this volume, for further reference on incorporating naturalistic data into sociolinguistic and psycholinguistic analyses).

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Table 1
Overview of the ERP studies on language switching (using single words or sentences) reviewed in this paper

Study	Type of task	Language switching task	Nº participants	Type of bilinguals	Main findings
Jackson et al. (2001)	Prod	Naming single digits. Both switching directions	19	Native English speakers with different L2's (French, German, Spanish, Mandarin, or Urdu) and different ages of first exposure to L2. Moderately proficient	N50: Early left fronto-central negativity. N320/N2: Left fronto-central negativity, only in switching from L1 into L2. LPC: between 385 ms and 700 ms at parietal sites, for both switching directions.
Christoffels et al. (2007)	Prod	Naming single pictures. Both switching directions	24	Native German speakers with Dutch as L2. Moderately proficient	N320/N2: Enhanced fronto-central negativity between 275-375 ms. N400: Enhanced fronto-central negativity between 375-475 ms for non-switch trials compared to switch trials ('switching benefit'), only in switching from L2 into L1. Switching effect not markedly different for cognate and non-cognate pictures.
Verhoef (2008)	Prod	Naming single pictures; language cues preceded pictures by	15	Native Dutch speakers with English as L2. Fairly high proficient*	Early posterior negativity (200-350 ms) for switch trials compared to non-switch trials in L2, but not in L1. Late anterior negativity (350-500 ms) for switch trials compared to non-switch trials in both L1 and L2.

		750 ms. Both switching directions			
Jackson et al. (2004)	Compr	Reading number words. Both switching directions	20	Native English speakers with different L2's (French, German or Spanish) and different ages of first exposure to L2. Moderately proficient	No N2 No LPC
Alvarez et al. (2003)	Compr	Go/no go semantic categorization task (language switching of word pairs). Both switching directions	28	Native English speakers learning L2 Spanish. Low proficient	N400: for switching from L1 into L2, but not from L2 into L1 Negative deflection at 500 ms in both switching directions

Chauncey et al. (2008)	Compr	Go/no go semantic categorization task (language switching of word pairs; prime masked). Both switching	20 (same participants for both experiments)	Native French speakers with English as L2. Moderately proficient	N250, particularly in switching from L1 into L2 N400 in both switching directions
Moreno et al. (2002)	Compr	Sentences with final word language-switched. Switching always from L1 to L2	34	English native speakers with Spanish as L2. Fairly high proficient	N400: Enhanced negativity of language switches between 250-450 ms, in regular sentences but not in idiomatic expressions. LPC: Between 450-650 ms and between 650-850 ms, in both regular sentences and idiomatic expressions. Higher L2 proficiency was associated with earlier peak latency and smaller amplitude of LPC.
Proverbio et al. (2004)	Compr	Sentences with final word language-switched. Both switching directions	16	Professional Italian-English simultaneous interpreters. Highly proficient	N400: effect larger in switching from L1 into L2 than in switching from L2 into L1 No LPC
Brenders (2004)	Compr	Sentences with	47	Dutch native speakers with English as L2.	N400 effect larger in switching from L1 into L2 than in switching from L2 into L1

	language-switched word in the final part of sentence. Both switching directions	Fairly high proficient	LPC: in both switching directions

Note. Prod = Production; Comp = Comprehension
*L2 proficiency level was not assessed, but previous proficiency measures obtained in bilinguals from the same population yielded that these bilinguals are fairly high proficient (e.g., van Hell & Dijkstra 2002).